Sellafield Ltd

The 2017/18

Technology Development and Delivery Summary

Contents

Foreword

Rebecca Weston,
Strategy & Technical Director

Sellafield is the UK's most complex nuclear site. As a pioneer it has supported defence, power generation, managed nuclear waste and reprocessed nuclear fuel. Our daily work presents nuclear, environmental, radiological, chemical and conventional safety and security challenges. We are committed to finding and developing new and better technologies to meet these challenges and deliver the Sellafield mission safer and sooner.

2018 is a pivotal year for Sellafield Ltd as we move towards the completion of our reprocessing mission with Thorp, which reprocesses oxide fuel from both UK and overseas customers, due to finish in December. This is leading to an ever increasing focus on clean-up and waste management activities at Sellafield and our research and development (R&D) activities are changing and preparing for these new challenges.

We recognise that investment in R&D and the active identification of technology transfer opportunities is critical to the successful delivery of our mission to safely operate, clean-up and decommission the Sellafield site. We know we cannot successfully deliver this R&D alone and we are committed to work and collaborate with a wide range of technology suppliers and academics. Experience has shown that the right supply chain partnerships bring innovation, knowledge, energy and enthusiasm leading to the delivery of ground-breaking R&D. The universities and organisations involved in the projects featured in this report are listed with the individual articles and in the tables on pages 5 and 6.

We have developed a number of different approaches to enable the supply-chain and academia to better understand our challenges and contribute to our R&D programme. Examples of these initiatives are described in this report and include our Game Changers programme, Innovate UK competitions, engaging with universities in national programmes and strategic partnerships. As part of these activities our staff travel the length and breadth of the UK to communicate the nature of our challenges and to encourage and help small and medium enterprises, universities and other supply-chain organisations to get involved. We are committed to continuing these activities and would encourage interested parties to get involved.

THE AREAS IDENTIFIED FOR R&D INVESTMENT TO DEVELOP TECHNOLOGIES:

- Waste treatment and conditioning of packages
- Condition monitoring and inspection of interim stored wastes and products
- Novel analytical techniques
- Post operational clean-out
- Decommissioning
- Robotics and artificial intelligence

Overview

Katherine Eilbeck,
Central R&D Manager

Welcome to the annual Technology Development and Delivery Summary featuring projects representative of the ongoing research and development to deliver the Sellafield mission. Sellafield Ltd recognises that investment in R&D and the identification of technology transfer opportunities is critical for the success of many of our activities to safely operate, clean up and decommission the Sellafield site. As a company Sellafield Ltd is preparing for the end of reprocessing and delivering its mission as efficiently as possible while providing value for money.

The future for the Sellafield site is the:

- Continuing hazard reduction programme of legacy facilities
- Management of the closure, and decommissioning, of the current spent fuel reprocessing plants, and associated facilities
- Continuation of waste management operations together with the implementation of new ones
- Management of the land
- Safe storage of waste forms pending final disposal

In recent years Sellafield has identified key themes where opportunities for the employment of innovative technologies, tools and techniques, to reduce costs, improve safety and reduce timescales were identified (these are listed on page 3). These are managed by Integrated Research Teams (IRTs) providing a multi-disciplinary approach with input from the end user, this report features articles from most of these.

Working collaboratively with the supply chain is a keen element of our R&D delivery strategy and last year a unique agreement was formalised between ourselves and the National Nuclear Laboratory (NNL). Sellafield Ltd has a long history with the NNL our partner, which is featured in about a third of the projects and articles in this report. As well as working with each other there are a number of examples in this report where NNL have been key facilitators acting as a bridge between Sellafield Ltd and academia and the wider supply-chain.

Sellafield Ltd continuously strives to deliver the mission with safe and cost-effective technologies and understands that R&D is critical in achieving this aim. I hope you enjoy reading this summary and are inspired to get involved. Please contact us should you see an opportunity for collaboration and/or coordination of research, development, or technology transfer in one of our key challenge areas.

Get in touch

Further information about the history, current operations and future plans of the Sellafield site can be found on the Sellafield Ltd website:

https://www.gov.uk/government/organisations/sellafield-ltd

If you want to learn more about research and development at Sellafield Ltd, have feedback on this document or have an idea for a project, please contact:

technical.innovation@sellafieldsites.com

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Projects included in this report

Project	Delivery partners
Spent fuel management and nuclear materials	
Processing of the first special nuclear material storage cans through NNL's Central Laboratory	National Nuclear Laboratory
Real-time in-situ monitoring of ^{137}Cs in the AGR Storage Pond using a SARA ^{137}Cs probe	ENVINET GmbH
Experiments to underpin the export of legacy aluminium clad fuel	Interface Analysis Centre, University of Bristol
Site decommissioning and remediation	
First Generation Magnox Storage Pond planning tool	Saker Solutions Ltd.
Magnox Swarf Storage Silo stream distributed simulation	Saker Solutions Ltd.
Silo Emptying Plant machine relocation tool	Saker Solutions Ltd.
Magnox Swarf Storage Silo maintenance planning tool	Saker Solutions Ltd.
Mechanism of underwater uranium hydride formation determined by isotopic substitution reactions	Interface Analysis Centre, University of Bristol
Legacy ponds underwater visibility improvement strategy	Delivered by Sellafield Ltd only
Management of hydrogen during export of uranium bit bins from the First Generation Magnox Storage Pond	Delivered by Sellafield Ltd only
Measurement of hydrogen emission rates from skips of Magnox swarf storage silo	Wood., Mirion Technologies
Magnox Swarf Storage Silos third extension swarf flattening project	WeSubsea UK Ltd., National Nuclear Laboratory
Management of oversized items in the Magnox Swarf Storage Silo	Nichols Group, DBD Ltd., React Engineering Ltd.
Variable buoyancy heavy lift remotely operated vehicle	National Nuclear Laboratory, ROVtech Solutions Ltd.
Post operational clean-out IRT	National Nuclear Laboratory, C-Tech Innovation Ltd., ProNu-Dec Ltd., University of Birmingham
Thorp pneumercator access tank inspection	viZaar Industrial Imaging AG, Gen2
Highly Active Liquor Evaporation and Storage sparge agitation test rig	National Nuclear Laboratory
MIRRAX: a reconfigurable robotic platform for the survey of access-limited areas	The University of Manchester
CARMA: Sellafield's first autonomous robotic platform for the radiometric mapping of large floor areas	The University of Manchester
AVEXIS: a small submersible robotic family for the underwater exploration of facilities with restricted access	The University of Manchester, Forth Engineering Ltd.
Non-destructive depth profiling development	Createc, Costain, Cavendish Nuclear
Plant status monitoring using neutron detectors	Cavendish Nuclear
Laser decontamination	TWI Ltd.
Black Ghost - biometric vest	Equivital™
Glovebox and crate breakdown by laser cutting	National Nuclear Laboratory, TWI Ltd.
Characterisation of excavated materials from areas of the Sellafield site with a low risk of radiological and chemical contamination	Delivered by Sellafield Ltd only
Land quality knowledge management tools	Delivered by Sellafield Ltd only
Integrated waste management	
First Generation Magnox Storage Pond skip disposal – active demonstrator	The Decommissioning Alliance: Atkins Ltd., Jacobs UK Ltd., Westinghouse Electric Company UK Ltd.
Box Encapsulation Plant waste handing robots	Sellafield Ltd, National Nuclear Laboratory, KUKA Systems (UK) Ltd, NSG Environmental Ltd, TÜV SÜD Nuclear Technologies
Magnox Swarf Storage Silo $3m^3$ box project	Fauske Associates, DBD Ltd.

Understanding alpha activity in legacy waste retrieval effluents and mitigation using chemical settling aids	National Nuclear Laboratory
Handling and treating First Generation Magnox Storage Pond sludge	The Decommissioning Alliance: Atkins Ltd., Jacobs UK Ltd., Westinghouse Electric Company UK Ltd.
Robotic Manipulation for Nuclear Sort and Segregation (ROMANS)	University of Birmingham (UK), Commissariat a l'energie atomique et aux energies alternatives (France), Technische Universität Darmstadt (Germany), Le Centre national de la recherche scientifique (France), National Nuclear Laboratory
Proof-of-concept trials for in-situ testing of filter performance on Sellafield Self-Shielded Boxes	Interface Analysis Centre, University of Bristol
Export Cell trials in support of the Self-Shielded Box project	Delivered by Sellafield Ltd only
Waste treatment, conditioning and packages IRT	Nuclear Decommissioning Authority, National Nuclear Laboratory, Radioactive Waste Management, Atomic Weapons Establishment, TÜV SÜD Nuclear Technologies, Galson Sciences Ltd. University of Sheffield, Banah UK Ltd. Nuclear Advanced Manufacturing Research Centre
Condition monitoring and inspection IRT	NSG Environmental Ltd, National Nuclear Laboratory, ABS Consulting, National Physical Laboratory, RTL Materials Ltd, trading as RolaTube Technology, James Fisher Nuclear Ltd., University of Strathclyde
Enterprise wide and enabling research and development	
Engineered composite repairs	The work is being run by the Health and Safety Laboratory, sponsoring industrial partners are: National Grid, TAQA, Shell, Nexen, EDF Energy, Total, ConocoPhillips, Centrica, SGN, Sellafield Ltd, Health and Safety Executive, Apache In kind support: Metalyte Pipeworks Ltd, Neptune Research Inc, Team Furmanite, IMG, Clock Spring, Walker Technical, Belzona Polymerics Ltd., Henkel.
Developing an agent based evacuation modelling architecture	Saker Solutions Ltd.
Machine learning and artificial intelligence	Delivered by Sellafield Ltd only
Novel analytical techniques	National Nuclear Laboratory
Environmental monitoring and assessments beach monitoring tool	Jacobs (via Design Services Alliance)
Geographic information system to produce a web-based master planning tactical land request tracker	Delivered by Sellafield Ltd only
Innovative method using a geographic information system to present master planning concepts	Delivered by Sellafield Ltd only
Enabling functions	
Centres of Expertise	Delivered by Sellafield Ltd only
Integrated innovation in nuclear decommissioning competition	Nuclear Decommissioning Authority, Innovate UK
University engagement	Various universities, National Nuclear Laboratory, Nuclear Decommissioning Authority
Game Changers	National Nuclear Laboratory, FIS360

Spent fuel management and nuclear materials

Spent fuel management at Sellafield includes the storage and reprocessing of spent fuel from nuclear reactors across the UK and overseas. The Magnox reprocessing plant reprocesses fuel from Magnox power stations across the UK and is expected to have completed its work by 2020. Oxide fuels are reprocessed through the Thermal Oxide Reprocessing Plant (Thorp) and following the closure of this plant the plan for the remaining Advanced Gas-Cooled Reactor (AGR) and other spent oxide fuels will be interim storage, pending packaging and disposal to a Geological Disposal Facility (GDF).

To facilitate the safe ongoing storage of the stock of civil plutonium stored at Sellafield, a programme of work is in place that brings together the activities and facilities required to treat and/or repackage plutonium product and residues.

This section covers the progress on some of the R&D supported by Sellafield Ltd which offers solutions in improved efficiency, reliability and safety in the management of spent fuels and nuclear materials:

- Processing of the first special nuclear material storage cans through NNL's Central Laboratory
- Real-time in-situ monitoring of ^{137}Cs in the AGR Storage Pond using a SARA ^{137}Cs probe
- Experiments to underpin the export of legacy aluminium clad fuel

Processing of the first special nuclear material storage cans through NNL's Central Laboratory

The aim of this work is to underpin the ongoing safe and secure storage of plutonium dioxide (PuO_2) powder which has been stored at Sellafield for more than 40 years. This material is expected to remain in storage for decades to come and therefore, it is important to understand:

- The effects of long-term storage on the properties of PuO_2
- Head-gas evolution with time
- The potential for package pressurisation

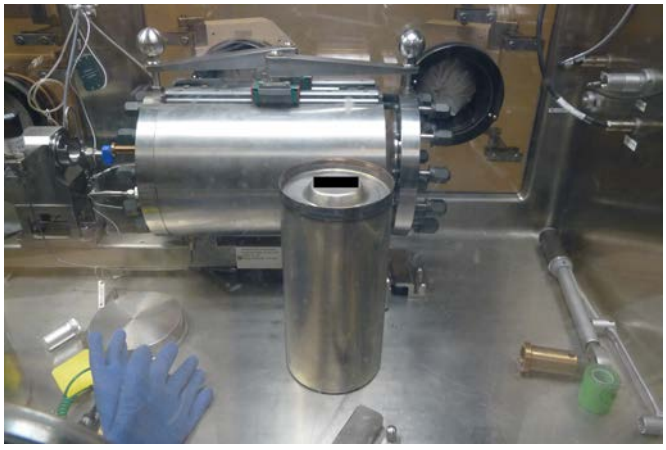
A new area of the National Nuclear Laboratory's (NNL's) Central Laboratory was commissioned to undertake destructive analysis on the inner and outer cans used to store PuO_2, as well as analysis of the head-gas and powders sampled from inside the plutonium cans. This facility is expected to be used extensively over the next few years.

The 2016/17 Technology Development and Delivery Summary highlighted the initial commissioning of the NNL facility and some of the preliminary analytical results obtained on powder samples. During 2017/18, the commissioning work progressed so that full size storage packages were brought into the laboratory and then punctured to analyse the gases released from the head space inside the welded outer can. Samples of powder and storage container materials were then taken for further measurements using the installed analytical methods that were described in the 2016/17 summary report. After sampling, the remaining powder was heat treated and then placed into a new storage can for export back to Sellafield stores. Five such packages have been processed through the plant and these will be returned to Sellafield stores by the end of 2018.

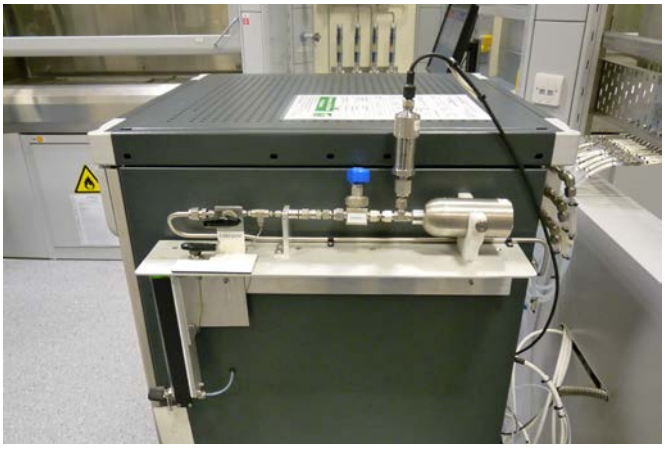
The 2017/18 summary highlights the results from two different measurements: can puncture including head-gas analysis and the specific surface area (SSA) of the powder.

Can puncture measurements

The can puncture rig consists of a pressure vessel that is used to contain the PuO_2 package. The can is punctured inside this pressure vessel using a low-sparking copper-beryllium needle that is pushed into the lid of the package. The pressure vessel is connected to an argon gas supply and a vacuum pump that facilitates evacuation and argon purging of the rig (i.e. the pressure vessel and associated pipework) to minimise risks of contaminant gases from the glove box atmosphere compromising the gas analysis. In addition, the pressure vessel is connected to two gas ampoules, located outside the glove box, that are used to capture samples of gas for analysis by gas chromatography (GC).



The can puncture rig pressure vessel



Gas ampoule connected to gas chromatography

Gas analysis data for the first 5 packages processed in the new facility are presented in the table. Following can puncture and gas sampling, the can is cut open and PuO_2 powder samples are retrieved for analysis. Specific surface area from the Brunauer-Emmett Teller (BET) analysis and crystallite size (obtained from powder X-ray diffraction analysis) data are also listed in the table.

Year of manufacture	Packaging atmosphere					SSA of recovered powder (m^2/g)	He release fraction (%)	Crystallite size (nm)
		He	***N_2***	***Ar***	***N_2O***			
1975	Air	61.2	28.8	10.0	0.037	2.24	79	15
1979	Air/Argon	52.3	1.25	46.3	ND	2.56	68	17
1982	Air/Argon	14.8	47.5	37.8	0.032	2.51	26	53
2002	Air/Argon	29.4	61.6	9.05	0.027	4.70	68	18
2002	Air/Argon	28.3	57.6	14.1	0.005	5.50	57	19

Gas analysis data

Information received showed that all packages contained an inert atmosphere upon piercing, consisting of helium (He), nitrogen (N_2) and argon (Ar) gases, the oxygen (O_2) inventory from the original packaging atmosphere was consumed. Four out of the five packages contained small quantities of nitrous oxide (N_2O) and no packages contained detectable quantities of hydrogen (H_2).

Specific surface area analysis

The measured specific surface areas ranged between 2.24 and 5.5 m^2/g indicating an apparent average decrease in measured SSA following long-term storage and further work is in progress to determine the cause of this decrease. This information is relevant when re-use options are being considered.

Helium release fraction

The helium release fraction, which is the fraction of helium released into the head-gas compared with that generated from alpha decays during years in storage was high and this shows some correlation with PuO_2 particle size. The fraction of helium released into the head-gas is important when considering the lifetime of storage cans.

Over the next few years further package types and their special nuclear material (SNM) contents (for example, Thorp welded packages and rolled seal tins containing mixed oxide (MOX) residues) will be characterised as well as a broader range of Magnox packages. The work underpins the safe storage of PuO_2 on the Sellafield site, it was carried out in the NNL Central Laboratory and in collaboration with NNL staff is greatly enhancing the ability of Sellafield Ltd to characterise the long-term behaviour of SNM packages and their contents. Furthermore, the data obtained can be used to more accurately predict gas generation rates to provide information on the timeframes required for repackaging. Information with respect to PuO_2 properties following long-term storage is important when considering potential long-term disposition options.

Challenge:

Understand the effects of long-term storage on the properties of PuO_2, head-gas evolution with time and the potential for package pressurisation

Solution:

Analysis of head space gases and PuO_2 powders using a range of techniques in NNL Central Laboratory

Benefits:

Underpins the safe storage of PuO_2 for decades to come

Status:

Ongoing with plans to extend to further package types

TRL* change:

TRL 8 to TRL 9

Delivery partners:

National Nuclear Laboratory

External publications/press releases/weblinks:

Robin Taylor, Jeff Hobbs, Robin Orr, Helen Steele, Characterisation of plutonium dioxide, Nuclear Future, 14 (2018), 40-50.

Contact details:

Jeff Hobbs, Helen Steele (Sellafield Ltd)

Robin Orr, Robin Taylor, Mark Farrer, Adam Eilbeck, Sean Woodall, Hannah Colledge and Josh Holt (National Nuclear Laboratory)

**TRL (technology readiness level)*

Real-time in-situ monitoring of ^{137}Cs in the AGR Storage Pond using a SARA ^{137}Cs probe

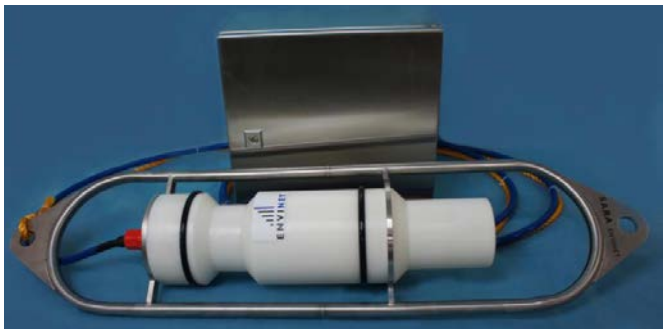
Detection of increased ^{137}Cs activity levels is an important indicator of fuel cladding failure in fuel storage pond water and historically ^{137}Cs monitoring has been carried out by pond water sampling on a weekly basis. A project was undertaken to provide real-time monitoring of ^{137}Cs in parallel with routine pond water sampling so that an early indication of any increase in activity can be promptly addressed.

To complement routine sampling an ENVINET SARA Spectroscopic Gamma Monitoring System is to be installed in the AGR Storage Pond (AGRSP). The data received from the probe are transmitted to a laptop, which uses specialist software to display gamma spectra and activity data for the detected radionuclides in real-time. Equipped with a bespoke detector, the SARA probe will deliver live data providing confirmation of the current weekly reported ^{137}Cs activity based on pond water analysis. Being the first in-situ radiometric probe to be deployed for long-term monitoring on the Sellafield site, the challenges of this work also include the identification of an appropriate place in the pond to install the probe to ensure representative measurement based on operational limitations of both pond and probe operations.

During 2017/18 Sellafield staff received training in the use of the probe and dedicated software at ENVINET in Germany. The probe was delivered to Sellafield in January 2018 and a successful laboratory test carried out to prove the functionality of the equipment and software using a ^{137}Cs source and a number of additional sources that were readily available. The process to facilitate the installation of the probe is currently being undertaken with installation expected in 2018/19 at which point the full radiometric capability will be tested in the conditions for which it was designed.

SARA ^{137}Cs probe

SARA probe casing for underwater use



SARA probe in mooring bracket and electronics box

SARA probe underwater with mooring

Challenge:

Real-time method for the measurement of ^{137}Cs activity in a fuel storage pond

Solution:

In-situ radiometric probe to support pond water analysis

Benefits:

Early indicator of fuel cladding failure

Status:

Non-active testing is complete with preparation for installation in the pond underway

TRL change:

TRL 8 to TRL 9

Delivery partners:

ENVINET GmbH

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Xavier Poteau xavier.poteau@sellafieldsites.com

Experiments to underpin the export of legacy aluminium clad fuel

To support the decision-making process for the retrieval and management of legacy Windscale Pile fuel and British Experimental Pile 0 (BEP0) fuel currently stored in the First Generation Magnox Storage Pond (FGMSP) at Sellafield, a project was undertaken to investigate the corrosion behaviour of the aluminium cladding of the uranium metal fuel. The current strategy is to transfer BEP0 fuel to the Fuel Handling Plant (FHP) for interim containerised storage and identify a waste route for Pile fuel.

Despite being stored for a number of years in a highly alkaline environment in FGMSP (where the pH is 11.5 and magnesium (Mg)-based sludge is present), some of the aluminium fuel cans are intact. Degradation of the cladding by corrosion and dissolution would have been expected due to the increased solubility of aluminium in alkaline solutions. Recent work in NNL has suggested that aluminium is passivated (i.e. a light coat of a protective material forms around the aluminum and this prevents further corrosion) by the presence of magnesium in FGMSP. This is beneficial from an effluent management perspective because elevated soluble concentrations of aluminium in the feed to the downstream plant Sellafield Ion Exchange Effluent Plant (SIXEP) could be problematic. However, if the fuel is moved from FGMSP to containerised storage at FHP there is a risk of aluminium dissolution where there is an absence of magnesium ions (pH 13.5, no Mg-based sludge present). This could produce a solution containing a significant aluminium concentration that would be transferred to SIXEP during fuel management operations in FHP. If a solution containing soluble aluminium entered the carbonation tower in SIXEP, then colloidal aluminium-hydroxide could form, which could lead to fouling of the ion exchange beds and interfere with the process for abating soluble caesium and strontium prior to sea discharge.

In 2017/18 a project was carried out at the University of Bristol to investigate the solubility of aluminium under pond water conditions. A series of corrosion and characterisation experiments were undertaken as follows:

- Characterisation of corrosion products of pre-corroded aluminium samples
- Corrosion of aluminium samples at elevated temperature (40°C) and varying pH

Characterisation of corrosion products of pre-corroded aluminium samples

Information on aluminium chemistry in the presence of magnesium ions and the formation of a passivation layer was required to provide an understanding of aluminium-clad fuel corrosion under FGMSP storage conditions. Aluminium samples were pre-corroded in:

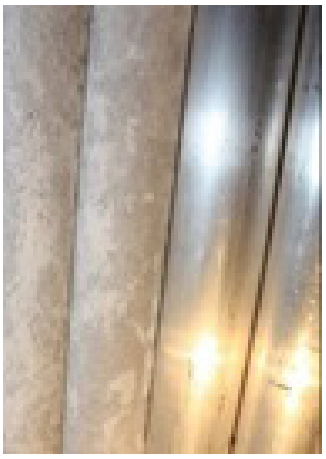
- Saturated magnesium hydroxide solution ($Mg(OH)_2$)
- Corroded Magnox sludge (CMS)

The corrosion products of both the pre-corroded and clean samples, provided by NNL, were characterised with a range of spectroscopic techniques.

Summary of experimental techniques and their application used at the University of Bristol to characterise clean and pre-corroded aluminium samples

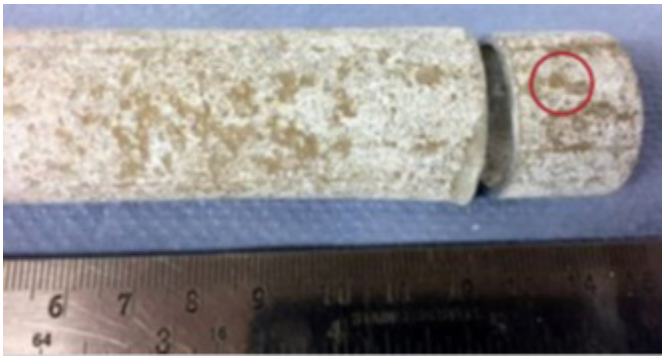
Experimental technique	Application
X-ray diffraction (XRD)	Crystallographic phase composition
Scanning electron microscopy and focussed ion beam (SEM & FIB)	Surface morphology and oxide thickness
Energy-dispersive X-ray (EDX)	Elemental composition
Raman spectroscopy	Ionic species identification

The results showed that corrosion of aluminium in a magnesium-based solution leads to formation of a Mg-rich corrosion layer. This effect was more pronounced for the aluminium sample corroded in saturated $Mg(OH)_2$ solution, see the EDX maps.

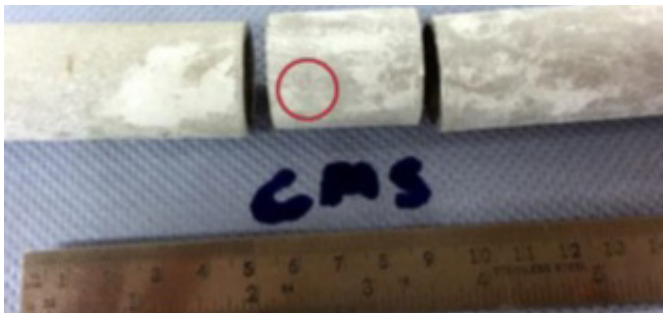


Left: Aluminium samples (1050A grade), corroded in saturated $Mg(OH)_2$ for 9 months. Right: clean aluminium samples

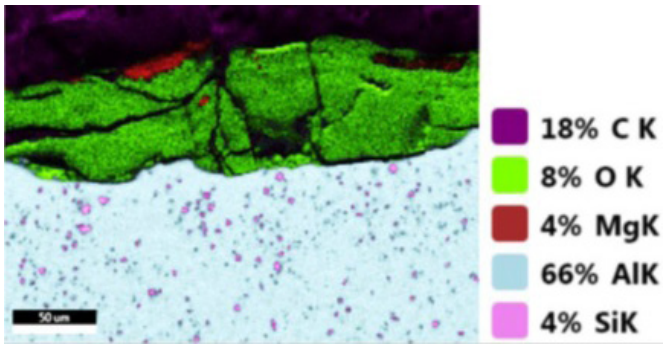
Left: Aluminium samples (1050A grade), corroded in CMS for 11 months. Right: clean aluminium samples



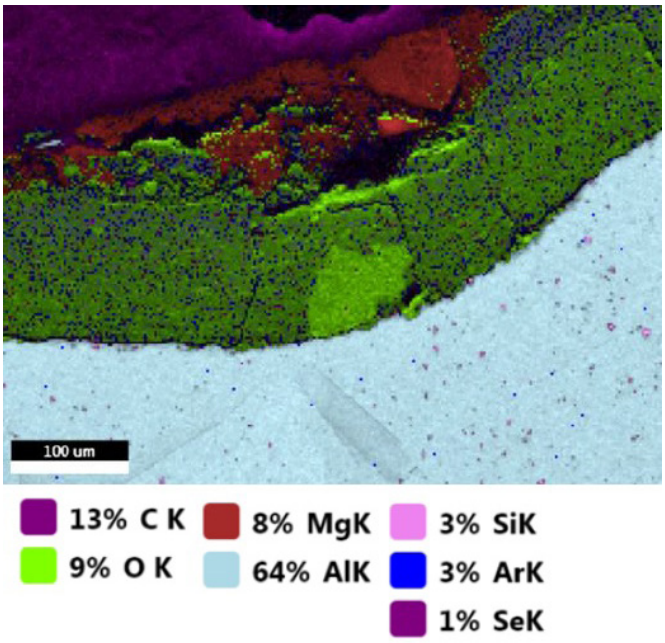
1050A grade aluminium sample corroded in $Mg(OH)_2$ revealing two distinct corrosion regions (brown and white)



1050A grade aluminium sample corroded in CMS, visual inspection indicated two distinct corrosion regions: grey/brown and white



EDX map from the cross section of 1050A grade Al sample corroded in CMS. Red colour indicates magnesium presence in the corrosion layer

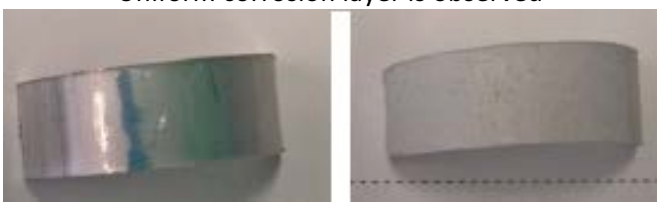


EDX map from the cross section of 1050A grade Al sample corroded in saturated $Mg(OH)_2$. Red colour indicates magnesium presence in the corrosion layer

Corrosion of aluminium samples at elevated temperature and varying pH

Corrosion experiments of both clean 1050A grade aluminium alloy and pre-corroded 1050A grade aluminium alloy at a temperature of 40°C (carried out at this temperature to accelerate the corrosion process) and different pH were undertaken followed by characterisation of the corrosion products. This provided information on the impact of pH on aluminium corrosion and therefore an understanding of the impact of pH on fuel transfers from FGMSP to FHP and the impact of aluminium on SIXEP.

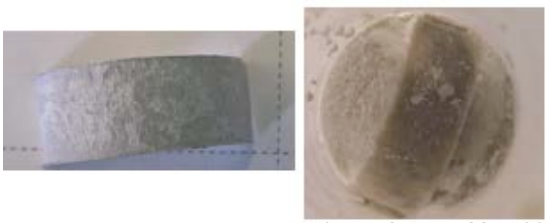
Summary of the corrosion experiment for clean aluminium samples corroded for 9 weeks

pH	Time	Result	Identified corrosion products	Mass change
7	Up to 9 weeks	No visual changes to the sample surface  As received 9 weeks at pH =7	Carbonate, hydroxide and oxide species	Almost no change
11.5	After 9 weeks	Uniform corrosion layer is observed  As received 9 weeks at pH =11.5	Gibbsite: γ-$Al(OH)_3$ and Bayerite: α-$Al(OH)_3$	Increase ~3.5% in the first 3 weeks and then remained stable
13.5	After 1 week	Sample dissolved  As received 1 week at pH =13.5	Gibbsite > Bayerite MgAl-OH	Dissolution

Summary of corrosion experiment for pre-corroded aluminium sample in saturated $Mg(OH)_2$

pH	Time	Result	Identified corrosion products	Mass change
7	Up to 9 weeks	Slight changes to the sample surface  As received 9 weeks at pH =7	Bayerite > Gibbsite MgAl-OH	Increased by 0.6% over the first 7 weeks, then remained stable
11.5	Up to 9 weeks	Slight changes to the sample surface  As received 9 weeks at pH =11.5	Bayerite $Mg_2Al(OH)_7$	~3.25% increase over the first 3 weeks and then remained stable
13.5	After 1 week	Sample dissolved.  As received 1 week at pH =13.5	Gibbsite > Bayerite	Dissolution

Summary of corrosion experiment for pre-corroded aluminium sample CMS

pH	Time	Result	Identified corrosion products	Mass change
7	Up to 9 weeks	Slight changes to the sample surface  As received 9 weeks at pH = 7	Bayerite	Slow increase by 0.4% over the first 5 weeks and then stable
11.5	Up to 9 weeks	Slight changes to the sample surface  As received 9 weeks at pH = 11.5	Bayerite > Gibbsite MgAl-OH	Rapid increase by ~2% during the first 1 to 2 week, and then slow increase
13.5	After 1 week	Sample dissolved  As received 1 weeks at pH = 13.5	Gibbsite and Bayerite MgAl-OH	Dissolution

Summary

The experiments have shown that:

- Aluminium corrosion depends on pH.
- Aluminium is stable at pH of 7 and 11.5 with some initial corrosion occurring at higher pH and it dissolves at pH 13.5.
- Pre-corroded aluminium samples are more subject to corrosion at pH7 than the clean aluminium samples, however the mass change was very low, about 0.5-0.6%.
- Pre-corroded aluminium samples in saturated $Mg(OH)_2$ behave similarly to the clean aluminium samples at pH 11.5 with an initial corrosion and mass change of 3.5% during the first 3 weeks of corrosion.
- Pre-corroded aluminium samples in CMS corrode faster than clean aluminium or pre-corroded aluminium samples in saturated $Mg(OH)_2$ with a mass change of 2% during the first 1-2 weeks, the mass change continued, increasing slightly over 9 weeks of the experiment.
- Characterisation of corrosion products of pre-corroded samples indicated a Mg-rich layer (presumably Mg incorporated into bayerite layer), this is more pronounced for the sample corroded in saturated $Mg(OH)_2$ and this acts as a protective layer slowing down the corrosion at pH 11.5.
- High pH (> 11.5) leads to formation of gibbsite: γ-$Al(OH)_3$ and dissolution of the sample. This indicates that at high pH bayerite transforms into gibbsite leading to liberation of Mg into solution (dissolution of protective Mg-based layer).

This project is now complete and the results were used to underpin the decision-making process for the retrieval and management of aluminium-clad fuels stored in a legacy pond at Sellafield. The project has shown that aluminium is resistant to corrosion at a lower pH of 7 and 11.5 and is readily dissolved at pH 13.5. This information has been used to produce a position statement to identify the risks posed to SIXEP by the various proposed options for the storage of aluminium-clad fuel in FHP. Therefore, it has been recommended that storage of aluminium-clad fuel at pH 13.5 should be avoided in order to minimise the potential for an elevated soluble aluminium challenge to SIXEP and the subsequent risk of an adverse impact on the SIXEP ion exchange beds. If a storage regime of pH 11.5 or less is adopted then no further technical assessment is necessary. Additionally, the work has shown that aluminium corroded in a magnesium buffered solution is more resistant to corrosion due to the formation of a magnesium-rich protective (passivated) corrosion layer. Thus, explaining why the corrosion of aluminium-clad fuel in the presence of magnesium-based sludge can be retarded in some cases. This is relevant to the current storage conditions in FGMSP and explains why the cladding has not completely degraded during storage.

Challenge:

To underpin the legacy fuel export strategy

Solution:

Characterisation and corrosion experiments

Benefits:

Supports the decision making process for the retrieval and management of aluminium-clad fuels stored in a legacy pond

Status:

Complete

Delivery partners:

Interface Analysis Centre, University of Bristol

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Site decommissioning and remediation

Site decommissioning and remediation presents a number of challenges at Sellafield including the:

- Reduction in the risks and hazards posed by the deteriorated legacy facilities containing significant quantities of corroding radioactive waste.
- Decontamination, dismantling and demolition of redundant facilities.
- Management and remediation of contaminated land to ensure the protection of the workforce, public and environment.

This section documents the significant progress, in 2017/18, on a number of R&D programmes to meet these challenges:

Risk and hazard reduction programme

- First Generation Magnox Storage Pond planning tool
- Magnox Swarf Storage Silo stream distributed simulation
- Silo Emptying Plant machine relocation tool
- Magnox Swarf Storage Silo maintenance planning tool
- Mechanism of underwater uranium hydride formation determined by isotopic substitution reactions
- Legacy ponds underwater visibility improvement strategy
- Management of hydrogen during export of uranium bit bins from the First Generation Magnox Storage Pond
- Measurement of hydrogen emission rates from skips of Magnox swarf storage silo
- Magnox Swarf Storage Silos third extension swarf flattening project
- Management of oversized items in the Magnox Swarf Storage Silo
- Variable buoyancy heavy lift remotely operated vehicle

Post operational clean-out, planning for decommissioning, monitoring, decontamination and dismantling of redundant facilities

- Post operational clean-out IRT
- Thorp pneumercator access tank inspection
- Highly Active Liquor Evaporation and Storage sparge agitation test rig
- MIRRAX: a reconfigurable robotic platform for the survey of access-limited areas
- CARMA: Sellafield's first autonomous robotic platform for the radiometric mapping of large floor areas
- AVEXIS: a small submersible robotic family for the underwater exploration of facilities with restricted access
- Non-destructive depth profiling development
- Plant status monitoring using neutron detectors
- Laser decontamination
- Black Ghost - biometric vest
- Glovebox and crate breakdown by laser cutting

Land management

- Characterisation of excavated materials from areas of the Sellafield site with a low risk of radiological and chemical contamination
- Land quality knowledge management tools

First Generation Magnox Storage Pond planning tool

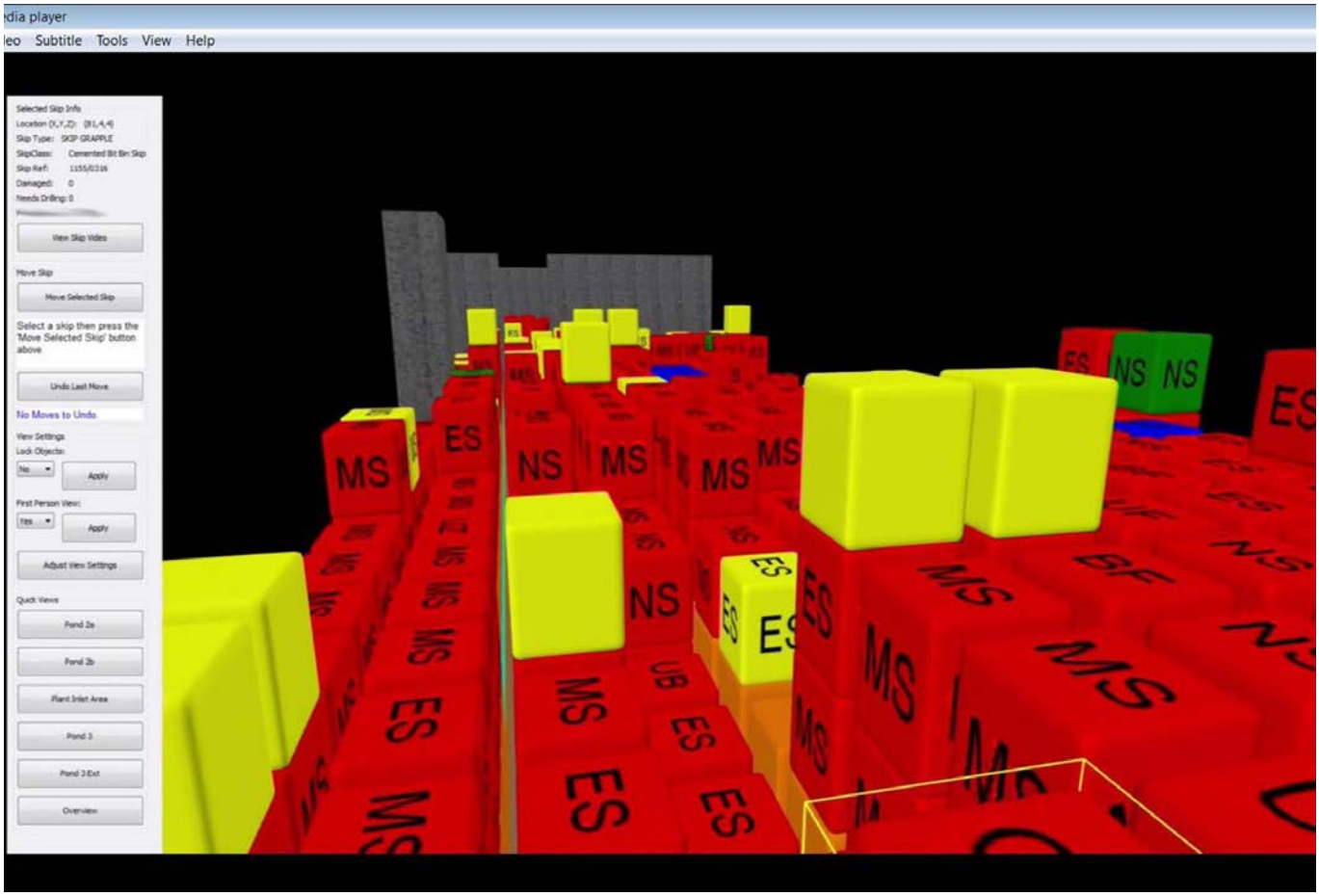
The First Generation Magnox Storage Pond (FGMSP) is one of the legacy facilities undergoing a programme of waste retrievals and there is a requirement to ensure that historic skip and inventory data, previously held in separate databases, are adequately managed and auditable. These data are required for:

- Planning campaigns of skip moves
- Tracking of the inventory of skip contents
- Transfer reports, such as fuel consolidation
- Reporting and accounting purposes

Sellafield Ltd partnered with Saker Solutions Ltd. to develop the FGSMP planning tool to fulfil these requirements. This resulted in the development of a 3D virtual reality model of the pond in which the user can plan moves using a touch screen or mouse. The model allows the user to navigate around the pond in the 3D environment, identifying skips in accordance with their name, type or tooling requirements. A skip can be selected for relocation and the model recommends where the skip can be moved to and allows the user to visually confirm destination positions.

The model has been configured with a number of key features:

- To maximise understanding of the in-pond environment, it allows the user to view information such as embargoed positions, transportation routes, skip types and preferred stacking locations.
- Video footage and other external data and media can be appended and linked to each skip and pond location.
- The tool supports features for managing inventory and its comprehensive reporting provides detailed information on how the status of the pond and the inventory stored in the skips has changed as campaigns are authorised and executed.
- Using the centralised pond data, the FGMSP simulation model is run with up-to-date information. This provides a useful insight of the timeline for decommissioning of the pond together with an understanding of the constraints that may delay any planned activities.



View within the tool showing the 3D landscape

Control device for the planning tool

Workflow for setting up and executing skip move campaigns

The planning tool has enabled Sellafield Ltd to dramatically reduce the effort required to maintain up-to-date records for FGMSP and it has significantly reduced the time it takes to compile skip campaigns. However, the greatest benefit is in the tool's ability to visualise and automatically document campaigns. This ensures that plans are thoroughly understood by all parties leading to a reduction in the time required for approval and execution.

The benefits of the work are:

- Improved understanding and ability to communicate campaigns and moves
- Single data source for all skips and inventory
- Full accountability with respect to data
- Protection from planned actions that would violate constraints and rules
- The ability for the tool to proactively suggest where skips should be placed
- Automatic retention of all historic data
- Comprehensive reporting of skips and inventory data including the ability to print diagrams showing skip locations
- Reduced effort to maintain data associated with skips and inventory
- Reduced time to create and approve campaigns
- Operational plant data are now maintained and used daily by the plant operators

Challenge:

Improvements to auditability of FGMSP skip and inventory data

Solution:

3D virtual reality model

Benefits:

Improved management of skip and inventory data, improved planning, understanding and execution of campaigns and moves

Status:

The tool is deployed and being used to plan campaigns

Delivery partners:

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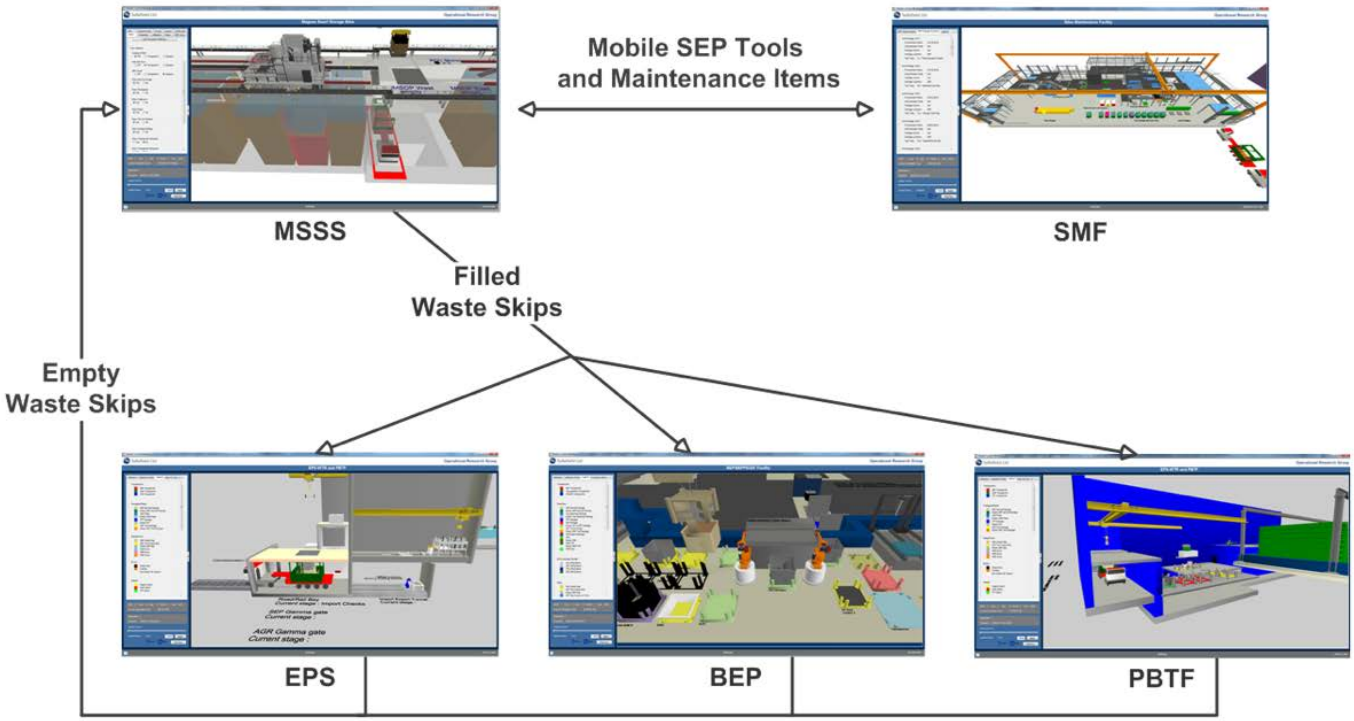
Magnox Swarf Storage Silo stream distributed simulation

The Magnox Swarf Storage Silo (MSSS) is an aging storage facility that has been prioritised for decommissioning as part of the risk and hazard reduction programme at Sellafield. In order for this to happen, all the waste in the silos and the liquid it is submerged under must be removed to allow the building to be demolished. The MSSS distributed waste stream models simulate the operations of the MSSS facility and its supporting facilities, including the downstream waste processing plants: Encapsulated Product Store - Waste Transfer Route (EPS-WTR), Box Encapsulation Plant (BEP) and Package to Box Transfer Facility (PBTF) and Silos Maintenance Facility (SMF), where tools to facilitate retrievals are stored. The models predict each facility's throughput capability, the impact they have on each other and any issues arising from external factors such as transport.

It is important to consider the multiple plants within the MSSS waste stream to provide an accurate picture of throughput. For example, waste is emptied from MSSS into single use waste skips and transported using reusable Silo Emptying Plant (SEP) packages to downstream plants. The availability and storage of these SEP packages are key factors in how efficiently MSSS can be decommissioned.

The MSSS stream distribution simulation is illustrated in the image (distributed simulation architecture) and consists of the following key features:

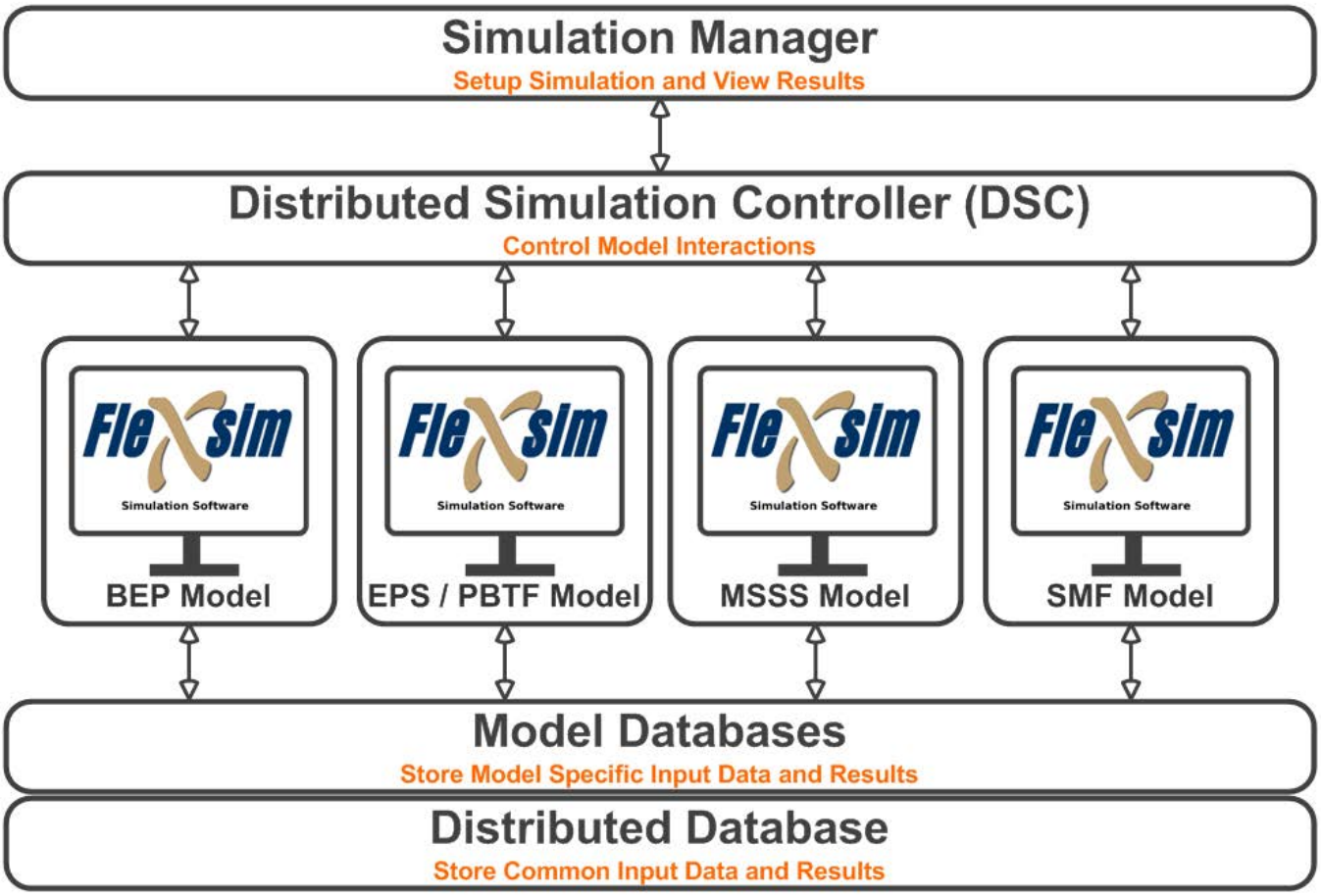
- Four separate sophisticated simulation models running in parallel whilst communicating with the distributed simulation controller (DSC) over a local area network. Each of the simulation models are developed in such a way that they can be run as part of the distributed simulation suite, or in a standalone mode; meaning they do not rely on the other model's input.
- Simulation manager configures all scenarios to run on the models in both a distributed or standalone mode. All results generated are accessible from here.
- Distributed simulation controller is the "nerve centre" used to handle all synchronisations and communications between the simulation models. These communications share resources such as packages, waste and transporters across the models at run time.



MSSS stream distributed model connections

In 2017/18, Sellafield Ltd's requirement to understand the complex interactions of the MSSS waste stream presented an opportunity to apply research carried out by Saker Solutions Ltd. and Brunel University on distributed simulation. The MSSS project pushed the boundaries of what had previously been achieved with distributed simulation in a commercial environment, much of the practical work undertaken had only ever been discussed in theory. New methodologies were developed to allow for reliable, efficient communication between the simulation models without having a detrimental effect on the simulation's run duration.

This flexibility of the system allows analysts at Sellafield to experiment with and answer questions specific to an individual facility, alongside broader questions relating to the stream lifecycle. The latter of which would not be possible without the introduction of the distributed simulation suite.



The image shows the distributed simulation architecture

Challenge:

To understand the complex relationship between the plants in the MSSS waste stream

Solution:

Distribution simulation modelling

Benefits:

Represents a real complex system so that decisions can be made and the impact of changes studied

Status:

Complete and is in use at Sellafield

Delivery partners:

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Silo Emptying Plant machine relocation tool

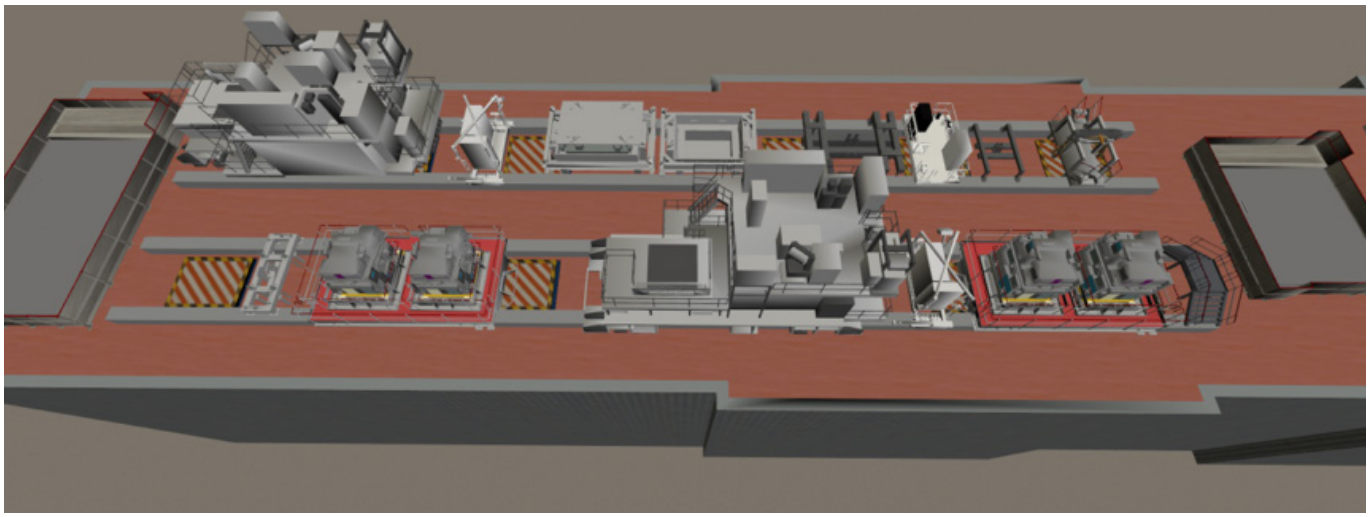
The waste stored within MSSS is held under water in 22 concrete compartments. These compartments will be visited by three mobile SEP machines, which are required to move a number of times during waste retrievals to access all 22 compartments. Additionally, ancillary equipment is needed to perform retrieval operations, for example, park stands for SEP packages, liners which contain the Silo Roof Plugs (SRP) and service platforms to conduct wash operations, all of which will be stored on the operations floor. The amount of equipment needed throughout retrievals is expected to result in the operations floor becoming congested, added to this there are also structural and operational constraints relating to the movement of these items that will make operations challenging. The relocation of SEP machines is a multi-step process, with multiple items of ancillary equipment needing to be repositioned, the series of moves that facilitates and encompasses the movement of a SEP machine is referred to as a “choreography”.

A need was identified for an application to assist with planning for SEP machine relocations that could meet the following requirements:

- To provide an easy to use planning environment that is aware of spatial, structural and operational constraints. All moves require meticulous planning, with foresight to ensure that anything done now does not hinder future moves and require work at a later date.
- To allow any created choreographies to be visually demonstrated to a wider audience. There are often multiple options available when creating a choreography and the ability to clearly demonstrate these in order to get a consensus of the best option to choose is vital.
- To act as a knowledge repository for item dimensions and rules. Key information was previously stored across multiple systems without a central source point.

During 2017/18, a SEP machine relocation tool was developed by Saker Solutions Ltd working in partnership with Sellafield Ltd to meet the identified requirements. The resulting tool enabled the MSSS pre-operations team to experiment with the movement of SEP machines and ancillary equipment, whilst taking into account the structural and operational constraints faced during the inactive and active commissioning phases of the SEP machines and through into mechanical waste retrievals from the compartments.

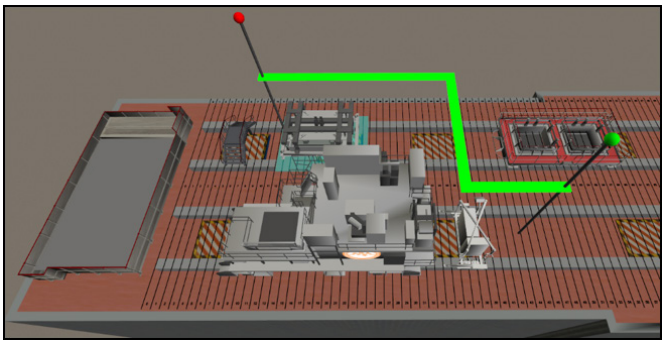
The tool comprises of a custom built .Net application which includes an embedded instance of the FlexSim simulation software, this is supported by a SQL Server database which holds spatial data relating to all objects alongside user input parameters and results.



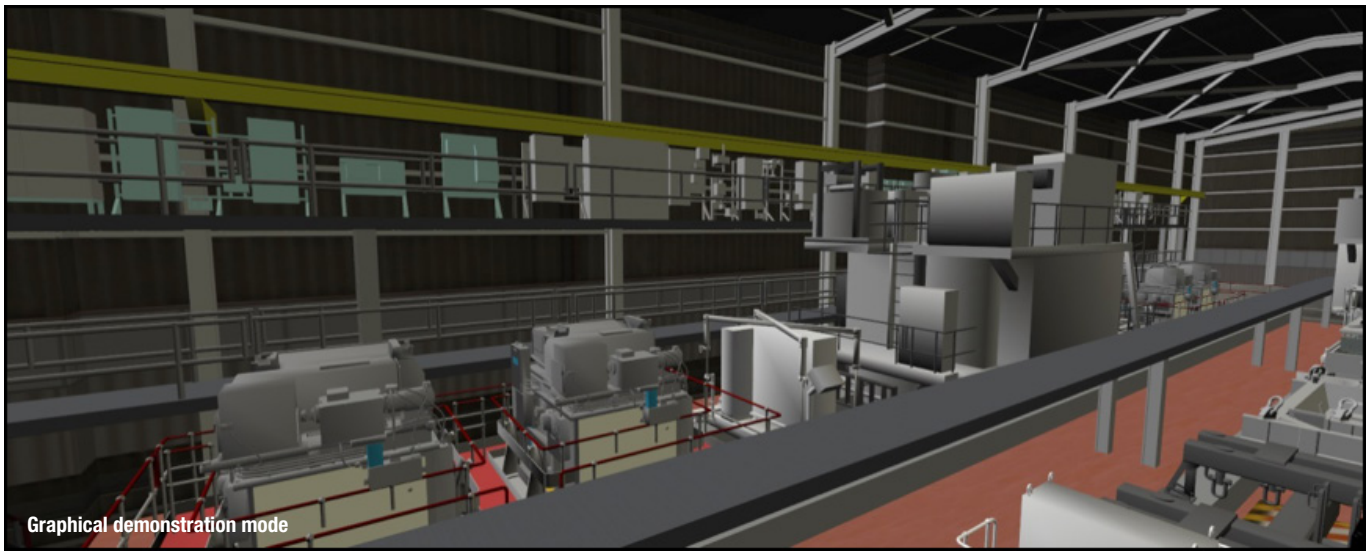
MSSS SEP machine relocation tool overview

Some key features of the tool include:

- A full 3D, spatially aware planning environment to ensure that the tool automatically prevents any item movements into or over areas that do not have enough space or adequate clearance.
- Structural and operational constraints relating to SEP machine or ancillary item placement and movement. This allows choreographies to be created without the user having to be fully aware of all constraints, these will be checked automatically.
- Automated and custom travel route creation for the crane to move an item on the operations floor that meets all relevant constraints. This can be overwritten by the user to account for additional exceptions the tool is not aware of or to add in further clearance from items where space allows.



Custom crane travel route creation



Graphical demonstration mode

- Suggested location highlighting when moving items to reduce the amount of time taken to produce valid choreographies by only showing destination locations at which all constraints have already been checked.
- Multiple graphical modes that are tailored towards choreography creation or demonstration. This allows the user to enter a mode which will allow them to quickly and efficiently create a choreography, then demonstrate it with additional graphics enabled to give more accurate representation of space constraints within the building and to give the audience a greater sense of what is involved.
- Full item tracking and auditability - the tool records all relevant information relating to a choreography and allows the user to enter notes against each individual move. This ensures any decisions can be fully documented and audited at a later date.
- Reports including full details of the choreography created alongside crane routings and risk indicators.

The MSSS SEP machine relocation tool has been extremely well received by the MSSS pre-operations team and it has provided a significant number of benefits over traditional methods:

- Time: Choreographies can now be created and validated in minutes rather than hours or days.
- Error reduction: All spatial and operational constraints are automatically tracked and calculated by the tool. The user is prevented from creating any invalid moves that would violate these.
- Demonstration and knowledge transfer: Together with reports detailing all parameters involved within a choreography, the tool allows the user to visually demonstrate it within a 3D environment. This functionality has proven to be immensely beneficial when communicating and discussing plans across the team.
- Scheduling and job planning: The tool provides time estimates to complete each choreography which can be fed directly into project plans at the facility. It also assigns risk levels to individual movements within the choreography, highlighting where additional staffing requirements may be needed.
- Knowledge repository: This facility removes risk by opening up the planning process to multiple users, removing the reliance on a handful of specialist staff.

MSSS SEP machine relocation tool workflow

Challenge:

Planning for the relocation of the SEP machines

Solution:

Computer software application with multiple features

Benefits:

Fast, easy to use with low error

Status:

Validation testing is complete and the tool is being employed by the MSSS project team

Delivery partners:

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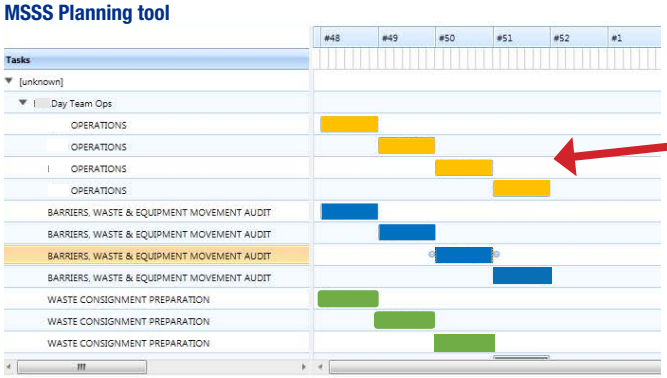
Magnox Swarf Storage Silo maintenance planning tool

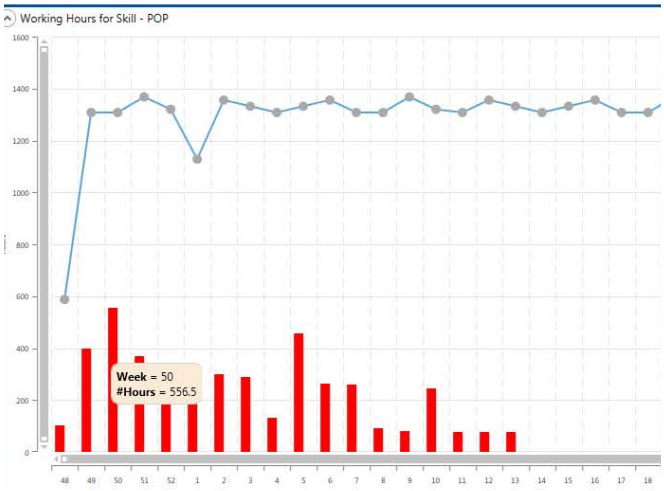
There is a need to ensure that the examination, inspection, maintenance and testing schedule is adequately resourced throughout the planning phase for retrievals in MSSS. In 2017/18, Sellafield Ltd initiated a project with Saker Solutions Ltd. to develop a planning tool that can be used to assess the impact of the availability of skilled resources against the programme of tasks to be undertaken in MSSS. The application was required to highlight where the availability of skilled resources falls short of demand as well as where the demand is such that the resources are not fully occupied.

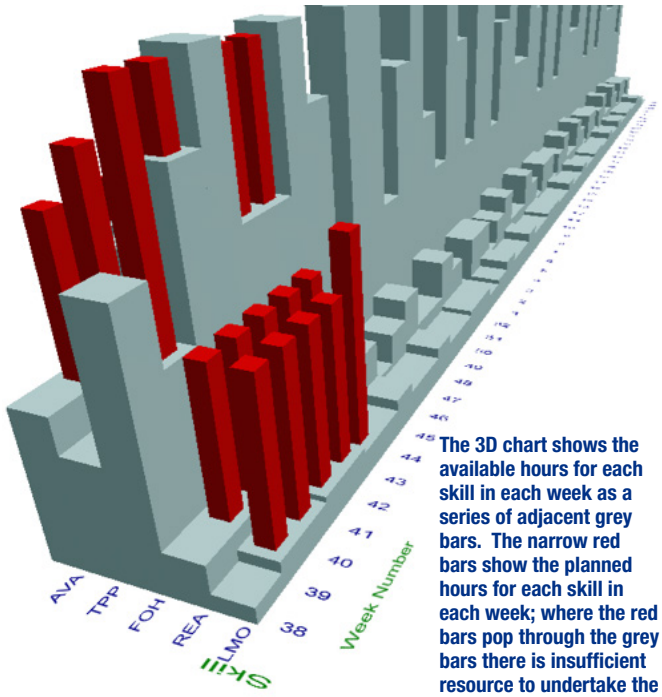
The application developed considers the availability of skills separately and over the course of the planning phase. It uses graphics to show the gap between the demand for skills (total number of hours) to complete the tasks against the availability of resources with these skills, on a week-by-week basis. Additionally, the tool can be used to determine the benefits or impact of changing the profile of the workforce. For example, additional upcoming maintenance commitments, future skilled availability, service frequencies and resource shift patterns. This allows proactive planning of the recruitment and deployment of skilled resources so that work can be responded to in a timely and cost-effective manner.

MSSS Planning tool



Working hours for skill - POP





The 3D chart shows the available hours for each skill in each week as a series of adjacent grey bars. The narrow red bars show the planned hours for each skill in each week; where the red bars pop through the grey bars there is insufficient resource to undertake the planned tasks.

The planning board shows the tasks scheduled. Selecting a task shows the planned hours (red bar) against the available hours (line) for the skill needed to undertake the selected task.

Challenge:

Resource management for the planning phase of MSSS

Solution:

Proactive graphic planning tool

Benefits:

- Ability to quantify the gap between resource availability and work content on a skill-by-skill basis and analyse how to align these more closely.
- The graphical nature of the tool communicates the difference between resource availability and demand in a clear concise manner to facilitate understanding among all parties.
- The tool provides the means to plan for the timely recruitment of skilled resource.

Status:

System testing of the MSSS maintenance planning tool commenced in October 2017 and is now in use within the MSSS operational readiness team.

Delivery partners:

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Mechanism of underwater uranium hydride formation determined by isotopic substitution reactions

One of the most problematical uranium corrosion products on the Sellafield site is uranium hydride (UH_3) produced by storing uranium underwater in sealed containers, resulting in a reaction between uranium and hydrogen. Once formed UH_3, can react further on contact with air or water creating challenges in terms of heat generation and hydrogen production (this was observed during active component examinations at Sellafield in the 1990s), therefore it is important to know exactly how and under what conditions UH_3 is formed.

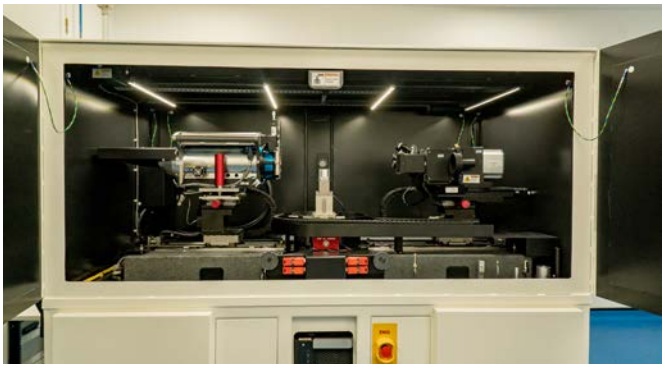
In order to understand the mechanism of UH_3 formation, isotopic spiking was used in controlled corrosion experiments, substituting hydrogen gas (H_2) with deuterium gas (D_2) and replacing water (H_2O) with heavy water (D_2O).

This research is important and relevant to all uranium stored underwater in sealed containers which may have suffered a temporary ingress of water leading to UH_3 formation from the reaction of uranium with hydrogen gas collecting in the container headspace or hydrogen from water. These containers are stored in legacy ponds and silos and will be subject to retrieval handling procedures. Breaching one of these containers for any reason during handling could expose active uranium hydride to air and water leading to substantial heat generation, activity release and hydrogen gas ignition.

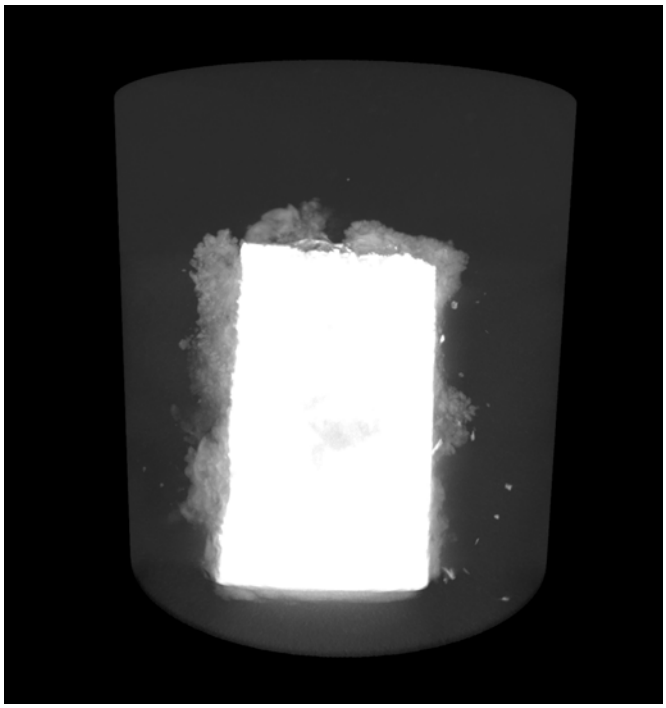
The research was carried out at the Interface Analysis Centre, University of Bristol, using isotopic labelling and the results showed that:

- Below 0.5 bar pressure, UH_3 is produced by hydrogen generated from uranium oxidation by water and not headspace hydrogen.
- Above 0.5 bar pressure, hydrogen collecting in the headspace of a container contributes to UH_3 formation.

This work shows how UH_3 formation takes place and that the absence of hydrogen from the system may not prevent UH_3 formation in any sealed container where water has access to uranium. These results can now be used to support the retrievals strategy for handling these containers.



Test chamber of the Ziess Versa x-ray tomography system (top image is the internal chamber and the bottom image is the exterior)



X-ray radiography image (produced in the test chamber) of the uranium hydride test sample, showing uranium (white) typical dendritic uranium hydride morphology (medium grey) and corroded Magnox sludge CMS (dark grey background)

Challenge:

Understand the mechanism for uranium hydride formation in sealed containers of uranium

Solution:

Isotopic substitution experiments

Benefits:

Improved understanding will avoid potential releases of activity and hydrogen ignition. Underpins retrievals strategy

Status:

The implications of the work and the impact on operations will be considered in 2018/19

Delivery partners:

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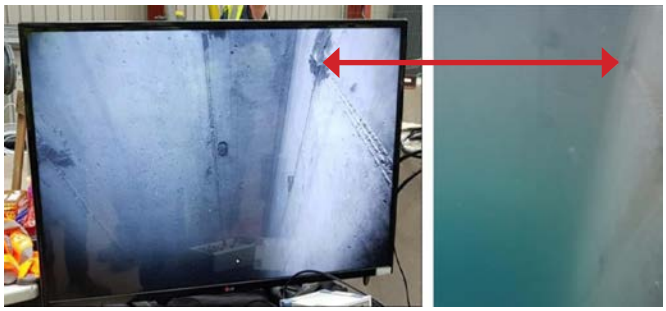
Legacy ponds underwater visibility improvement strategy

Reduced pond water visibility presents a challenge to the retrieval of the solids and sludge inventory from the legacy fuel storage ponds. As the high hazard risk reduction programmes continues to move forward, the identification and deployment of technologies that allow pond operations to progress has become increasingly important.

Visibility within the legacy ponds is affected by the presence of suspended particulate material and from phytoplankton creating seasonal algal blooms. To enable continued in-pond operations during poor underwater visibility conditions, an overall visibility improvement strategy has been produced. This includes the evaluation of commercially available and emerging technologies that improve the clarity and/or resolution of images of the underwater pond environment. Improvement of image clarity/ resolution allows intricate operations to be undertaken in the near-field (for example, remotely operated vehicles (ROVs) that are used to "pick and place' items) as well as improving navigation and location in the far-field.

During 2017/18, a number of technologies were researched and these included ultra-high definition sonar and low light cameras. Because of the potential effectiveness of the low light cameras, these were trialled in the Pile Fuel Storage Pond (PFSP) in November 2017. Their successful deployment facilitated the recovery of two redundant rams (part of the pond furniture used in the decanning process) in very turbid pond water conditions.



The image on the left is the output from the low light camera, compared with the image on the right, taken with a normal camera

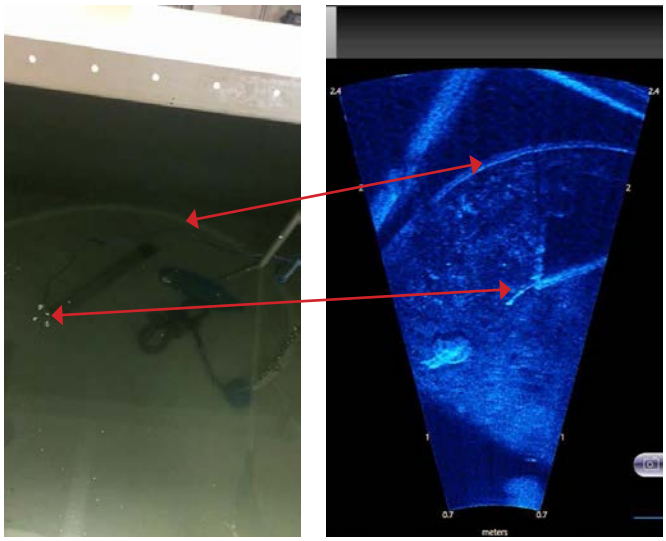


Image taken with an underwater camera (left) and ultra-high definition sonar output (right)

Future work on this project includes research to address the cause of reduced pond water visibility at source (i.e., suspended particles and phytoplankton). A number of mitigation measures will be evaluated including biocides, settling aids and filtration. "Dehazing" algorithms are also being developed to improve image resolution and further work is required if the technology is to be deployed in real-time.

PFSP pond furniture removal (rams). The retrieval of the rams was very challenging for a number of reasons including pond visibility. A new low light camera that is designed to be used in areas of poor visibility was procured and deployed to support the retrieval of these items. Once retrieved, the rams were size reduced and drained to allow them to be processed as LLW.

Left picture taken with underwater camera (on-board ROV) and the right image is processed using a bespoke dehazing algorithm which is being developed. The images illustrate how significant improvements to the images can be made using this technique.

Challenge:

Improved visibility in legacy ponds to aid retrievals

Solution:

Ultra-high definition sonar and low light cameras

Benefits:

More efficient retrieval operations at a reduced cost

Status:

The visibility strategy is ongoing and looking at a broad range of options such as mitigation techniques which enable operations in turbid environments, abatement methods to accelerate the settling of sediment and removal of the algal bloom. This includes shorter term solutions using commercial off-the-shelf techniques as well as longer term R&D.

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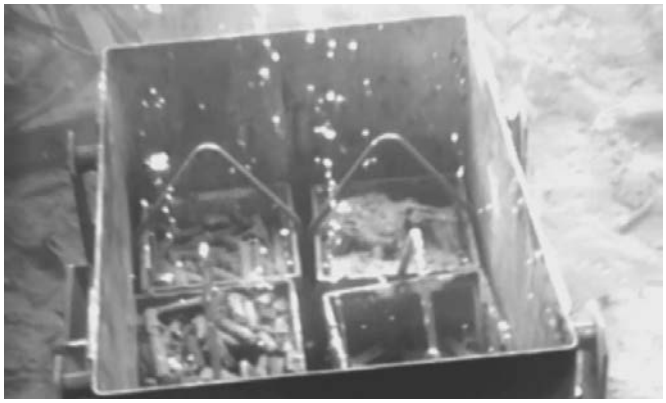
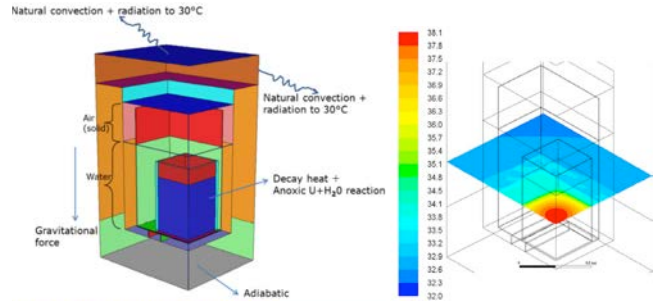
Management of hydrogen during export of uranium bit bins from the First Generation Magnox Storage Pond

An opportunity to accelerate risk and hazard reduction in the FGMSP, was identified, by starting to export uranium "bit bins" (untipped, uncemented uranium) to FHP 21 months earlier than scheduled for interim storage. Corrosion of uranium and radiolysis of water can occur during export of the bit-bins generating hydrogen gas and posing a flammability hazard to operators and equipment. To ensure the safe export of bins to FHP could begin, a hydrogen management strategy was required.

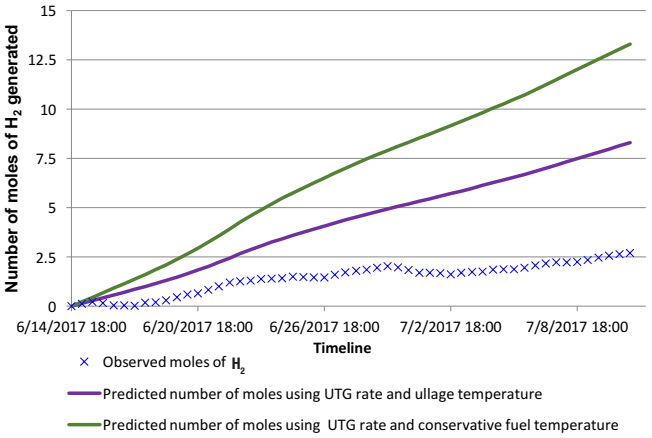
In 2017/18, a full-scale plant trial was planned and carried out to demonstrate that the behaviour of a uranium bit-bin skip during export is within predicted limits. A multidisciplinary team managed the trial which measured the temperature and internal pressure of a flask containing a full uranium bit-bin payload over 26.5 days. The hydrogen generation rate within the flask was found to be significantly lower than the predicted rate. The output of the trial was instrumental in demonstrating the behaviour of bit-bins during the proposed export process and successful implementation of a hydrogen management strategy. Following this, export of the bins began in November 2017, a major step in the continuing risk and hazard reduction programme.



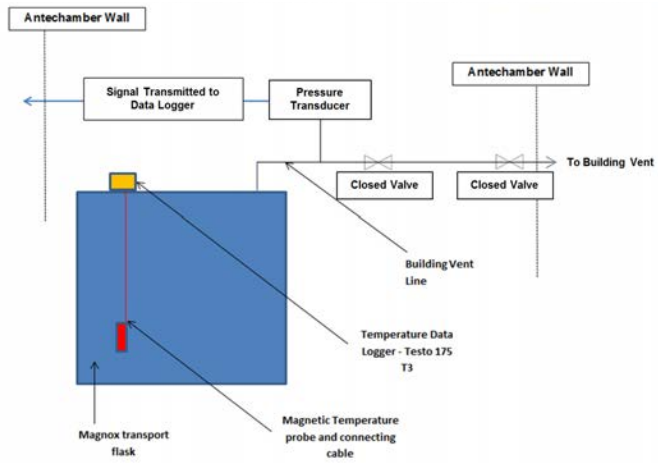
Photograph of the skip used in the trial during transport into the export cell. Bubbles of hydrogen gas can be seen emerging from the bins due to agitation during transport.



Geometry (left) and thermal cross section (right) from a Computational Fluid Dynamics (CFD) model of a water filled flask containing a uranium bit bin skip. This model was used to underpin the hydrogen management strategy for bit bin export.



Comparison of the amount of hydrogen generated during the trial to the predicted behaviour (UTG = Uranium Technical Guide; refers to corrosion rate equation derived from laboratory studies). Ullage temperature refers to the flask temperature measured during the trial and the conservative fuel temperature refers to the fuel temperature estimated by the CFD model.



Schematic representation of the experimental configuration employed during the trial.

ENERGISE
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For everyone working on the Sellafield mission
Sellafield Ltd

U-bitter believe it

As Energise went to press, the First Generation Magnox Storage Pond was on the brink of starting to deliver its latest major breakthrough in hazard and risk reduction with the first ever export of 'u-bit bins' (untipped, uncemented, uranium bit bins) from the legacy pond to the Fuel Handling Plant.

Following on from the start of bulk sludge exports (March 2016) and bulk fuel exports (April 2016), the first u-bit bins export is the most significant step of 2017 in hazard and risk reduction in the legacy pond.

The bins, which contain fuel fragments and some sludge, represent a quarter of FGMSP's total fuel-bearing inventory. By sending them straight to the more modern pond rather than attempting to sort their contents in the legacy facility, they will be exported more than two years earlier than originally scheduled.

Getting the u-bit bins and their skips out will also help accelerate decommissioning because it makes more space in the pond to allow work such as sludge removal.

Once in FHP they will be stored in ullage containment, where conditions and activity levels will be closely monitored to check that the contents aren't impacting on other areas of the pond or downstream plants such as SIXEP.

"What we're achieving here is our value streams approach in action," said Head of Legacy Ponds Dorothy Gradden. "We're speeding up hazard and risk reduction through simplification, we're using existing facilities rather than building new ones, and we're working effectively with our supply chain partners. Seeing the first u-bit bin coming out is a big moment for Sellafield."

Head of Magnox Stuart Pearson said: "Accepting u-bit bins for safer storage in our pond is another example of how we're rethinking our approach to risk to deliver wider benefits. We've built a compelling strategic case to do this and underpinned that with scientific research. It's the sort of mindset which which will drive progress in other areas of our clean-up mission in the future."

BREAKTHROUGH: Soon it will be a case of "bin there, done that"

Simpler, swifter and safer

The new method for getting u-bit bins out of the legacy pond has a number of benefits, and has required a new way of thinking.

- **Original strategy:** Develop and build a £10m tipping system in one of FGMSP's wet bays so that the contents of the u-bit bins could be tipped, sorted and segregated and then consolidated for export. The contents would then stored in the Fuel Handling Plant before being conditioned in a yet-to-be-built facility, the £1billion Bulk Uranics Fuel Treatment capability (BUFT).

Upside: Greater certainty on contents of material being exported; ability to remove sludge from bin contents.

Downside: Dose-intensive work; technically challenging, with risk of contents remaining stuck even after tipping attempts; disturbs sludge

Front cover of the November 2017 issue of Energise magazine, which showcased the first export of bit bins from FGMSP.

Challenge:

Understanding hydrogen behaviour during the export of uranium bit-bins

Solution:

Trial to compare predicted hydrogen generation with actual measured generation

Benefits:

This work has allowed uranium bit-bins to be exported from FGMSP, representing significant hazard and risk reduction

Status:

The project is complete with exports underway since November 2017

TRL change:

Physical and chemical properties from laboratory scale studies of non-irradiated systems (TRL 3) were used to generate a computational simulation of the bit bin system in the trial environment and a hazard management strategy for the trial (TRL 4/5). The trial demonstrated the management of hydrogen generation during export of actual waste at full scale (TRL 8)

External publications/press releases/weblinks:

Energise November 2017: U-bitter believe it

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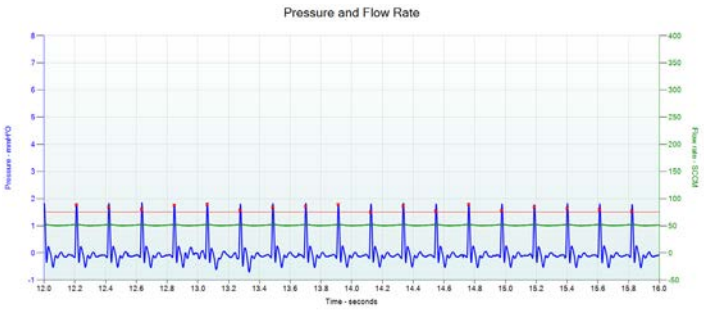
Measurement of hydrogen emission rates from skips of Magnox swarf storage silo

There is a requirement to measure hydrogen emission rates from skips containing Magnox sludge retrieved from MSSS, prior to lidding and consignment to interim storage. The measurement will be used to understand whether hydrogen emissions from skips are consistent with predictions and to facilitate operational/campaign and strategic decisions associated with continuous hydrogen generation and release.

The waste will be exported from MSSS under the cover of water and a number of options for performing the measurement are currently under consideration. One such option is to infer continuous hydrogen release rates by counting bubbles on the liquor surface above the waste, estimating the volume of gas associated with each bubble and using this information to estimate the gas release rate, using a machine vision-based system. The system works by automatically interrogating live video from a camera, using a bespoke machine vision software algorithm. The objective of this project is to establish viability of the technology and to compare it against other available techniques to underpin decision making.

Previous work (phase 1) established the credibility of the technology and developed it from TRL 2 to TRL 3 (see 2016/17 Technology Development and Delivery Summary). During 2017/18, phase 2 of the work was carried out to establish viability of the technology and progress the project to TRL 6. This involved full-scale trials with appropriate test materials, carried out by Wood (formerly Amec Foster Wheeler), to complete software development. The results demonstrated that the machine vision-based system can infer volumetric gas release rate from identifying, tracking, and counting bubbles on the liquor surface, against a wide variety of challenging waste variables. Phase 2 assessed the robustness of the system, accuracy of results in the environment(s) where it will be deployed and the variability of the wastes.



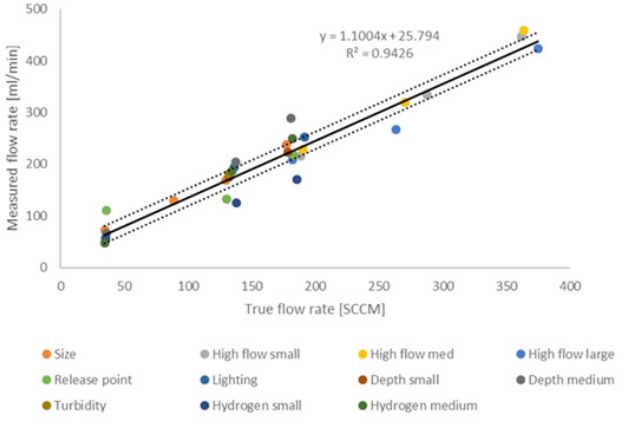
When a bubble of hydrogen was generated this created a pressure pulse in the air supply in the rig, this was monitored. This gas line trace shows the pressure fluctuations.

Specifically, phase 2 provided an understanding of the effect of the variability of the waste on:

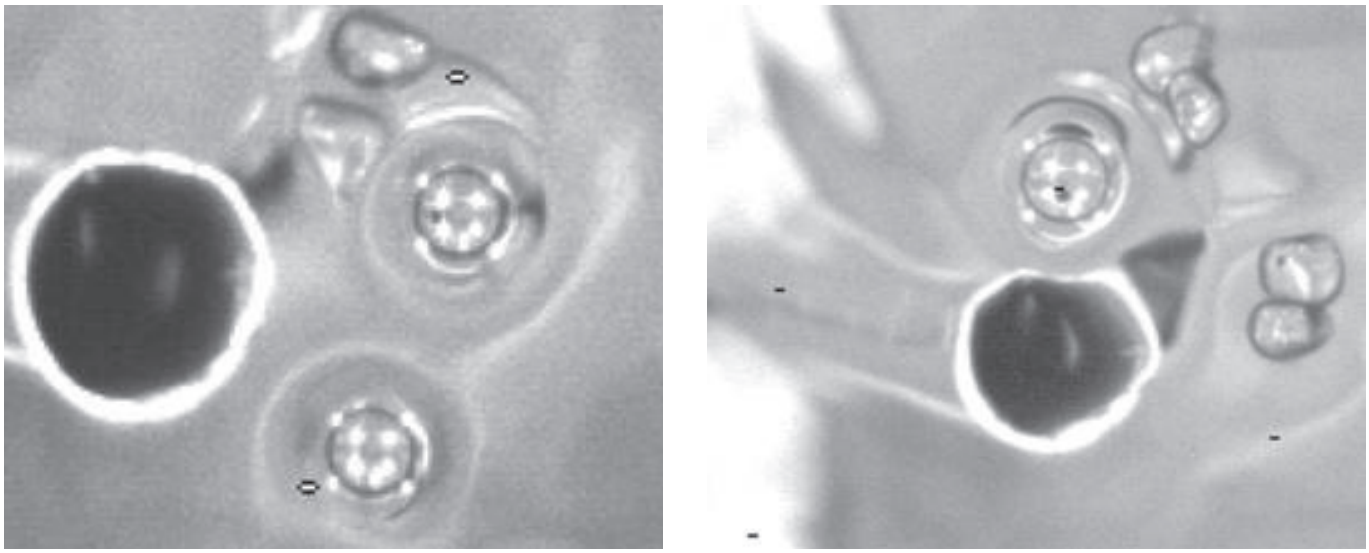
- The range/limits the technology can tolerate
- Measurement accuracy
- Limits of detection

The successful completion of phase 2 supports the decision for proceeding to phase 3 (system procurement and installation on plant at Sellafield), which will take place through 2018/19. Compared to more conventional methods of measuring hydrogen gas emission rates this system has a number of advantages, the most significant of which is ease of deployment (the main requirement is an installed camera). This would therefore provide a low maintenance, simple system to provide information to support campaign management. The main disadvantage is that the system is unable to discriminate between hydrogen and other gases which may be present (either generated or entrained within the waste).

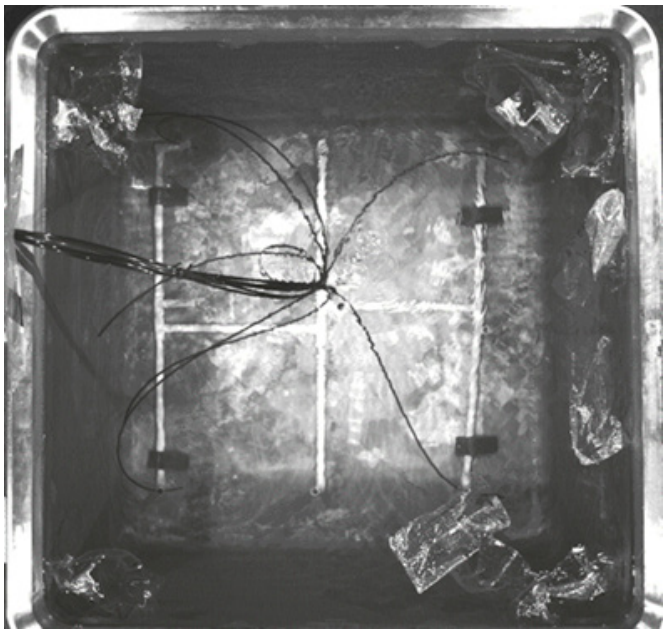
Photograph of the phase 2 test rig with BEP lighting using a Sellafield Ltd skip and a Mirion full resolution camera.



This shows the results from the control tests. The control data were used to give an indication of the accuracy of gas flow rate measurement



The cameras providing the images are expected to be exposed to radiation and this can affect their quality. Radiation may remove the pixels permanently or create a temporary snow effect (by "whiting" out the pixels). Tests were carried out to simulate the effects of pixel radiation damage and the impact on measurement accuracy. The images show examples of white (left) and black (right) simulated radiation pixel damage.



Floating debris may be an issue with the machine vision system because it may cause reflections which look like bubbles or it may obscure surface bubbles preventing them from being counted. These are examples of the type of floating waste used in the tests. The top image shows mixed debris. The bottom image shows clear plastic bag debris.

Challenge:

Assessment of hydrogen release rates from skips of legacy sludge

Solution:

Bubble analysis and measurement from a live video feed

Benefits:

Simple system, low maintenance and easy to deploy

Status:

Ongoing with phases 1 and 2 complete. Phase 3 - system procurement and installation on plant at Sellafield will take place during 2018/19.

TRL change:

TRL 3 to TRL 6

Delivery partners:

Wood, Mirion Technologies

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Magnox Swarf Storage Silo third extension swarf flattening project

Cladding material removed from the decanning of irradiated Magnox fuel prior to reprocessing operations has been retrieved from the third extension of MSSS using the Swarf Retrieval Facility (SRF). Retrievals that took place in the 1990s removed a significant amount of swarf but it also left craters which built up around the silo due to the limited reach of the removal grab. The aim of this project was to create a method to flatten the swarf craters to allow further retrievals with the SEP machines and by collapsing them, it will allow liquor levels to be reduced as part of the hazard reduction programme. The Sellafield Innovation Centre was tasked with delivering a solution to this problem.

Following an optioneering process to identify potential solutions, a six-inch dredging device was sourced and hired from WeSubsea UK Ltd. The dredger, which is used to redirect underwater debris and sediment, was trialled on test material (non-active Magnox swarf) at NNL's testing facility in Workington in February 2018. This trial successfully demonstrated the dredger's ability to redirect swarf and collapse craters. The dredger can also be used to invert swarf craters and manually position material directly underneath the SEP machine, making operations more efficient.

Trial venue with test material added

Dredger unit setup

Still image of dredger removing test material

Challenge:

Swarf crater flattening prior to continued retrievals

Solution:

Dredging device

Benefits:

Allows movement of swarf to convenient locations so that retrieval operations may continue via the SEP machines

Status:

Ongoing with further trials on partially corroded swarf and sludge planned. WeSubsea are looking to produce a smaller, electrical version of their dredger for future deployment

TRL change:

Dredger TRL 7 (established technology and capable in a nuclear environment environment). Overall delivery system not yet designed

Delivery partners:

WeSubsea UK Ltd., National Nuclear Laboratory

Contact details:

Project Lead: James Charlton
james.charlton@sellafieldsites.com

Team: Joe Stubbs, Tyler Butterfield, Natalie Scott, Laura Brown, Chidera Okeke, Tom Chadwick

Innovation Centre: Stuart Gorman, James McGarley, Jamie Martin

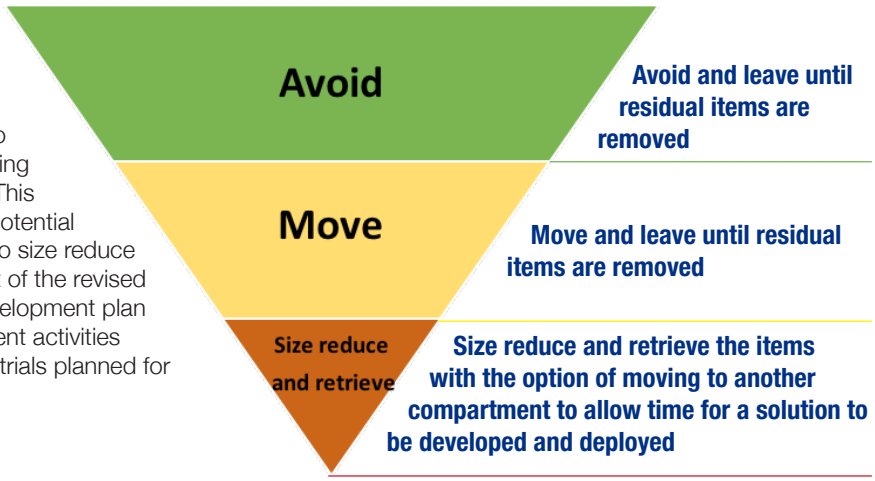
MSSS Strategy & Technical: Mike Wilcock

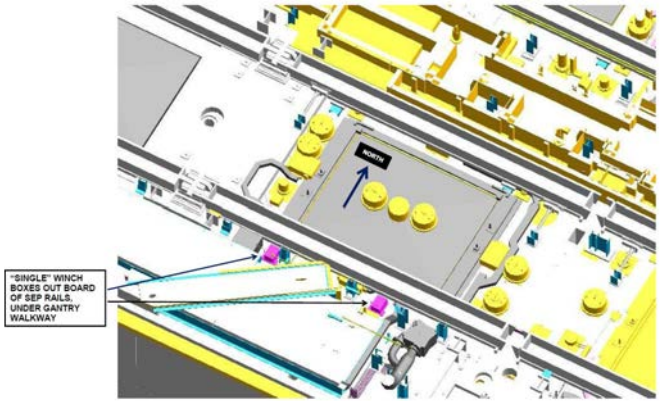
Management of oversized items in the Magnox Swarf Storage Silo

There are items within the MSSS compartments that have the potential to slow down bulk retrieval of waste because they are too large for the waste route. The existing approach is to size reduce these items using a water jet cutting technique, however because there are a number of problems associated with this method, a project was initiated to consider alternative approaches.

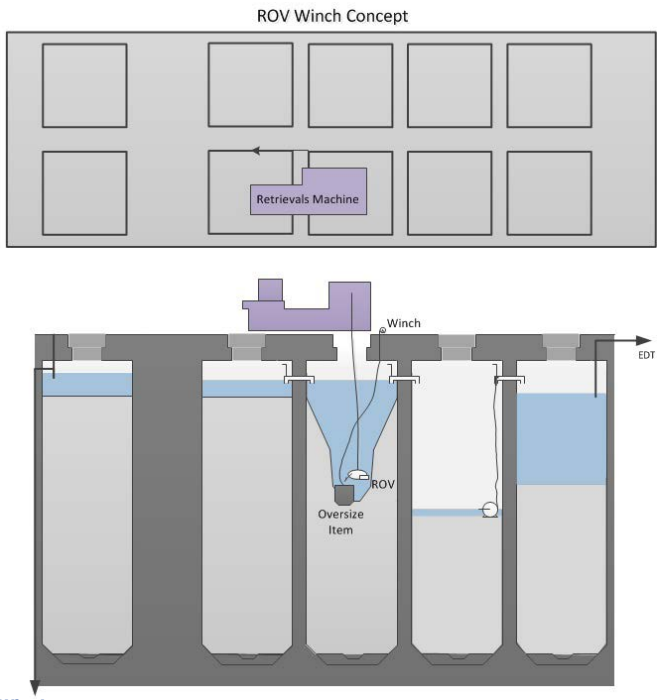
In May 2017 a process was undertaken to define the problem and identify success criteria, constraints and requirements. This generated the following strategy for the management of oversized items, it follows a waste retrievals hierarchy:

The next stage of the work identified a method for the movement of items and it was concluded that the most effective method would be to use a ROV to attach a tether, followed by winching to one side of the compartment. This stage of the work also identified potential technologies that could be used to size reduce the items. Following endorsement of the revised approach an engineering and development plan was prepared with key development activities identified, these are ongoing with trials planned for 2018/19.





Possible winch locations



Winch concept

Challenge:

Management of oversized items in MSSS

Solution:

Waste management hierarchy, avoid, move, size reduce and retrieve

Benefits:

A new approach has been defined that ensures continued retrievals of bulk waste with minimal downtime on encountering any oversized items in the silo

Status:

Ongoing with key development activities identified:

- ROV-enabled winching and tethering system trials
- Waste handling trials demonstrating that oversized waste can be manoeuvred into the retrievals housing in the correct orientation
- Specific trials demonstrating selected cutting technique can work in the relevant environment

TRL change:

Tethering using an ROV TRL 3 and size reduction TRL 3

Delivery partners:

Nichols Group, DBD Ltd., React Engineering Ltd

Contact details:

Mike Wilcock mike.wilcock@sellafieldsites.com

Variable buoyancy heavy lift remotely operated vehicle

Pond operations at Sellafield require the capability to move objects around so that their decommissioning programme can be delivered, there are however, two challenges:

- The picking up of heavy items (this is beyond the capability of the present ROVs).
- Minimising the disturbance of the material on the pond floor. Disturbance reduces pond visibility and this has an impact on operations.

In 2017/18, NNL in partnership with ROVtech Solutions Ltd. won an award to develop a prototype ROV to remove items from the pond floor, using a novel way of controlling lift in a way that reduces the disturbance of sludge. The variable buoyancy device was designed to be positioned by an external ROV with descend and ascend control via an internal bladder arrangement. Initial trials showed that the device is capable of lifting a mass of up to 30kg, but there were difficulties in targeting and picking up material. The link to the external ROV was not sufficiently rigid to allow fine position control. Improvements in the valve system controlling the buoyancy were then installed to give better descend and ascend control and the link to the external ROV was changed to a simple bolted bracket.

Initial trials with the modifications showed better positioning control, these are ongoing, and if this proves to be an effective system, further trials will be undertaken in a Sellafield pond. A new pick up jaw was also designed and trials are expected in 2018/19.

Image showing link from the Rovtech device (left) to an external ROV (right)

New pick up jaws

New pick up jaws

Safe retrieval after successful prototype test

Challenge:

Lifting and moving heavy objects in a pond with minimum disturbance to pond visibility

Solution:

Closed loop variable buoyancy lifting device and a long reach arm

Benefits:

Lifting and movement of heavy items off the floor to a transport skip, continuously with minimal effect on pond visibility. This will increase productivity and reduce the load on other key equipment in the facility

Status:

Ongoing. The prototype has been built and further development is ongoing on the targeting and pick up mechanism

TRL change:

TRL 3 to TRL 6

Delivery partners:

National Nuclear Laboratory, ROVtech Solutions Ltd.

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Post operational clean-out IRT

Post operational clean out (POCO) is an activity that will be undertaken following the completion of plant operations in order to prepare a facility for the next phase of its lifecycle, this might be a period of care and maintenance or decommissioning. The extent of activities undertaken during POCO to meet this objective will vary from facility to facility, for example straight forward clean-up of a facility or cell using available wash systems may be sufficient for some plants but others may require extensive remote intervention and the removal of equipment. For all facilities the cost of undertaking further POCO will be assessed against the benefit that could be gained.

The overall aim of the project is to make as significant an impact on residual inventory and hazard as is practicable, making best use of existing infrastructure and reagents wherever possible. This will be achieved by applying innovative approaches to the characterisation of facilities and waste; methods for accessing facilities; techniques for the removal of activity and hazardous material (or fixing where appropriate); and management of resultant effluent and waste. This report presents the progress made during 2017/18 in a number of key areas of the POCO programme, which is managed by an IRT.

Initially the project focused on the following research:

- Assessment of ELENDES (Electrochemical Enhancement of Nuclear Decontamination Solutions)
- Magnetic ion exchange
- Routing of POCO effluent through existing plants at Sellafield
- Electrically assisted surface decontamination
- Ultrasonic removal of oil and grease

In addition to the experimental programme discussed in the following sections, a POCO tiger team was formed. The tiger team carried out an assessment of options to apply innovative techniques to the POCO of reprocessing vessels resulting in the identification of a number of innovative approaches to enhancing the effectiveness of POCO operations.

ELENDES

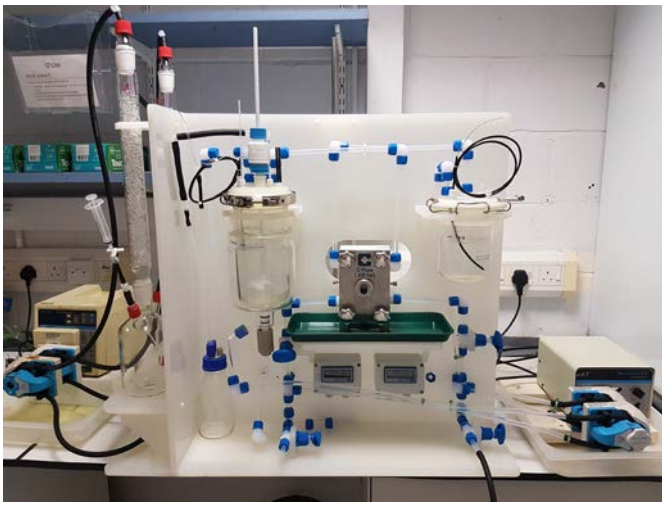
Over recent years, NNL and C-Tech Innovation Ltd. have developed an electrochemical technology (ELENDES) that:

- Is capable of treating a range of organics found at Sellafield
- Enables the use of effective decontamination reagents that have previously had limited application due to complications with subsequent processing of effluent and waste.

Work has demonstrated that:

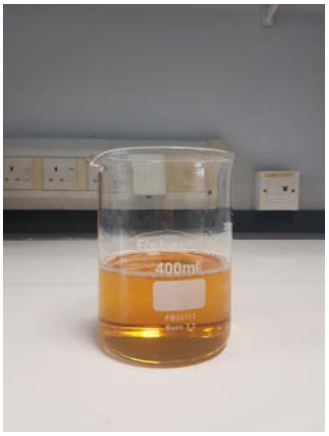
- Waste decontamination solutions containing hydrochloric acid and complexants can be treated to levels that are acceptable for processing through existing effluent infrastructure.
- Decontamination solutions enabled by the ELENDES technology are capable of decontaminating active plant samples to exempt levels.
- Oxidation of soluble and insoluble organic molecules (solvents, organic acids and oils) to carbon dioxide is readily achieved with high efficiency using both direct and mediated electrochemical oxidation.

In 2017/18 work was undertaken to demonstrate the treatment of oily wastes where the oil was electrochemically oxidised to carbon dioxide and water.



Laboratory scale treatment unit used to process oils

Preparations were also undertaken by C-Tech Innovation Ltd, Sellafield Ltd and NNL to explore an active deployment of the technology on a facility at Sellafield. The team performed an appraisal of operational requirements, scale of deployment and siting options.

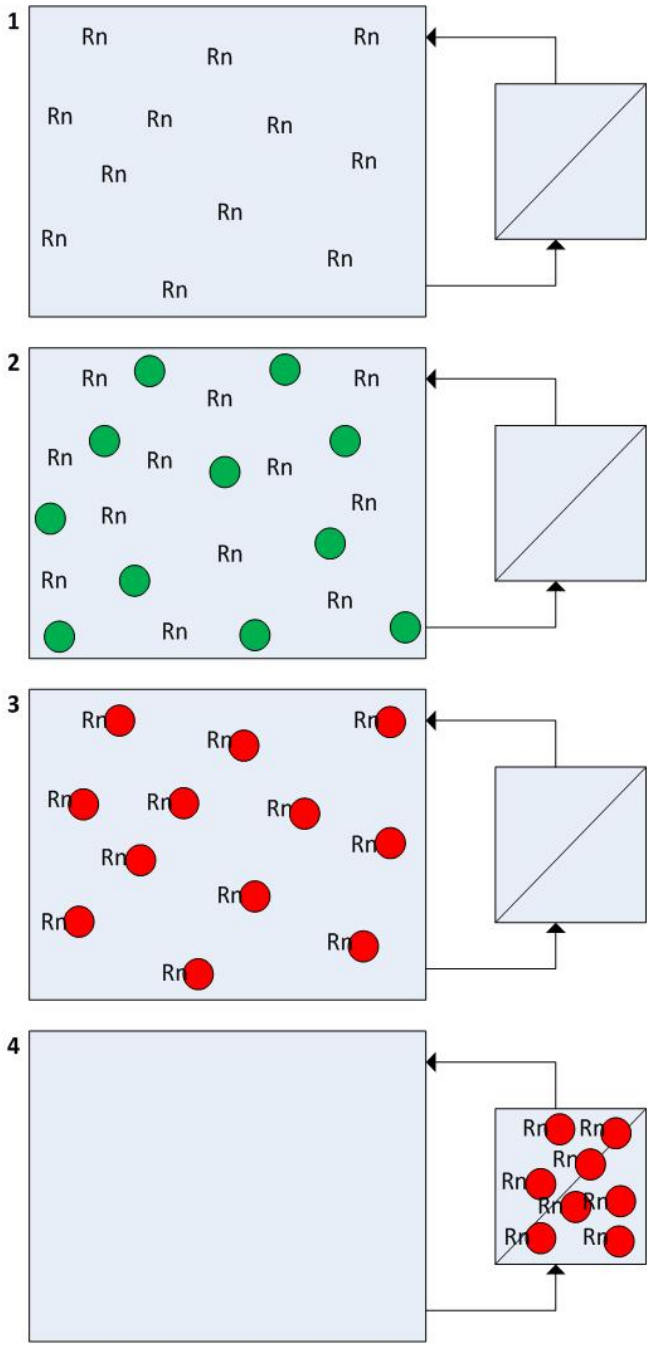


Oil waste (left), treated oil waste (right)

Magnetic ion exchange

Magnetic ion exchange materials can be used to remove radionuclides from decontamination effluents and plant washouts and there is an opportunity to use this technique in future scenarios where effluent routes may not exist or are difficult to access. The application of magnetic ion exchange materials would allow the activity to be collected in-situ on the ion exchange material before the 'loaded' ion exchanger and associated activity is recovered on a magnetic filter for disposal. This approach makes the plant undergoing POCO independent of effluent capability and may increase options for future routing of effluent.

The principle was proven using a small-scale rig that reproduced plant features such as pipes, bends, obstructions and tanks. It was concluded that refinement of the ion exchange materials and magnetic filters would be required to progress this concept.



Magnetic ion exchange:

1: Radionuclides (Rn) in solution

2: Ion exchange material introduced (green circles)

3: Radionuclides taken up onto ion exchange material (red circles)

4: Loaded ion exchange material recovered on magnetic filter

Image of the rig used to circulate and recover magnetic ion exchange material

Magnetic ion exchange material captured on magnetic filter

Routing of POCO effluent through effluent plant at Sellafield

POCO operations may be enhanced by the application of decontamination reagents. Historically the reagents that have been used during normal operations at Sellafield have been limited due to concerns about the potential to compromise process chemistry, plant integrity and down-stream operations such as abatement and waste disposal. A significant amount of research has been sponsored by the effluent plants, SIXEP and Enhanced Actinides Removal Plant (EARP) to extend the understanding of the capability of the plants to process effluent that is outside of the normal operating envelope. A task was undertaken to understand the range of decontamination reagents that may be of interest to POCO teams and then to explore their potential impact on effluent processes at EARP and SIXEP. This was achieved through the use of modelling tools that have been adapted from international approaches to substantiating waste disposal and validated against experimental and plant data.

The work assessed the impact of 26 reagents over a range of relevant chemistry and process conditions in SIXEP and EARP and a preliminary classification of reagents was produced, using a traffic light system. The findings were as follows:

- EARP – For many of the effluents, the process chemistry either mitigates the potential impact of the reagents, or they could be processed with minor modifications to the plant. This finding presents several new options to POCO teams and highlights the potential for EARP to support POCO operations.
- SIXEP - For effluents routed through this plant, there is far less mitigating chemistry and much greater caution should be applied, the assessment did however identify some options for consideration that may benefit operations in some of the donor plants to SIXEP.

The model and output can now be applied to scheme specific scenarios and help with the planning of reagent deployment during POCO.

Electrically assisted surface decontamination

Sellafield reprocessing infrastructure includes significant amounts of contaminated steel and with a significant proportion of the contamination associated with surface coating and activity engrained in the first 10's of microns of the steel. Removal of this material can dramatically reduce the activity leading to significantly reduced local dose and cost savings associated with reduced waste classification.

Electropickling is a mature metal finishing technology which can effectively remove the surfaces of metals. Nuclear experience has shown impressive decontamination (decontamination factors of up to 10^6) and that metallic waste can be treated to free release levels. NNL have worked with C-Tech Innovation Ltd. adapt an enhanced electropickling technology (Electrically Assisted Surface Decontamination - EASD) for use in the nuclear industry, using nitric acid as the electrolyte so as to ensure compatibility with Sellafield effluent and waste processing routes.

Work included a review of prior experience of the technology and active demonstration trials at laboratory scale using coupons cut from active nuclear facilities across the UK. The following conclusions were drawn:

- Multiple examples of successful decontamination of metallic waste have been identified in internal and external literature with decontamination factors of 106 and free release of material possible.
- Prior application of electropickling on the Sellafield site may have been limited due to limitations on the discharge of spent electrolyte. The increased availability of effluent plant (such as EARP) to accept POCO effluent will address this limitation with the activity and iron released during decontamination, compatible with EARP.
- Surface removal rates of 6 micron/minute are achievable in nitric acid.
- Electrolyte can be re-used extensively (e.g. up to 80g/L Fe) without significant degradation in performance.
- Surface coatings that insulate surfaces (such as paint and grease) compromise performance and would need extended processing times or pre-treatment. Such situations are likely to be the exception.
- Active test work with three different types of contaminated metal showed that waste reclassification (either from low-level waste (LLW) to very low-level waste (VLLW) or from VLLW to free release) was possible within minutes.

Work is now ongoing to develop in-situ deployment options.

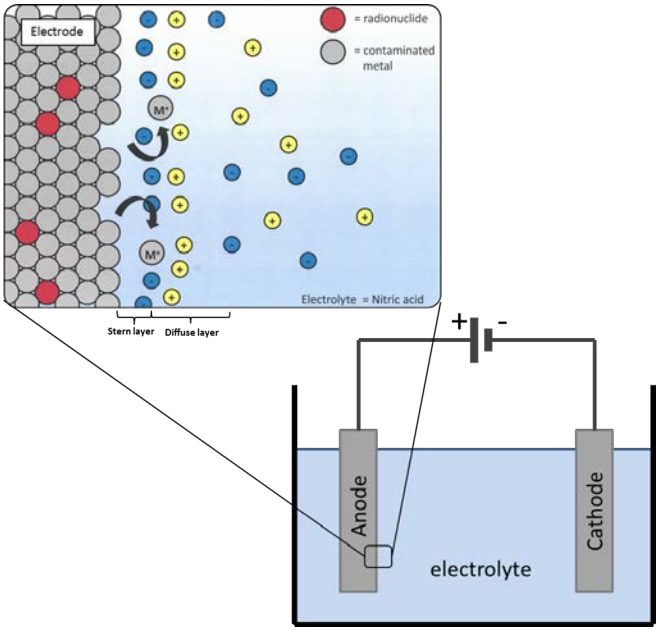
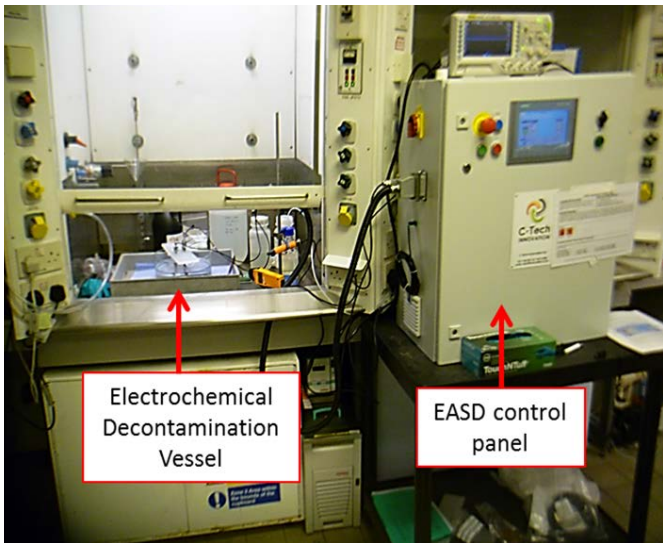


Illustration of removal of metal surface and activity achieved by applying a current



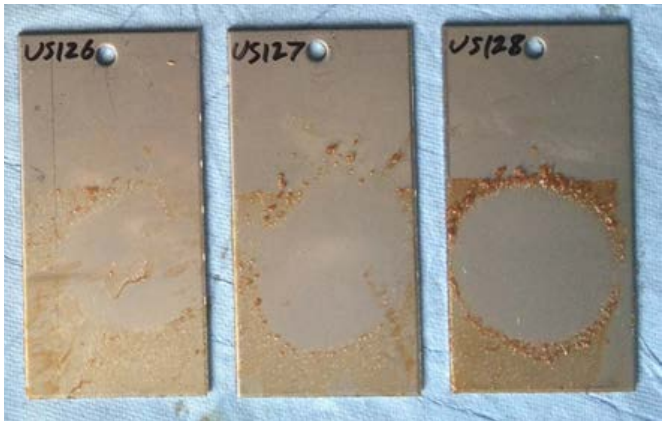
Proof of principle test rig in active laboratory

Ultrasonic treatment of oils and grease

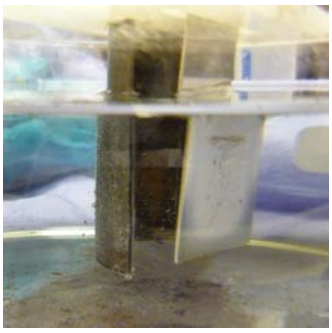
Contaminated organic wastes (such as oils and solvents) present problems during the operation of nuclear facilities (e.g. presenting the risk of fouling effluent treatment plant such as SIXEP and EARP), complicate decommissioning by presenting a barrier to decontamination operations (physical film preventing access to surfaces) and they can be a hazard to operators (dose and fire hazard during cutting operations).

Ultrasonic technology was explored as a method to remove oils and greases from surfaces and as a method to generate emulsions (which can be treated by ELENDES). Work was conducted using ultrasonic horns which amplify ultrasonic energy to remove oils, solvent, grease and paint that had been deposited onto metal coupons.

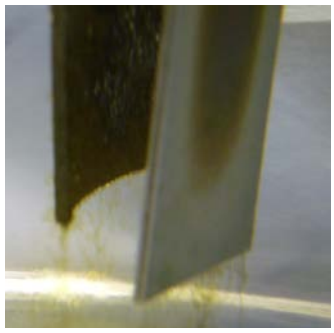
Coupons prior to treatment



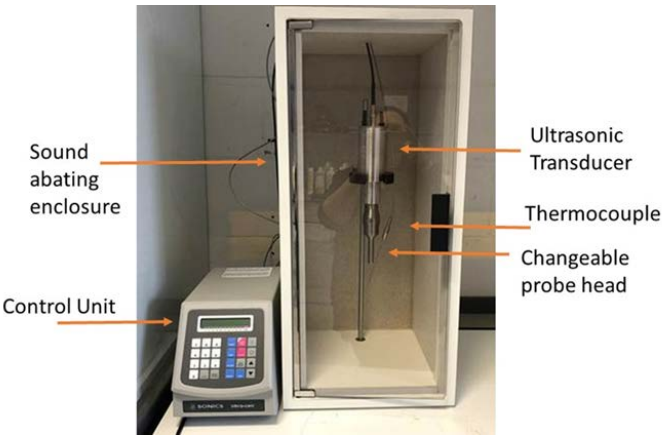
Treated coupons



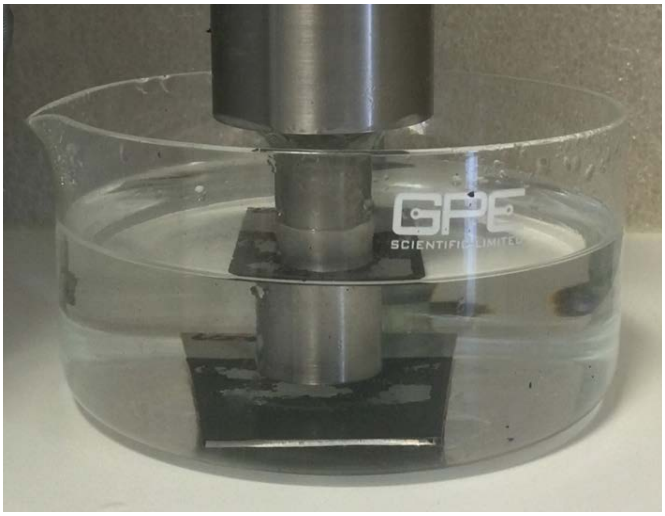
Cut section of contaminated pipework undergoing decontamination



Pipework being removed mid-treatment showing contamination and metal surface being removed



The ultrasonic method was found to rapidly remove deposited organics leaving a clean surface.



Ultrasonic horn above a test coupon

Delivery partners:

National Nuclear Laboratory, C-Tech Innovation Ltd., ProNu-Dec Ltd., University of Birmingham

Contact details:

For more information on the IRT please contact the programme lead:

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Thorp pneumercator access tank inspection

Sellafield is preparing for the management, closure, and decommissioning, of the current spent fuel reprocessing plants, and associated facilities. Planning for the POCO of Thorp is progressing with characterisation required to provide information to support the POCO strategy. Highly active aqueous raffinate from the reprocessing of spent fuel is stored in tanks that are very challenging to access for inspection and a project was initiated to develop and test a device that could be used for this purpose.

An access route for the raffinate tanks was identified via a 17m long, 15mm diameter, pneumercator line with four, 90° bends and two, 40° bends. This specific line is the hardest access route to a vessel in Thorp and if an inspection device can be successfully deployed using this route then other less challenging pneumercator lines in Thorp should provide easier access. In 2017/18 and building on earlier research this project was delivered via the Sellafield Innovation Centre. The project team devised a working prototype which consisted of an viZaar VUMAN E3 endoscope camera, a protective/friction reducing sheath (which included an end protector on the sheath end), a box for the camera to be stored inside and other auxiliaries to assist with operation. A successful non-active demonstration of the device was carried out at the Gen2 facilities in Workington.

This project has provided a cost effective and radiologically safer solution over the current technique to inspect vessels in Thorp avoiding cutting into contaminated cells and vessels to provide access. The system is also designed to be re-useable with a one-off purchase cost of the equipment. Additional development work will be undertaken by the Thorp POCO team in 2018/19 to test the device further, this will include a 3-stage test in non-active chemical vessels, then if successful in a low active vessel and finally in a highly active vessel.

viZaar VUMAN E3 endoscope

Camera end with protector

Challenge:
Inspection of tanks in Thorp for characterisation

Solution:
Device developed for deployment via an existing pneumercator line

Benefits:
Cost effective, safe solution which avoids intrusive cutting into contaminated areas

Status:
Additional development work will be undertaken by the Thorp POCO team in 2018/19 to test the device further, this will include a 3-stage test in non-active chemical vessels, then if successful in a low active vessel and finally in a highly active vessel.

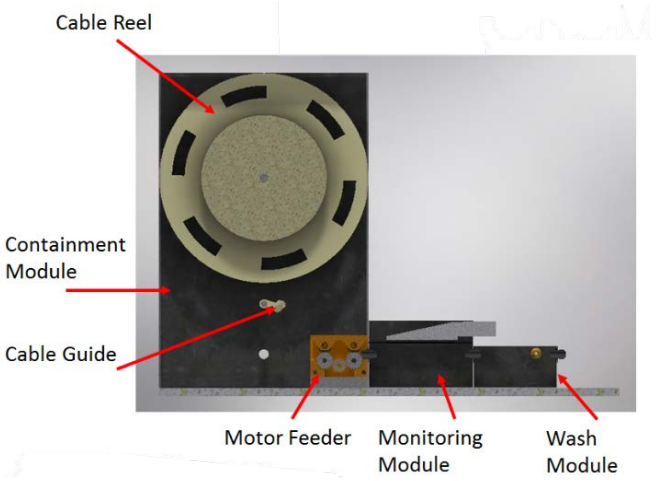
TRL change:
TRL 1 to TRL 7 (from concept to demonstration within 5 weeks)

Delivery partners:
viZaar Industrial Imaging AG, Gen2

Contact details:
Graduates and Degree Apprentices: Sam Creed, Jonathan Bates, Jason Hill, Ellie Graves, Rhodri Farrer, Glen Norris, Sohrab Azimi

Innovation Centre: Stuart Gorman, Jamie Martin
sam.creed@sellafieldsites.com

The picture shows the sheath material being deployed down the mock version of the 17m pneumercator line. Following deployment of the sheath, the camera is then deployed down the line inside the sheath.



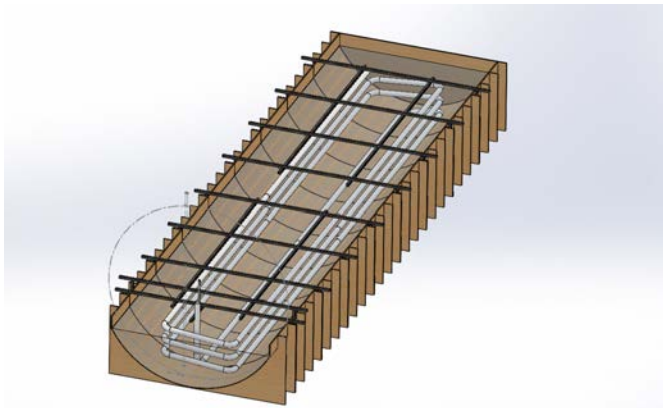
Cross section of the camera containment modules

Highly Active Liquor Evaporation and Storage sparge agitation test rig

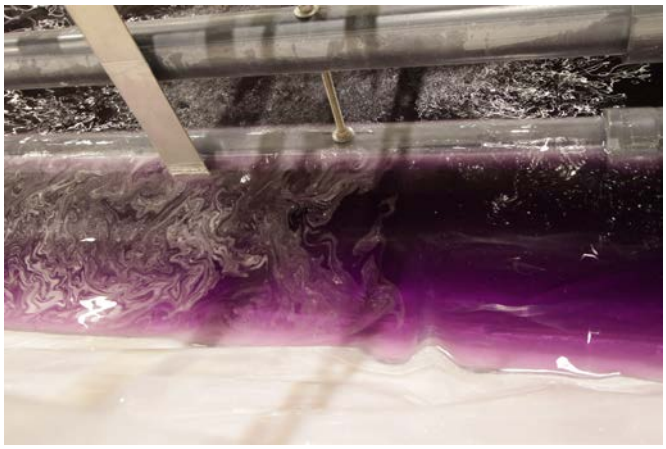
To simplify future decommissioning activities, POCO of the Highly Active Liquor Evaporation and Storage (HALES) facility aims to remove as much of the radioactive inventory from the plant as possible utilising existing plant equipment and waste routes. The Oldside storage tanks in HALES were built during the 1950s and supported the first reprocessing operations on the Sellafield site, by storing liquid waste. They are tanks with a simple design and therefore solids formed by concentration of the liquor will have settled over the course of the operational history of the plant. The POCO strategy for the tanks involves the use of chemical reagents to dissolve the solids and allow them to be transferred into newer parts of the plant for re-precipitation and treatment using the established route.

Previous research and development found that the dissolution process could be accelerated by agitating the liquor to disrupt the concentration gradients that would otherwise form as the solids dissolve (mitigating the risk that POCO of these legacy wastes would require extended operation of the facility). Optioneering and subsequent computer modelling suggested that blowing compressed air down dip legs already present in the tanks could provide sufficient agitation and avoid the need to develop complicated and expensive engineering to introduce new equipment to the tanks.

Building on this research, in 2017/18 Sellafield Ltd funded the construction of a full-scale test rig at NNL's Workington laboratory. The fit-for-purpose rig consists of a ply wood construction and replicates the geometry and internal furniture present in the HALES tanks. Trials were undertaken to determine the amount of agitation that can be achieved throughout the tank depending on the volume of reagent present and the air sparging rate used. These were successful and confirmed that the proposed approach to agitate the tanks by sparging air through installed instrument lines can generate sufficient movement of the reagent, giving confidence that POCO of these tanks is achievable in the proposed operating time-scales for the plant.



Computer model of the test rig showing internal furniture



Mixing zone of two currents heading in opposite directions

Challenge:

Mobilisation of solid materials from historic storage tanks

Solution:

Dissolution of material whilst accelerating the process with air sparging

Benefits:

Avoids expensive engineering alterations to the plant

Status:

Results from the trials are being used to develop the requirements for engineering modifications to plant, and to inform final laboratory trials to underpin the use of proposed reagents

TRL change:

TRL 3 to 4

Delivery partners:

National Nuclear Laboratory

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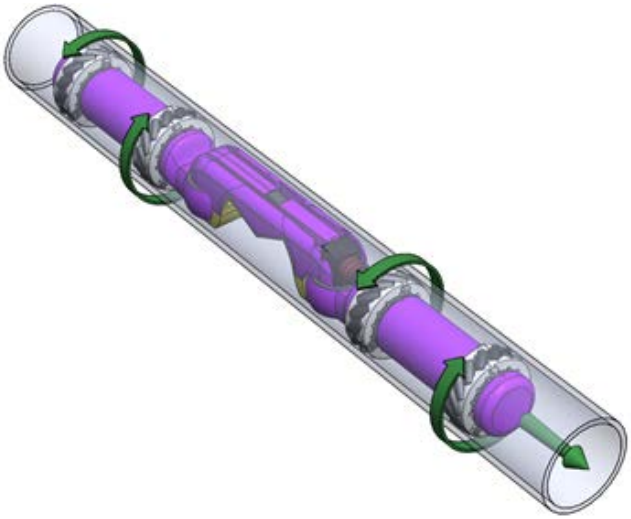
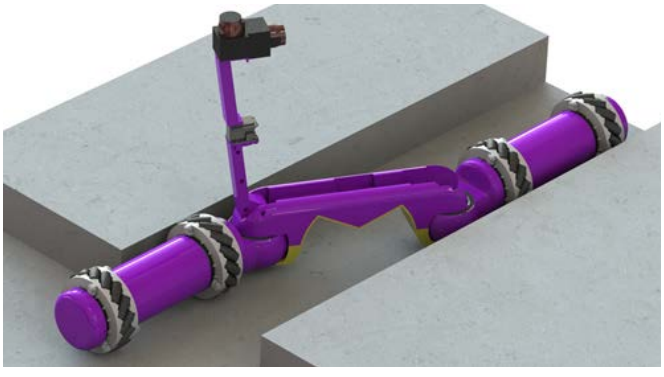
Brian Clifford brian.a.clifford@sellafieldsites.com

MIRRAX: a reconfigurable robotic platform for the survey of access-limited areas

A number of buildings on the Sellafield site require geometric and radiological characterisation as part of the planning process before decommissioning can begin. As human suited entries for characterisation are expensive, time consuming and carry a high-risk factor, alternative ways to gather essential information about a facility are being developed. Furthermore, many of the facilities at Sellafield have been sealed for an extended period of time and initial access is often restricted to 140 mm or 270 mm diameter entry ports.

Over the past few years, Sellafield Ltd and The University of Manchester have been developing the MIRRAX (Mini Robots for Restricted Access Exploration), a new robotic platform which might offer a potential solution to the issue of remote characterisation of some of these facilities. The MIRRAX remote inspection vehicle has been specifically developed to explore and characterise enclosed facilities which have limited access ports. Its reconfigurable design means that it can currently be deployed through entry points with diameters as small as 160mm before changing its footprint shape to provide a stable platform for mobile characterisation. The MIRRAX prototype is equipped with LiDAR (light detection and ranging) because its current plastic frame cannot accommodate a larger payload, this is for demonstration purposes. There is potential for redesign work which could include a metal frame to support other sensors such as a collimated radiometric camera. This would enable the platform to semi-remotely characterise rooms by generating a 3D map and a radiological overlay in real-time as well as providing live video feed.

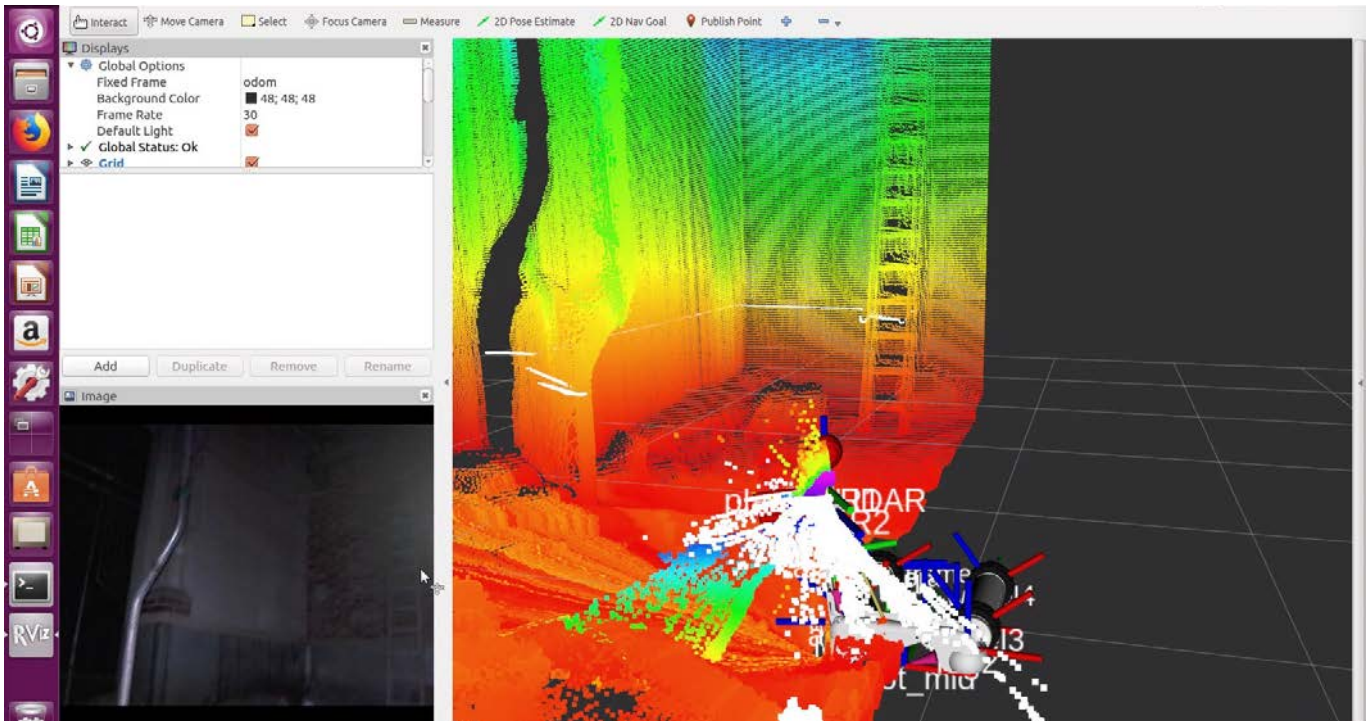




The MIRRAX has omnidirectional capabilities and it can manoeuvre obstacles

Building on previous work (see 2016/17 Technology Development and Delivery Summary), the MIRRAX prototype was deployed in March 2018, in the First Generation Reprocessing Plant (FGRP) to scan an area of interest. Upon retrieval, the sensor package (LiDAR) was taken from the robot to be reused and the MIRRAX platform was then disposed of as planned. This trial demonstrated the capability of the disposable vehicles as a means of characterising unknown environments.

The MIRRAX was deployed in FGRP to scan a previously un-surveyed area of the facility



This image shows the live output from the LiDAR during deployment

The benefits of this technology include:

- Collation of survey data using already existing penetrations before initiating more expensive operations, particularly in areas that are difficult to access.
- Small scale, low-cost and disposable.
- Can be adapted to for a range of activities in a variety of locations such as corrosion mapping, radiological mapping and leak detection.

Challenge:

Characterisation of restricted access areas

Solution:

Mini robotic platform that can be deployed via existing ports

Benefits:

Small, efficient, cheap and disposable

Status:

Prototype system has been verified and deployed in FGRP at Sellafield. Learning from experience document is in preparation

TRL change:

Further underpinned at TRL 6

Delivery partners:

The University of Manchester

External publications/press releases/weblinks:

http://uomrobotics.com/nuclear/roboticplatforms/autonomous%20exploration/mirrax150.html

Contact details:

Xavier Poteau xavier.poteau@sellafieldsites.com

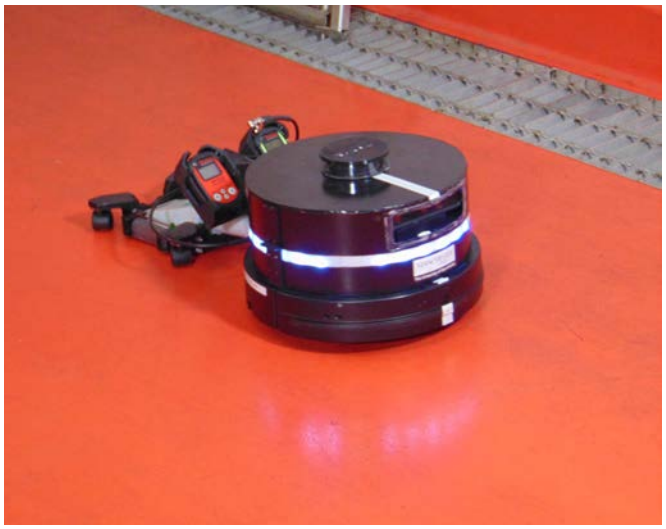
CARMA: Sellafield's first autonomous robotic platform for the radiometric mapping of large floor areas

Sellafield Ltd's decommissioning programme will run through until at least 2120. As part of this, radiological protection personnel will continue to play an essential role in promoting a strong safety culture. Activities are carried out on the Sellafield site whilst ensuring that the principles of ALARP (as low as reasonably practicable) are followed so that personnel are protected from harmful exposure to ionising radiation.

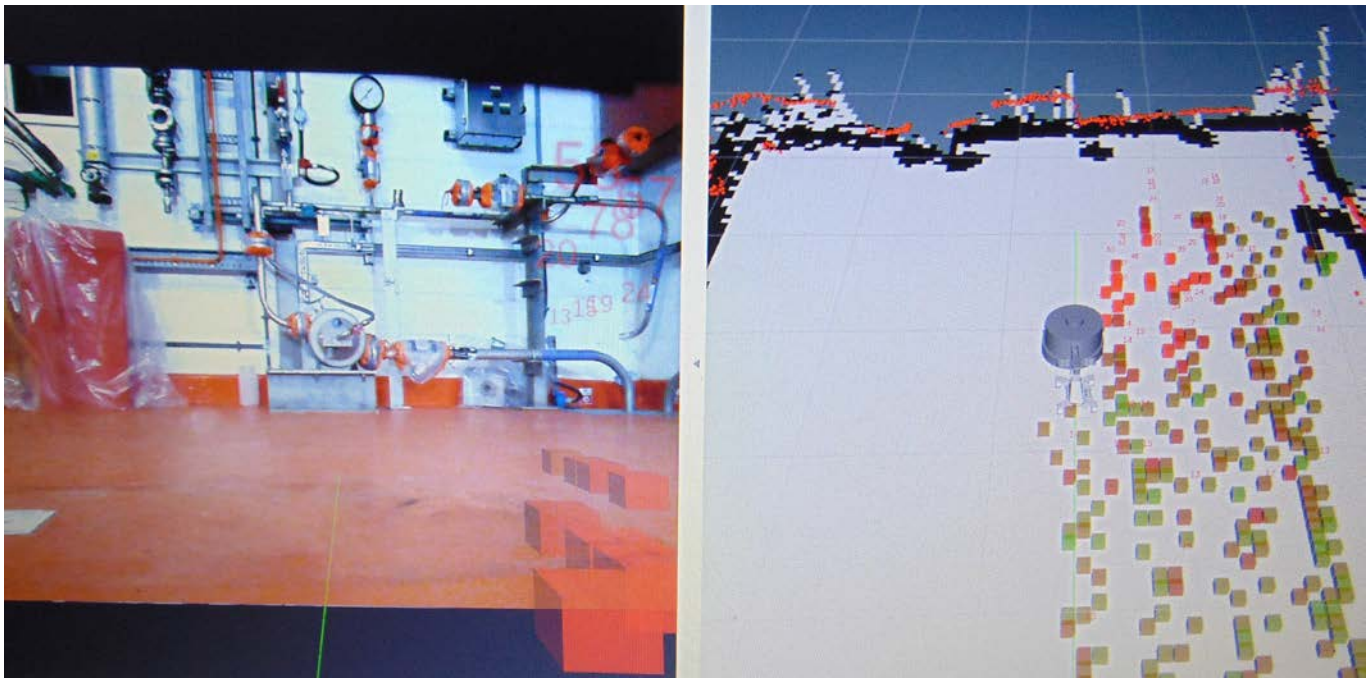
The bulk of radiological protection monitoring is currently carried out as part of surveys using COTS (commercial off-the-shelf) and handheld radiation monitors. Some of these surveys are by their nature very repetitive and the potential to allow for better resource alignment to priority tasks could be improved by upgrading the current manual-type surveys to more autonomous methodologies, this could increase productivity, improve safety and reduce cost.

The CARMA (Continuous Automated Radiation Monitoring Assistance) platform is the first autonomous platform to be deployed on the Sellafield site. It has been developed by The University of Manchester and Sellafield Ltd to offer autonomous and wireless radiometric floor mapping in nuclear facilities. With the ability to autonomously navigate and avoid obstacles, this mobile radiometric tool is designed to cover large surface areas and replicates the radiometric procedures currently used on the Sellafield site. As well as offering the mapping of contaminated areas, CARMA provides a range of added benefits such as real-time hotspot location by augmented reality, automated gathering of radiometric data and improved consistency and reliability of data by eliminating measurement and transcription errors. Most importantly, the platform allows for the radiological protection personnel to focus on other more complex tasks while CARMA does the repetitive and lengthy tasks.

As part of the ongoing development of this platform, CARMA has benefited from close engagement with Sellafield Ltd end-users to improve the acceptance of autonomous systems in the workplace. A proof-of-concept demonstration of the first design of the platform, CARMA 1 was carried out in December 2017, on Thorp. The follow-up design, CARMA 2, is more robust, larger and offers improved capabilities when compared with CARMA 1, with a longer running time (up to 3 hours), better situational awareness and faster acquisition time (it is equipped with twice the number of radiometric probes and proximity sensors). Currently going through the last phase of testing, the CARMA 2 platform will be deployed to carry out complete floor surveys (alpha/beta/gamma) in active facilities across the Sellafield site in mid-2018.



Active demonstration of CARMA 1 in Thorp (December 2017)



The left is the augmented reality view on which a live view from the camera is superimposed with measurement points. The right is the real-time map under creation.

Images of the CARMA 2

Challenge:

Improved radiological monitoring of large floor areas

Solution:

Autonomous, wireless robotic platform

Benefits:

Increased productivity, improved safety and reduced cost

Status:

CARMA 1 critical functions verified and demonstrated in Thorp in December 2017

CARMA 2 critical functions and prototype verified

TRL change:

CARMA 1 was progressed to TRL 4 and CARMA 2 progressed to TRL 6 by April 2018

Delivery partners:

The University of Manchester

External publications/press releases/weblinks:

http://uomrobotics.com/nuclear/roboticplatforms/autonomous%20exploration/carma.html

Contact details:

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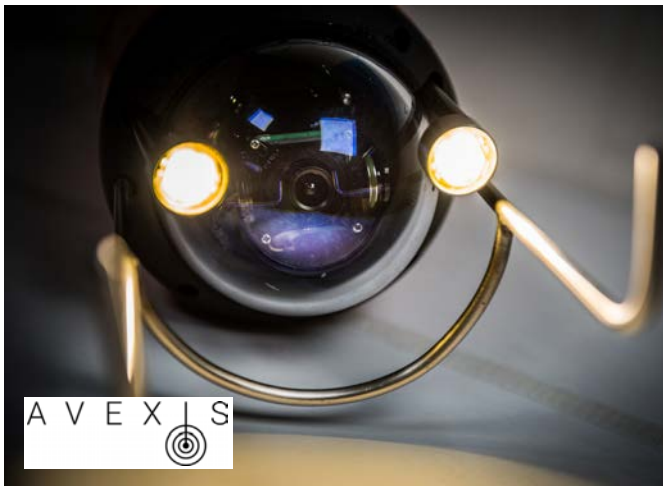
AVEXIS: a small submersible robotic family for the underwater exploration of facilities with restricted access

To enable underwater legacy facilities to be surveyed, Sellafield Ltd, The University of Manchester and Forth Engineering Ltd have worked closely together, over the past few years, to create the AVEXIS (Aqua Vehicle Explorer for In-situ Sensing) (see 2016/17 Technology Development and Delivery Summary for more details), a new class of small, low-cost, sacrificial underwater vehicles that is now being deployed on the Sellafield site to monitor challenging areas in these storage facilities using existing access points. Although commercially available ROVs have been used to explore the Sellafield ponds for a number of years, these do not address the physical dimensions of existing access points to some of the silos, caves or bays, most of them being 6" (150mm) wide.

Created as a sacrificial tool, the AVEXIS is expected to be used and then replaced at a fraction of the cost that a similar, re-useable, unit would require through maintenance. Using fast prototyping techniques, integrating off-the–shelf equipment and iterative learning through trials, have enabled the project to progress efficiently to commercialisation of a low-cost robotic platform for ponds and other underwater exploration.

Building on previous work the AVEXIS FORTH was successfully deployed in the MSSS in October 2017. The AVEXIS FORTH is now a commercial unit, to survey silos and dislodge debris without the water level being lowered. Further, the AVEXIS design is being evolved to address challenges from further afield. The AVEXIS-150 is under development by The University of Manchester for deployment into the damaged core of Japan's Fukushima Daiichi Nuclear Power Plant.

The AVEXIS FORTH unit about to be lowered into the silo at Sellafield



Challenge:

Improved underwater surveys of storage ponds and silos

Solution:

Remotely operated mini-submersible device

Benefits:

Low cost device able to access existing 6" ports

Status:

This project is complete with commercially available technology. It has successfully been deployed and retrieved from an active facility at Sellafield

TRL change:

Increased from TRL 5 to TRL 9

Delivery partners:

The University of Manchester, Forth Engineering Ltd.

External publications/press releases/weblinks:

https://www.gov.uk/government/news/the-new-robot-helping-clean-up-sellafield

http://uomrobotics.com/nuclear/roboticplatforms/aquatic/avexis/avexis150.html

http://hamlyn.doc.ic.ac.uk/uk-ras/news/development-and-testing-submersible-robot-exploration-fukushima-daiichi

Contact details:

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Non-destructive depth profiling development

Normal practice to determine the depth that contamination has penetrated into concrete is to drill core samples for laboratory analysis. This technique is destructive, time consuming, expensive and the number of samples removed can be limited. To underpin robust decisions on the decommissioning of facilities and avoid the costly removal of multiple samples a non-destructive technique is required. There are currently two viable techniques under development in the research and development community that have been tested at Sellafield.

- D:EEP: Estimating Entrained Products - Createc and Costain have received funding via the Innovate UK process to collaborate on this project
- Radiation Depth Profiler (RDP) – This has been developed by Cavendish Nuclear

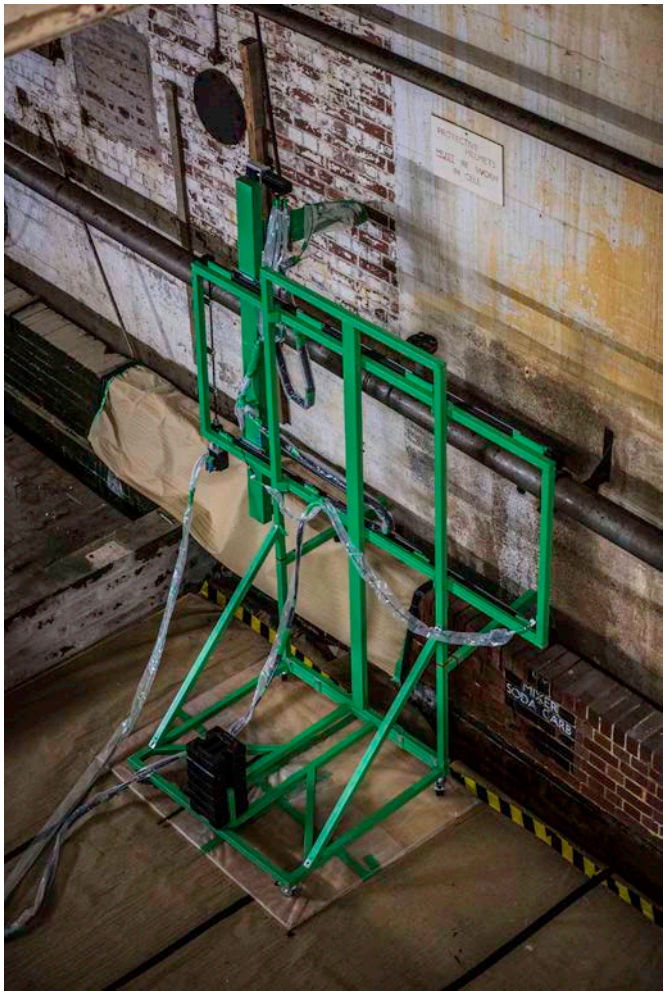
The technology is a non-invasive measurement technique to profile the depth of entrained radioactive contaminants in-situ, it can be used to determine the depth of contamination of gamma emitting isotopes up to a depth of about 150mm. The technique can be used to measure a single point of contamination or it can be used to provide a picture of an entire surface from multiple measurements taken. Both technologies were tested at Sellafield for their effectiveness in different scenarios during 2017/8.

In March 2017 the Cavendish Nuclear RDP and Createc D:EEP sensors were deployed at the PFSP as part of a dewatering trial which included a requirement to better understand the extent of ^{137}Cs contamination penetration from the water into the pond and wet bays concrete. The data from the trial were compared with analysis of concrete shavings and it was concluded that contamination is largely confined to the near surface of the pond wall. The project supported a revised dewatering strategy for PFSP in 2018, (for more details of the trial, see the 2016/17 Technology Development and Delivery Summary).

In January 2018 the D:EEP sensor was tested on a contaminated wall in the FGRP as part of an Innovate UK sponsored task where the D:EEP sensor was mounted to an X-Y deployment rig which enabled a surface area of approximately 3m x 2m to be remotely surveyed in a single deployment. The next phase of this work is an underwater deployment of D:EEP in a watertight box which will require a modification to the modelling algorithm. During 2017/18, preparation work was carried out for a trial in the Residual Sludge Tanks (RST). This deployment, down the side of a submerged chamber wall, is scheduled to take place in May 2018. The benefit of being able to deploy this method underwater means that future expensive dewatering trials may be avoided.

D:EEP trial on a contaminated wall in FGRP

The aim of ongoing trials is to validate technologies to measure radioactivity in concrete, analysis of the data is ongoing and the results will be compared with analysis of the wall shavings.



D:EEP trial on a contaminated wall in FGRP

D:EEP trial on a contaminated wall in FGRP

Challenge:

Accurate profiling of radioactivity within concrete

Solution:

Non-destructive gamma imaging coupled with modelling

Benefits:

Faster, cheaper with reduced risk to operators. Improved waste classification

Status:

Ongoing with further trials planned in May 2018 to test the underwater capability of D:EEP in the RST

TRL change:

TRL for both techniques is at 5. Once the results for all of the trials have been reviewed, the TRL rating will be re-assessed

Delivery partners:

Createc, Costain, Cavendish Nuclear

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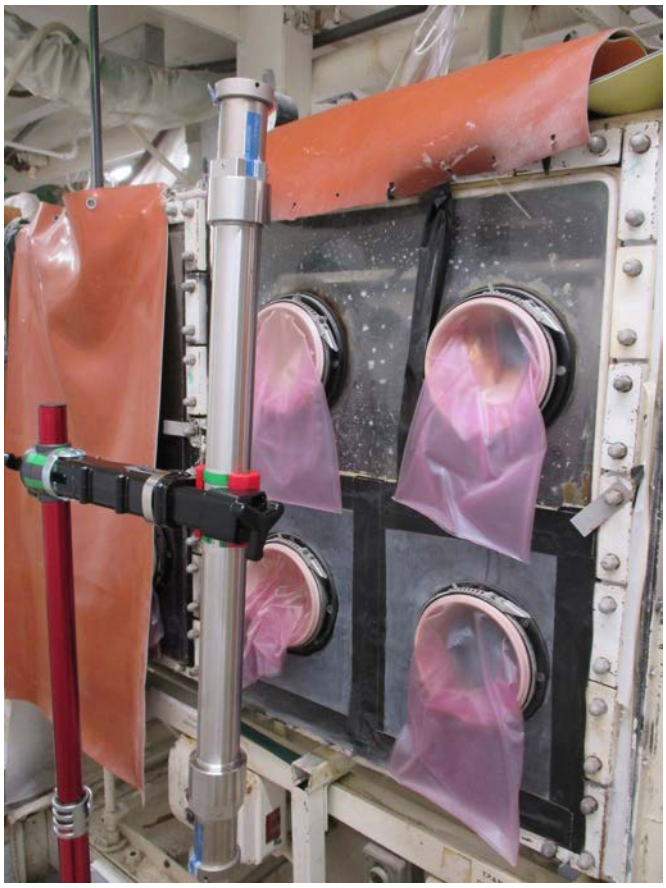
Phil Hayward phil.w.hayward@sellafieldsites.com

Plant status monitoring using neutron detectors

The standard method for the detection of fissile material in gloveboxes (in-situ) is by using neutron detectors. Over the last two years, Cavendish Nuclear and Sellafield Ltd have been investigating the potential to improve the current methodology which employs bulky detectors where all surfaces of the glovebox are completely surrounded to reduce uncertainty in the results generated.

During 2017/18, a light, compact, fast neutron detector was deployed at Sellafield, by Cavendish Nuclear, in four different facilities across the site to characterise fifteen gloveboxes. The next stage of the project is to compare the data collected from the new approach with values obtained from the current standard systems to assess the accuracy and precision of this equipment. These results, together with the operational experience gained from deployment, will be used to assess the potential benefit to the Sellafield business and identify any further development work required to enable this new characterisation capability to be integrated to business.

Because the equipment is easier to deploy, it offers significant benefits over the current detectors, for example it will be more suited to assess large areas (such as a laboratory of gloveboxes) and provide data for the characterisation of gloveboxes in challenging locations.



Neutron detector in various locations outside contaminated gloveboxes, measuring the fissile content inside

Challenge:

An improved method for the measurement of fissile material in gloveboxes

Solution:

Light weight, compact, fast neutron detector

Benefits:

Can more efficiently assess large environments (e.g. a laboratory of gloveboxes), and can be deployed in environments where access is more challenging

Status:

Ongoing with data to be compared with those collated from the current detectors

TRL change:

TRL 6 to TRL 7 or 8 (depending on application)

Delivery partners:

Cavendish Nuclear

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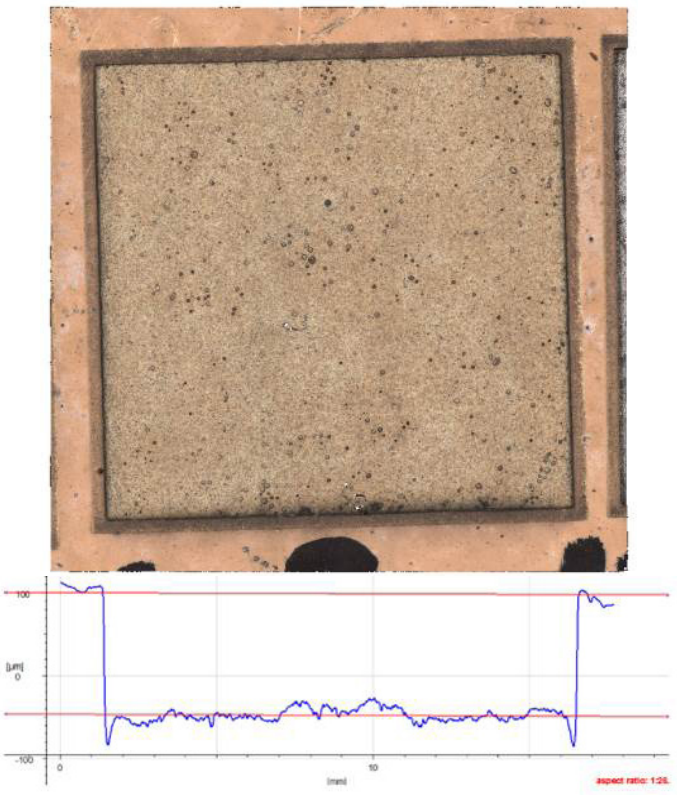
Laser decontamination

Across the Sellafield site, there are large volumes of metallic waste that have become contaminated due to past and current operations, and historic incidents. Decontamination of this metalwork is required in order to:

- Make a change in the waste classification of the item
- Reduce dose to operators and/or facilitate a change in operations (for example allowing operator access to a previously remote-only environment)
- Reduce surveillance and maintenance costs

There are a number of different techniques used for decontamination, and the effectiveness of each is dependent on a range of factors including: material properties, contamination mechanism, accessibility, and required decontamination factor (DF). While each technique is different, there are some known challenges that include:

- Large volumes of secondary waste generated
- Manually intensive operation
- Use of hazardous chemicals / liquids
- Some techniques are specific to particular material types
- Potential to damage uncontaminated material beneath the surface



3D scan of laser ablated area of sample materials (top) with the profile of the depth of material/coating removed shown by the graph (bottom)

In 2017/18, Sellafield Ltd worked with TWI Ltd. to understand the required laser parameters to effectively decontaminate a range of (non-active) sample materials. This trial involved a number of different laser systems and assessed performance of factors including decontamination factor, productivity and deployment constraints. A key piece of learning from the work is that some decontamination coatings are transparent to laser light, which makes their removal a challenge. Also, early indications of the particulate produced during laser ablation do not appear to be as problematic as previous "worst case" assumptions. These findings will help identify the Sellafield application which will most benefit from this technology.

Following this phase of work, 2018/19 will focus on analysis of the results from the trial and on more in-depth studies – targeting specific applications. These follow-up tasks will consider deployment logistics as well as assessing the disposability of the generated wastes.

Challenge:

Efficient removal of contamination from metallic materials

Solution:

Laser decontamination

Benefits:

Reduced secondary waste generation, no hazardous chemicals required, can be remotely deployed

Status:

Ongoing with completion of data analysis. Deployment logistics and disposability of secondary wastes to be assessed

TRL change:

No change to TRL but there is a better understanding of current capabilities to plan for future development

Delivery partners:

TWI Ltd.

Contact details:

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Black Ghost - biometric vest

Decommissioning methodologies normally rely heavily on manual operations, particularly for alpha decommissioning scenarios. This often involves operators making entries into hazardous environments, protected by an air fed suit to undertake physically demanding manual operations. As the Sellafield site approaches decommissioning operations on a wider scale, it is expected that there will be several million suited entries undertaken. Due to the physiological effects of wearing this type of personal protective equipment (PPE), working times are restricted, with heat exhaustion, dehydration and fatigue key factors. Additionally, every operator responds to the stresses of the work differently. By measuring and monitoring an individual's physiological parameters in real time, it may be possible to use technology to enhance the safety of operators and potentially increase productivity where safe and appropriate to do so.

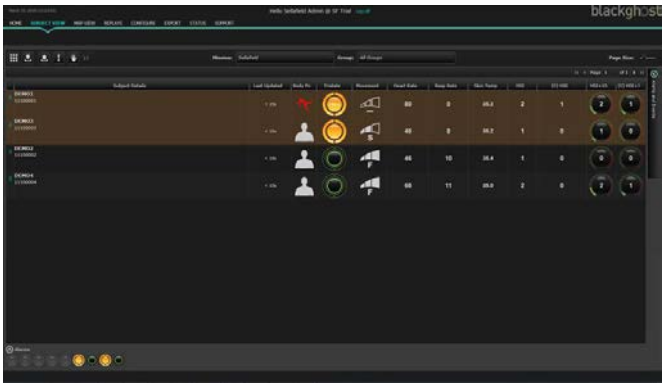
In 2017/18 an active demonstration of a Black Ghost biometric vest was undertaken in PF&S (Plutonium Finishing and Storage) in a collaborative project with Equivital™ (suppliers of the vest and software). The measurements taken by Black Ghost include ECG (electrocardiogram), heart rate, respiration rate, skin temperature, body position and location (using a global positioning system (GPS)). This enables vital assessments to be made on the operator's heat stress index, in real time. The demonstration proved that Black Ghost can operate in security critical buildings and with limited signal.

Black Ghost vest (top) and being worn under an air fed suit (bottom)

In 2018/19, a month-long trial is planned to determine:

- If the kit needs to be integrated with the site laundry or if it can be personal issue.
- How much data are required to enable medical decisions to be made for an individual.
- Operator usability.

Real-time monitoring of an operator's physiological condition would enable rapid decisions on their safety and reduce the potential for accidents/incidents. Providing data on the real-time health of individuals could avoid the application of conservative working time limits and therefore facilitate optimised deployment of workers to increase productivity.



The Black Ghost can measure factors such as heart rate and skin temperature. Output from the vest can be viewed on a computer or by using an app on a smart phone

Challenge:
Real-time monitoring of operator health

Solution:
Biometric data from a re-useable vest

Benefits:
Improved operator safety and increased productivity

Status:
Ongoing with planning for a month-long trial in FY 18/19

TRL change:
TRL 6 to TRL 7

Delivery partners:
Equivital™

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James Sant future.decommissioning@sellafieldsites.com

Glovebox and crate breakdown by laser cutting

There are more than 350 alpha-contaminated gloveboxes and 650 legacy crates on the Sellafield site that need to be decommissioned and prepared for disposal using manual operations (plasma torch cutting in air-fed suits), this can be both hazardous and time consuming. The cost is also expected to be high. There is an opportunity to decommission these items safer, faster and cheaper using semi-remote operations such as robotically deployed laser cutting.

This project set the ambitious target of establishing a robot/laser cutting capability for demonstrating size reduction of gloveboxes and crates on the Sellafield site, by 2019. Following this, the facility may be suitable to hand over for normal operations and business-as-usual use. To facilitate this development, Sellafield Ltd worked in collaboration with NNL and TWI Ltd. to build a non-active test facility at the NNL Workington Laboratory in 2017/18. This rig contained a 6 degree of freedom robotic arm, 10kW cutting laser, and a re-cleanable HEPA filter system to simulate the intended final design of the active demonstrator. A series of cutting trials were carried out to address uncertainties around fume generation and identification of optimal cutting parameters for bare, painted stainless steel, and steel coated in decontamination agents / strippable coatings.

Following the build of the non-active facility, the first laser cutting trials took place in February 2018, ahead of schedule. Towards the end of 2017/18, initial preparations for the active capability began which included the selection of the MOX Demonstration Facility (MDF) for the demonstration.

Challenge:

Glovebox and crate breakdown

Solution:

Laser cutting mounted on a 6-axis robot

Benefits:

Less hazardous remote technique over manual operations, faster and cheaper

Status:

2018/19 will see the design of the active facility developed and on-site construction beginning. The non-active setup at NNL Workington will continue to be utilised – providing valuable learning to aid the design and operation of the active capability

TRL change:

TRL 5 to TRL 6

Delivery partners:

National Nuclear Laboratory, TWI Ltd.

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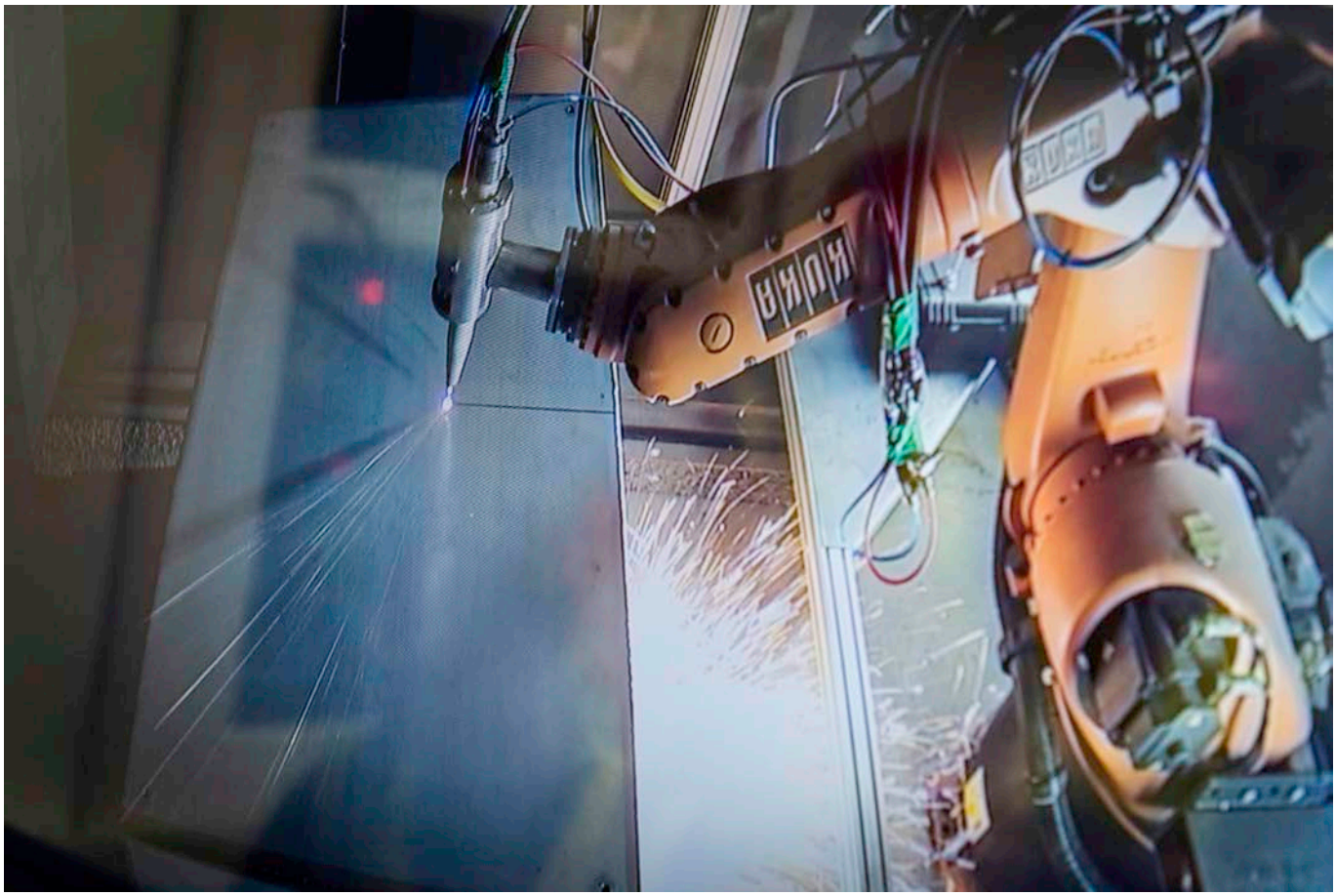
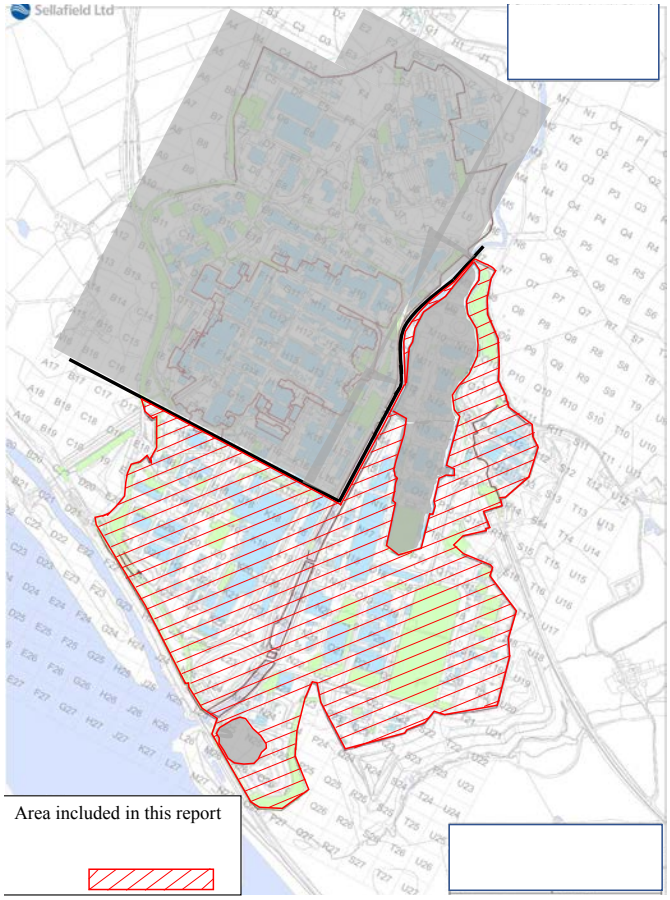


Laser cutting of an inactive simulant glovebox at the NNL Workington facility

Characterisation of excavated materials from areas of the Sellafield site with a low risk of radiological and chemical contamination

Sellafield Ltd has an ongoing programme of excavation works, primarily supporting construction activities, the majority of which generate waste materials which require characterisation in order to inform their waste management strategy. These characterisation activities have resulted in the collection of thousands of samples and subsequent data points covering the whole of the Sellafield site. An opportunity to make use of these data was identified and a review of the existing information undertaken. A technical report was prepared and this is used to provide a framework and underpinning evidence to support the potential re-use or disposal of excavated material from unclassified (C0) areas to the south and east of the Sellafield site without the requirement for further intrusive sampling.

The report enables the classification of waste as out of scope of Environmental Permitting Regulations (EPR) 2018 and non-hazardous, provided certain stipulations are met (for example, a suitable health physics and safety (HP&S) survey) shows no activity above local background levels, the material type is soil and provenance supports a very low risk of chemical and radiological contamination). If there is any uncertainty as to any of the stipulations then the technical report cannot be used and an alternative characterisation approach must be applied.



This is a map of the study area included in the technical report

Challenge:

Efficient waste management of excavated materials

Solution:

Technical report and guidelines on the re-use or disposal of excavated material

Benefits:

The characterisation time-line in much of the south and east of the site has been reduced to zero, reducing the effort required from the characterisation capability and enabling resources to be diverted to support higher risk and higher priority projects. Additionally, relevant projects that produce excavation wastes may now benefit significantly in terms of cost and schedule because destructive sampling and analysis, is avoided, as well as interim storage of solid waste pending the completion of characterisation activities.

Status:

- The technical report has been implemented enabling waste advisors to classify waste as out of scope of EPR and non-hazardous (providing certain stipulations are met) and thus avoid the typical characterisation time-line.
- The excavation process continues with new projects each week, a proportion of these will still require characterisation support. Data gained from these projects will lead to a greater understanding of the ground conditions, with the potential to further underpin this approach or even expand it into other defined areas of the site.

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Land quality knowledge management tools

Desktop-based geographic information system (GIS) software has been adopted at Sellafield for a number of years to manage and analyse subsurface soil and groundwater contamination, as well as for supporting strategy work, developing desktop studies and management options assessments, and for planning and operational support. In recent years there has been an increase in scope to focus more heavily on End State planning, and in the next few years a programme of work will support this. This work, and the management of contaminated land and groundwater, places significant focus on knowledge, information and data management. It will especially look at the impact of site operations on the subsurface of the Sellafield site and the geological, hydrogeological and hydrological setting in the local area.

A web based map platform was used to make key land quality datasets available which were otherwise stored locally on individual's machines or in paper archives. Not only does this method improve access to land quality information, the web map tool provides a single knowledge source for interested stakeholders to utilise in order to identify subsurface constraints. This can be used to support End State planning as well as current operations, providing access to data, for those within the company with need-to-know requirements, to boost stakeholder engagement and understanding and let individuals make more informed decisions. The tools will also allow subject matter experts to deal with enquiries efficiently.

Image of the Land Quality SharePoint Documents Map Tool

Image of the Land Quality Ground Conditions Register Map Tool

Image of the Land Quality Soil Disposal Authorisation Office Map Tool

Challenge:

Management and dissemination of land quality data

Solution:

Web map to allow sharing of data across the organisation

Benefits:

Supports knowledge management, decision making, planning and improves efficiency

Status:

The Land Quality SharePoint Documents and Ground Conditions Register Map Tools are in use and the Soil Disposal Authorisation Office Map Tool is currently being tested.

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Integrated waste management

Sellafield Ltd seeks to reduce waste volumes arising as part of ongoing activities as well as historic operations, ensuring that waste is stored safely, minimising the risk to the public and environment, through an integrated waste management programme. R&D supports both current and future operations and there is an extensive programme of work to address the challenges to operating plants as feeds change to process historic wastes and those arising from decommissioning operations.

This section illustrates the significant progress made over the last financial year in the management of wastes:

- First Generation Magnox Storage Pond skip disposal – active demonstrator
- Box Encapsulation Plant waste handing robots
- Magnox Swarf Storage Silo 3m^3 box project
- Understanding alpha activity in legacy waste retrieval effluents and mitigation using chemical settling aids
- Handling and treating First Generation Magnox Storage Pond sludge
- Robotic Manipulation for Nuclear Sort and Segregation (ROMANS)
- Proof-of-concept trials for in-situ testing of filter performance on Sellafield Self-Shielded Boxes
- Export Cell trials in support of the self-shielded box project
- Waste treatment, conditioning and packages IRT
- Condition monitoring and inspection IRT

First Generation Magnox Storage Pond skip disposal – active demonstrator

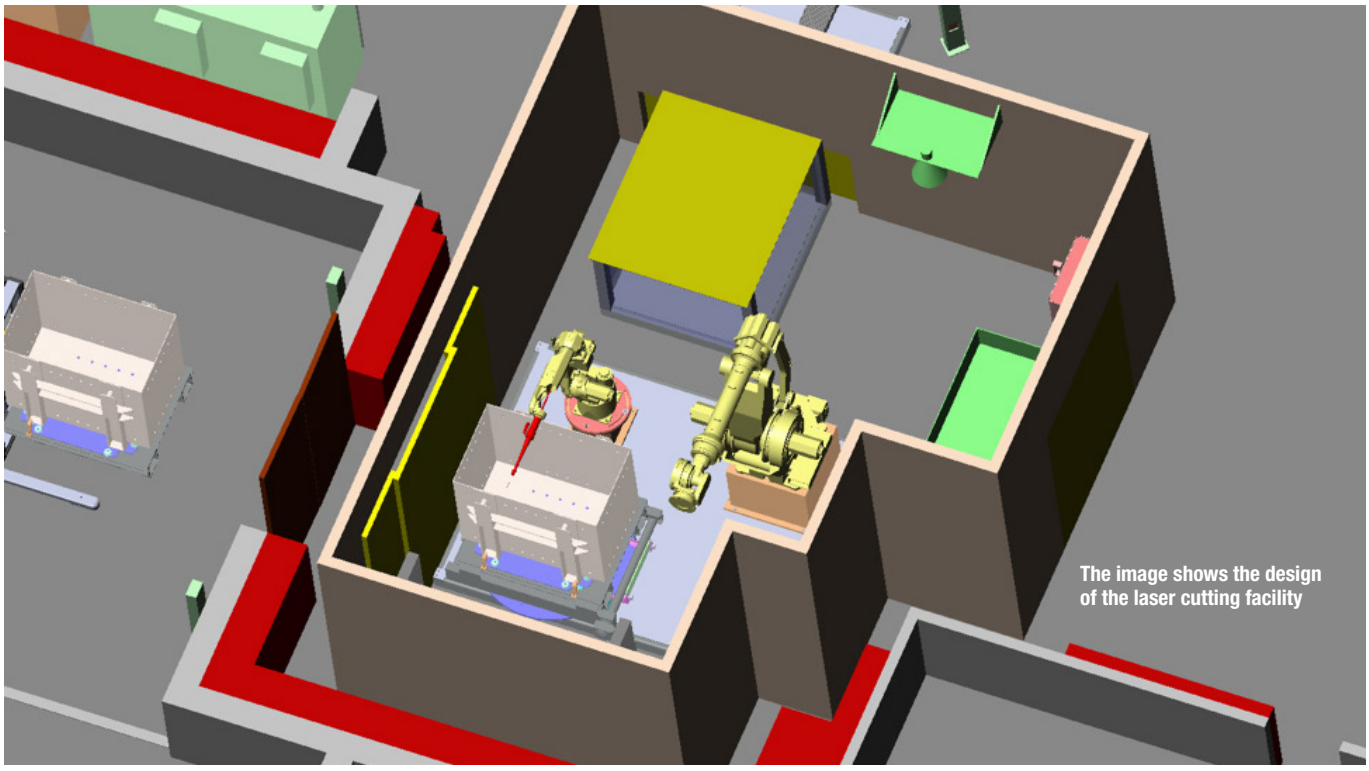
Empty Magnox fuel cooling skips need to be retrieved from the FGMSP so that space can be made available for sludge clearance. These skips generally fall into the intermediate level waste (ILW) characterisation range and the plan is to store them, on an interim basis, in shielded containers (two skips per container) in the Windscale Advanced Gas-cooled Reactor (WAGR) box store. However, the store has limited space and it is estimated that it will be full by the end of 2018 and further imports will be dependent on being able to export other waste. To address this issue, it has been suggested that by cutting up the skips and placing the cut sections into PacTec bags, it would allow up to six skips to be stored in one container.

In collaboration with The Decommissioning Alliance (TDA) Sellafield Ltd initiated a four-phase project to provide a facility for size reducing and decontaminating the empty skips. The design for this was based upon the results obtained from work previously undertaken by Magnox Ltd at the Hinkley Point 'A' site which utilised laser cutting and milling decontamination.

Building on Phase 1 (the initial proposal) phase 2 of the project was completed in 2017/18. Focussing on the challenge of meeting the requirements of FGMSP and processing the first 100 skips, phase 2 identified laser cutting as the most effective size reduction technique and the Waste Monitoring and Compaction plant (WAMAC) line 3 as the best available location for this to be carried out.

The next phase of the project (phase 3) which began in January 2018 is ongoing and is focussing on the development and design of the laser cutting facility with non-active trials expected to be complete by the end of 2018.

The provision of a capability to facilitate the storage and processing of the skips will enable the high hazard reduction programme to be continued efficiently. Demonstration of the cutting and decontamination process will also show if the technique can be applied to skips from other areas of the Sellafield site such as FHP and other metallic ILW.



The image shows the design of the laser cutting facility

Challenge:

Size reduction of skips for efficient packaging for interim storage

Solution:

Laser cutting

Benefits:

Packing solution for empty skips to enable sludge removal to continue. Reduced numbers of packages and therefore less burden on the store

Status:

Ongoing with phase 3 in progress to complete the design and undertake non-active trials. If these trials are successful then phase 4 will install the equipment on site (in WAMAC) and commence skip cutting by late spring 2019.

TRL change:

Underpinning TRL 7. The aim is to achieve TRL 9 and deploy the equipment on site

Delivery partners:

The Decommissioning Alliance: Atkins Ltd, Jacobs UK Ltd., Westinghouse Electric Company UK Ltd.

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Box Encapsulation Plant waste handling robots

A new waste handling facility, BEP is expected to process nuclear waste from legacy facilities at Sellafield by using robotic technology, this will involve:

- The recovery of a variety of legacy miscellaneous beta-gamma waste (MBGW) items from a number of different types of imported skips
- Operators will use a CCTV camera to identify waste items to decide if waste processing (e.g. disruption of the waste item) is required
- Processing and transfer of wastes to the export container ($3m^3$ box liner) for subsequent grout encapsulation

A project has been running since 2013 to develop the technical and engineering capability of the system to TRL 6. The focus for the technical programme included:

- Waste processing - Testing the effectiveness and performance of the robot system (including waste behaviour based on the use of appropriately selected test materials) for waste recovery, filling the waste container, waste disruption and waste compaction.
- Environmental performance - Reviewing the radiation and environmental tolerance of the robots, tooling and cameras.
- Tooling - Testing the ability and efficiency of tooling to carry out waste handling, processing and housekeeping operations.
- Engineering interactions - Testing the effectiveness of robots to interact with other engineered systems e.g. camera system, cell furniture, auxiliary equipment and effluent system.
- Robot recovery - Testing the effectiveness of the remote robot recovery system (i.e. robot removal/replacement, recovery drives, tool ejection and twist lock recovery from seizure).

The development needs for the robot system were identified through numerous multi-discipline data quality objective (DQO) workshops facilitated by TÜV SÜD Nuclear Technologies and Sellafield Ltd. The process, which spanned four years, identified and continually reviewed the development needs to prove the capabilities and limitations of the robots at full scale, in a realistic operating environment and to inform and optimise plant design. The DQO review, in October 2017, concluded that the robot system was TRL 6.

Full scale “proof-of-principle” trials, undertaken by NNL, KUKA Systems (UK) Ltd and Sellafield Ltd, for the robot system commenced in October 2014 at the NNL Workington Laboratory, before progressing onto engineering validation trials between February and October 2016. Since October 2016 further desk top assessments and full-scale trial work continued to validate and develop the engineering for the robot system. Engineering changes were also accommodated as a result of the strategy change for the processing of MSSS waste and automated sequences to enable the robots to perform repeatable and routine operations were developed and validated. Operations and timing data from the technical development work were analysed by NSG Environmental Ltd to produce a philosophy for the operational approach for waste processing (“waste requiring additional treatments” (WRATs) philosophy). This approach has been adopted to ensure that both product quality is maintained whilst managing the processing demands on BEP.

Key tasks for 2017/18 focussed on the completion of the technical development programme, for example environmental and radiation tolerance assessments for the robot system, final engineering validation trials and also elements of system optimisation. The output of the development work provided evidence to support the conclusion that BEP will have the capability to perform a wide range of waste treatment and processing operations using robots to deliver a robust product that meets the requirements of Radioactive Waste Management (RWM).

Full scale BEP robot rig at the NNL Workington Laboratory

Full scale BEP robot rig processing waste

Challenge:

Waste processing of nuclear materials from legacy facilities

Solution:

Off-the-shelf robots adapted to the requirements of BEP

Benefits:

Remote handling and processing of materials to reduce exposure to the operator. The development programme has provided the confidence that the robotic system can perform waste processing operations. Achievement of TRL 6 will allow the project to initiate procurement activities for the plant system

Status:

The technical development work is now complete and the output has been used in the preliminary design, procurement specification and operation philosophy.

TRL change:

TRL 4 March 2013 to TRL 6 November 2017

Delivery partners:

Sellafield Ltd, National Nuclear Laboratory, KUKA Systems (UK) Ltd, NSG Environmental Ltd, TÜV SÜD Nuclear Technologies

External publications/press releases/ weblinks:

- Legacy MBGW Processing: From Concept to Proof of Principle and Beyond (NNL Technical Conference on 1 April 2014 at Manchester University)
- NNL Workington Leads on Critical Trials on Robot Technology (NNL press Release No 121, Tuesday 16th December 2014)
- BEP Robot Project (NNL Technical Conference on 30 April 2015 at Manchester Marriott Victoria & Albert Hotel)
- Nuclear Institute Seminar on Developments for Delivering Decommissioning & Waste Management Seminar (17 June 2015 at Westlakes)
- STEM Presentation on BEP Robot Project (22 July 2015 at Lancaster University)
- Northern Robotics Network Launch Event (4 Sept 2015 at Media City, Salford Quays)
- BEP Robot Project at WM 2016 (10 March 2016 at Phoenix USA) BEP Robot Project at Nuclear Institute Conference (7 Dec 2016 at Rheged)
- BEP Robot Project at WM 2018 (21 March 2018 at Phoenix USA)

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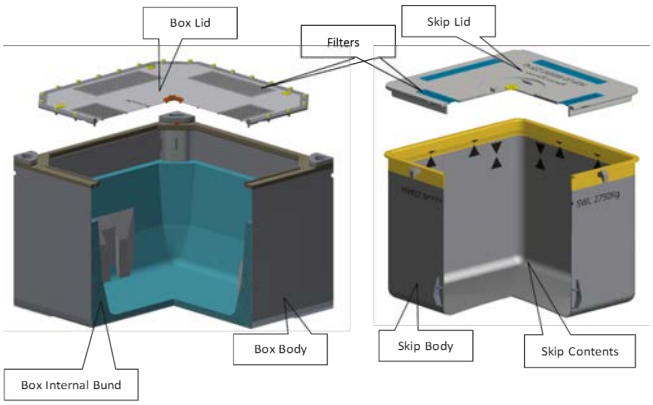
Magnox Swarf Storage Silo 3m^3 box project

MSSS at Sellafield has one of the highest combined risk and hazard of any industrial facility in the UK. The waste, which includes corroding Magnox swarf and uranium, needs to be safely retrieved and conditioned for disposal. A programme of work involving experimental trials and chemical modelling has significantly improved the understanding of waste behaviour in terms of hydrogen generation and waste pyrophoricity.

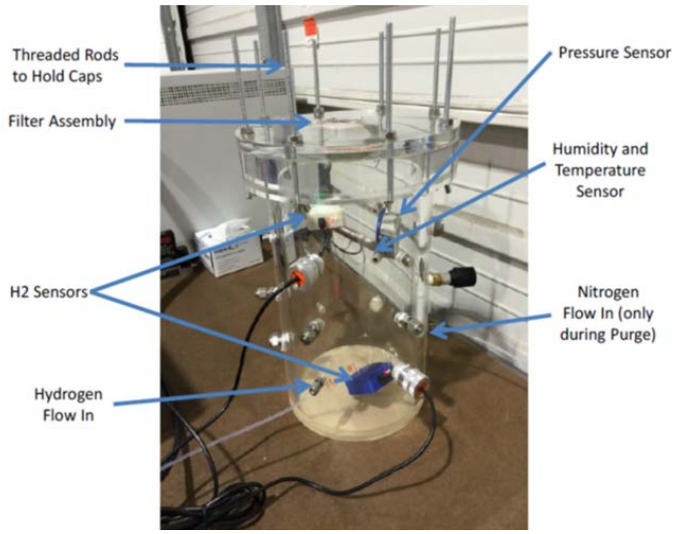
In June 2015, following a period of specialist peer review, the overall technical feasibility of an interim storage concept was successfully endorsed. The waste packages will consist of skips of MSSS waste inside a 3m^3 box with an internal concrete bund (see image). The skip and box lids include filters to manage evolved hydrogen and control water losses and the concrete bund is included to mitigate the risk of corrosion of the skip which might allow liquor to escape into the box over the very long timescales of interim storage. The interim storage option is being implemented across the MSSS stream projects, enabling acceleration of MSSS retrievals.

The aim of the MSSS 3m^3 box project is to identify and test the suitable materials for skip, box, lids and filters and develop a suitable formulation for the cementitious bund. Work to identify suitable materials for construction of the skip, box and lid was completed in 2016/17 with recommendations to use duplex stainless steel. The focus for the project in 2017/18 was longer term corrosion and performance trials on the filter, to provide confidence in performance over the long timescales expected for interim storage.

The experimental work was completed and the spent filter samples sent for analysis, the results will be collated in 2018/19.



Skip, box and lid designs



Challenge:

Performance of filters in 3m^3 boxes verified

Solution:

Long term corrosion trials

Benefits:

Confidence in the performance of the new and corroded filters over long-term storage period

Status:

Ongoing, the spent filters are under-going analysis and the results will be reported

Delivery partners:

Fauske Associates, DBD Ltd.

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Understanding alpha activity in legacy waste retrieval effluents and mitigation using chemical settling aids

The sludge treatment programme from FGMSP is retrieval and transfer to a dedicated facility, the Sludge Packaging Plant 1 (SPP1). SPP1 consists of three stainless steel Buffer Storage Vessels (BSV) which temporarily contain the retrieved sludge and allow gravity settling of the insoluble material and associated radioactivity to take place. The resultant clarified liquor (supernatant) is then decanted into the Effluent Collection Vessel (ECV) before discharge to SIXEP.

A research project was initiated because elevated alpha activity concentrations were identified in SPP1, in the decanted liquor, during initial operation of the plant. The cause of this was found to be slow-settling and colloidal material that was carried over in the decant liquor to the ECV. There is potential for this to have an impact downstream and therefore an assessment of the ability of SIXEP to effectively remove the activity was undertaken. This is a risk that also applies to legacy waste retrievals from MSSS. The 2017/18 R&D programme focussed on the following key tasks with some of the work carried over into 2018/19:

1. Review of settling aid options

A desk-based review was undertaken to determine products that would be suitable for removing the slow-settling active material from the effluent generated during waste retrievals from the ponds and silos. The output of this identified several polyacrylamide flocculants/coagulants that would be suitable for further testing.

2. Characterisation of alpha activity in plant effluent samples

Active plant samples were obtained from various locations, from SPP1 through to SIXEP, to identify the type of active particles that could persist through the sea discharge treatment process. The samples were successfully characterised to determine isotopic composition, shape, size and form and the results found that the majority of the active material was abated by SIXEP.

3. Testing of settling aids on plant samples

Three samples were obtained from SPP1 ECV and tested using the products identified in task 1. The aim of this was to determine whether settling aids would improve the settling behaviour of the active particles and hence remove suspended alpha activity from solution in a complex plant system during waste retrievals. The results of the testing work have identified a number of potential candidates that are suitable for this purpose.

4. Development of slow-settling simulants

This task identified and developed methods for the production of simple simulants that were representative of the active materials characterised and trialled in task 2 and 3 respectively. The aim of this was to test the effectiveness of the products identified in task 1 on simple systems in the presence of a single-type of particulate. During the task a method was successfully developed for the production of inactive slow-settling magnesium (hydrotalcite) particles, commonly found in active plant samples. In addition, a quantity of slow-settling uranium corrosion product was produced in chemical conditions analogous to FGMSP to test the settling characteristics of active uranic particles.

5. Testing of settling aids on simulants

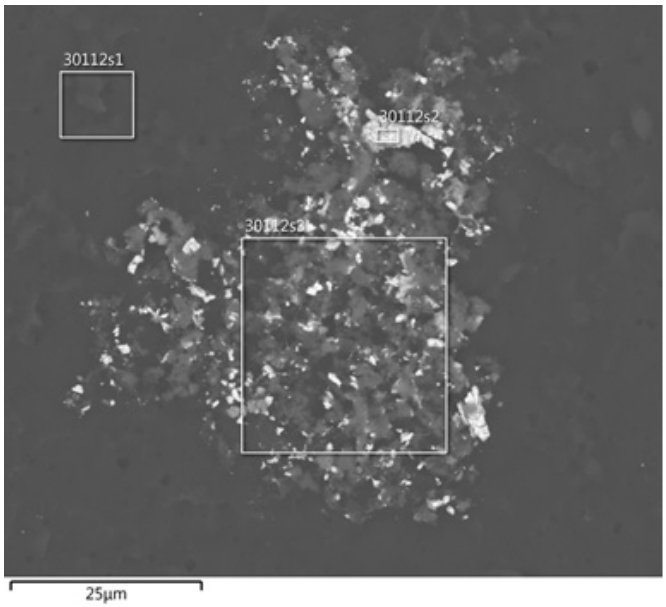
The products identified in task 1 were tested on the simulants developed in task 4, in order to identify whether settling aids could be selectively deployed to target the removal of specific particle-types from suspension (e.g. magnesium or uranium based). The results of the testing work have identified a number of potential candidates that are effective for settling suspended magnesium and uranium particles.

6. Understanding interactions of actinides with corroded uranium

The characterisation work using plant samples showed that the majority of the alpha activity (as plutonium (Pu) and americium (Am)) was associated with uranium corrosion product. The aim of this task was to determine how the actinides could be incorporated into the uranium corrosion product in the ponds and silos, in order to understand the mechanisms that could promote mobilisation or “release” into the effluent stream from the legacy waste when disturbed. The work during the financial year started some long-term corrosion experiments using uranium metal, to determine whether Pu and Am could be incorporated directly into the uranium corrosion product as it formed. This will be completed during financial year 2018/19.

The completion of the characterisation work has significantly enhanced the current level of understanding with respect to the behaviour of alpha activity and active particles in the effluents generated during legacy waste retrievals operations from the ponds and silos. Furthermore, significant steps have been made to address critical knowledge gaps aligned with how this material is abated in SIXEP before marine discharge. This has allowed for programme decisions to be taken and credible business risks aligned with the value stream to be addressed.

The experimental work to develop the use of chemical settling aids has increased the maturity of the technology from a theoretical idea to a “proof-of-concept” mitigation option that could be deployed to target the removal of active material from effluents generated during legacy waste retrievals, should this be required in the future. Additionally, effluent from sludge retrieval processes must be settled for a number of hours before discharge to SIXEP. The deployment of a suitable settling aid within the stream could therefore also be exploited as a means of minimising sludge settling times and thus optimising the sludge retrieval process, assisting in achieving 25% acceleration of legacy waste retrievals from the ponds and silos.



Environmental scanning electron microscopy (ESEM) image of an active particle containing magnesium and uranium isolated from an SPP1 effluent sample

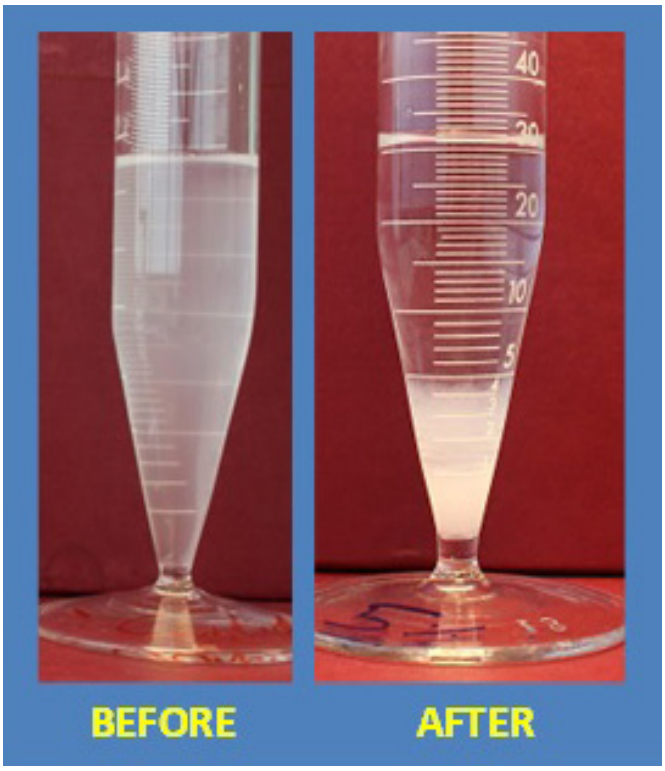


Image to show the clarification of liquor after dosing a settling aid into a suspension of slow-settling magnesium (hydrotalcite) simulant

Challenge:

Elevated levels of activity in the liquor from sludge transfers

Solution:

Chemical settling aids to improve settling

Benefits:

Optimum sludge processing programme, minimum impact on downstream treatment

Status:

Ongoing with the following tasks planned:

- Substantiate the use of settling aids to improve technical understanding of their capabilities
- Understand the impact of settling aids on the properties of bulk sludge

TRL change:

TRL 2 to TRL 4

Delivery partners:

National Nuclear Laboratory

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Handling and treating First Generation Magnox Storage Pond sludge

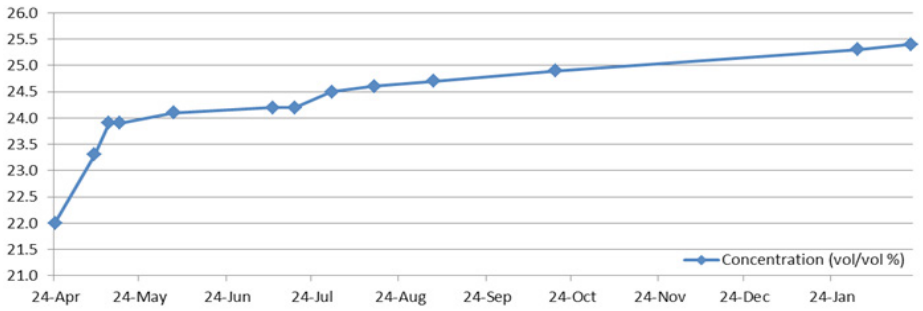
FGMSP contains a significant quantity of radioactive sludge produced from corrosion of Magnox fuel elements that have been stored underwater for extended periods. Retrieval of this sludge into modern storage is well underway and effort is now being focussed on delivering a treatment capability that aligns with long term disposal requirements. One of the key objectives of this project is to minimise the volume of waste packages produced by finding ways to incorporate as much solid sludge material, as possible, into each waste package. This requires knowledge of sludge settling behaviour and the application of technologies to remove water from the sludge.

During 2017/18, medium scale non-active trials were completed, by Sellafield Ltd, to provide information on short term settling and longer-term consolidation of sludge solids into a sludge bed. Small scale non-active trials and technical assessments were carried out to investigate the application of vacuum evaporation technology to further remove water from the settled sludge solids and therefore increase the sludge solids concentration during a conditioning step in the treatment process. This work has been delivered via the FGMSP programme partner, The Decommissioning Alliance (TDA).

The work provided a key insight into the behaviour of sludge with respect to the settling period required following remobilisation and the extent of consolidation of the settled sludge bed over extended periods of up to 1 year. The application of vacuum evaporation technology demonstrated the ability to remove water from sludge charged to a drum in order to increase the in-situ sludge solids concentration. The benefits of this technology include:

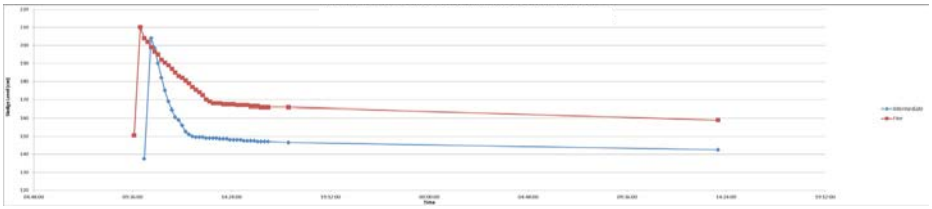
- Removal of water at temperatures significantly lower than normal atmospheric boiling point.
- Ability to control the rate and amount of water removed.
- Removal of the need for intrusive methods which require access into the internal environment of the drum to remove water.
- Minimisation of the carryover of sludge solids and the associated radioactivity out of the drum.
- Limiting temperature dependant hydrogen generation associated with further corrosion of the sludge.

Intermediate FGMSP Sludge test material - Concentration (vol/vol%) over time and layering



Consolidation of sludge test material over prolonged time period

Intermediate and Fine FGMSP Sludge Test Material Short Term Settling



Short term settling behaviour of sludge test materials

Challenge:

Efficient treatment and packaging of Magnox sludge

Solution:

Trials to understand behaviour of sludge settling solids and removal of water by vacuum evaporation

Benefits:

The R&D has provided data for the next phase of design of the treatment process. There is improved confidence that a reduced number of waste packages can be achieved.

Status:

Further full-scale inactive trials are being considered during the early design phases for the treatment process.

TRL change:

TRL 3 to TRL 5

Delivery partners:

The Decommissioning Alliance: Atkins Ltd., Jacobs UK Ltd., Westinghouse Electric Company UK Ltd.

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RoMaNS

ROBOTIC MANIPULATION FOR NUCLEAR SORT AND SEGREGATION

Sorting and segregation operations to process ILW such as those in the BEP project at Sellafield are primarily controlled by tele-operation (robots and tooling manually controlled by operators). The European Union Horizon 2020 RoMaNS (Robotic Manipulation for Nuclear Sort and Segregation) project improve the efficiency of this type of operation by aiming to be as autonomous as possible. To achieve this autonomous functionality, the rig will be controlled by a purpose-built computer system, comprised of multiple applications and components developed in partnership between all the RoMaNS consortium partners. There are challenges in integrating a range of robotic hardware – including grippers, shears and the robots themselves – into a computer system that would be overseen by an operator in a remote location.

Traditional robotic systems are typically built for repetitive and pre-programmable tasks, such as building and sorting objects on assembly lines. Every task a robot needs to perform is configured within the hardware itself – and while there might be some form of semi-autonomous control, such as an operator being able to tweak the parameters of selected actions, the action's activities themselves are tightly controlled by pre-programmed logic. These activities usually make use of sensors – detecting the presence of an item, such as when packing items into a box – or trigger conditions, such as the target box being full and needing to be replaced by a new empty box. RoMaNS has been designed so it can manage varied actions due to the unstructured nature of the sort and segregate task: items to be processed are spread randomly over the sorting table, so the location and type of objects on the table cannot be pre-planned. Using sensors and input devices such as point-cloud cameras, radiological detectors, machine learning from previously-successful actions and guidance from the operator themselves, the system plans its actions in real-time – requiring real-time control over all rig equipment.

The project began in 2016/17 with the initial system work packages defined, in the following year university based demonstrations were completed and this was followed by transfer and integration of the technologies into the NNL Workington Laboratory.

2018/19 is the final year for the project delivering a fully working system in 2019. Elements of the technology have been used in the BEP project and there are plans to transfer this technology to the alpha box size reduction project.

The RoMaNs test rig at the National Nuclear Laboratory Workington

Challenge:

Increased efficiency in the sorting and segregation of materials

Solution:

Autonomous sorting and segregation of materials

Benefits:

- Reduced manual operations reducing operator dose
- Increased efficient sorting making use of waste routes available
- More productive because it is capable of 24/7 operations
- Better packing fractions i.e. efficient use of space in a waste container
- Reduced decommissioning costs

Status:

Technology element has been used in BEP and there are plans for use in the alpha glovebox size reduction project

TRL change:

From low TRL to mid TRL over the first 2 years of the project

Delivery partners:

University of Birmingham (UK), Commissariat a l'energie atomique et aux energies alternatives (France), Technische Universität Darmstadt (Germany), Le Centre national de la recherche scientifique (France), National Nuclear Laboratory

External publications/press releases/weblinks:

https://www.h2020romans.eu/

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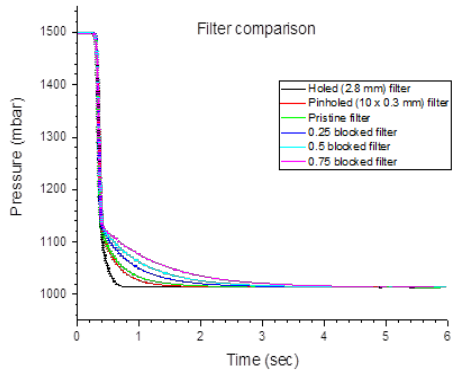
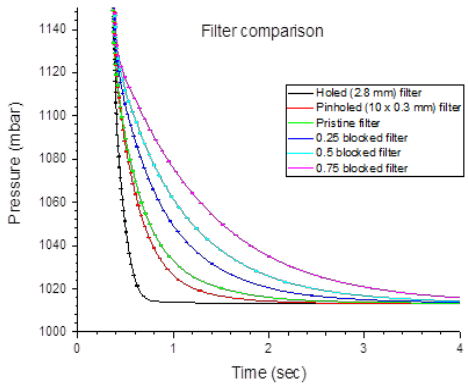
Proof-of-concept trials for in-situ testing of filter performance on Sellafield Self-Shielded Boxes

The Self-Shielded Box (SSB) is a thick-walled, robust container which is designed to store a variety of nuclear materials for 50 – 100 years, initially for feeds arising from FGMSP. These wastes can produce hydrogen which must be managed to ensure that flammable concentrations are not reached. Additionally, some of the wastes are reactive and consume oxygen and this must be replenished to avoid complete depletion. The SSB is a passive concept and therefore sintered metal filters are used in the design to facilitate the egress of hydrogen and the ingress of oxygen at the required rates and in this way, the gaseous environment within the container is managed effectively.

Over long timescales such as these, the filters play a crucial role and therefore they may need to be tested, in-situ, for factors that may affect their performance, such as corrosion. Corrosion could cause blockages in the filters or holes as a result of particulate entrainment, microbial growth, solidification of particulates and condensation. This may be unpredictable over such long timescales and therefore in-situ periodic testing of filters may avoid unnecessary filter replacement.





Pressure-time graph integrating all curves for the six filter conditions (above), expanded area of interest (He decay) (below)

During 2017/18, in collaboration with the Interface Analysis Centre at the University of Bristol three methods were developed for the in-situ testing of filters on SSBs:

- Positive pressure – applying a positive pressure to the filter and measuring the time taken to return to ambient
- Negative pressure – applying a vacuum above the filter and measuring the time taken to return to ambient
- A diffusion based test – measuring the rate of diffusion of helium across the filter at atmospheric pressure

Each of the three test methods were used in normal conditions (using pristine filters) and fault conditions (blocked and holed filters). A gas control rig (pictured) was specifically designed for this work.

Both the positive pressure and negative pressure methods were able to differentiate between all filter conditions and are therefore effective methods for use in in-situ testing of filters. The diffusion method was only able to identify the blocked fault condition.

Gas control rig specifically designed for the project consisting of He cylinder, vacuum pump applying ultra-high vacuum, bellows and bonnet needle valves, high-speed pressure transducer, 300ml volume vessel, software controlling computer, mass spectrometer sample head, custom-designed cylindrical stainless-steel vessel sampling volume, temperature probe, mass spectrometer

Challenge:

Testing of self-shielded box filters with waste inside the box

Solution:

External pressure testing of filter

Benefits:

- Confidence that the filters can be managed over long timescales
- SSBs maintaining their margins from a thermal excursion has been demonstrated
- Avoids the need to replace filters at the end of their lifetime if they are fully functional avoiding unnecessarily breaking containment of the SSB: this therefore limits dose uptake and the unnecessary creation of secondary wastes

Status:

Work is to be initiated to develop prototype pressure based test equipment with the potential for deployment on plant

TRL change:

TRL 1 to TRL 3

Delivery partners:

Interface Analysis Centre, University of Bristol

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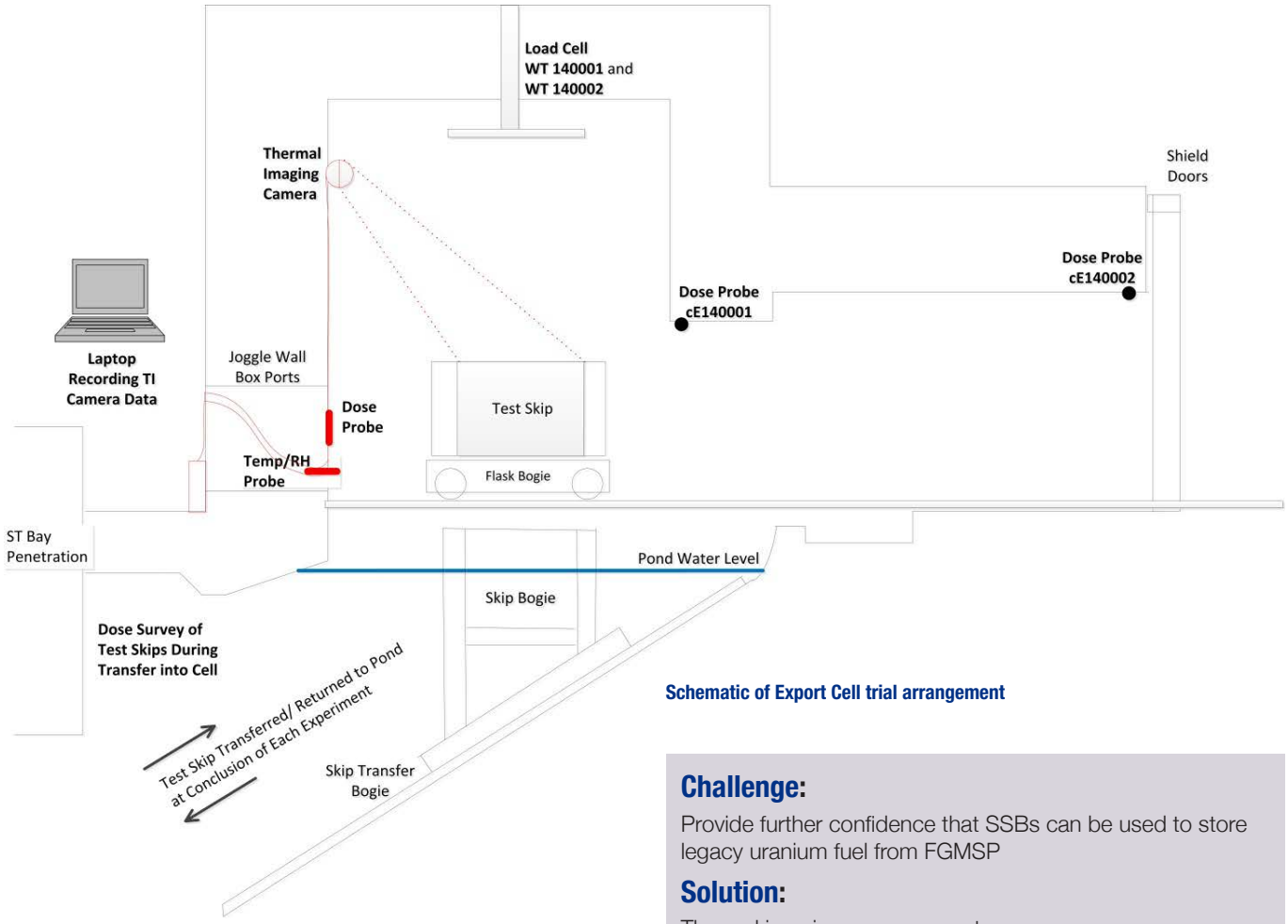
Export Cell trials in support of the Self-Shielded Box project

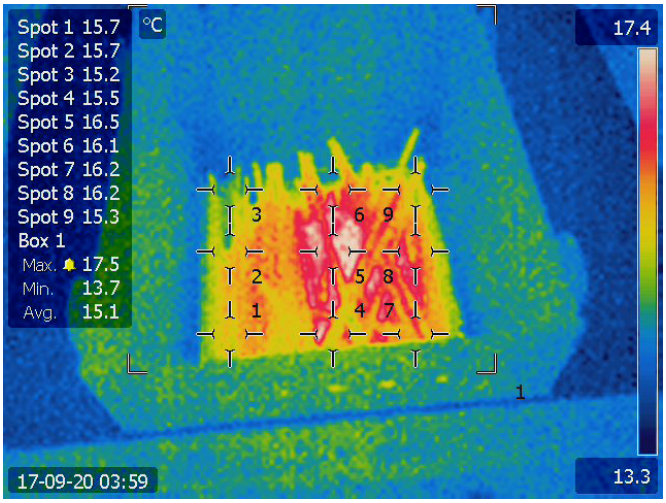
There is an opportunity to use the Sellafield Self-Shielded Box (see Proof-of-concept trials for in-situ testing of filter performance on Sellafield Self-Shielded Boxes, for additional information on SSBs) for the storage of legacy uranium metal fuel from FGMSP in the Interim Storage Facility (ISF). An opportunity was taken to gain further understanding through on-plant trials in advance of the start of exports to the ISF, these provided increased confidence in the technical case.

During 2017/18, active plant trials were carried out in the FGMSP Export Cell, for two different feeds of uranic material.

By means of a COTS thermal imaging camera, the temperature of legacy fuel was monitored over a prolonged period in dry conditions. The results from this work demonstrated the behaviour of FGMSP's legacy fuel in dry storage conditions (compared to environmental conditions), as well as producing evidence to support the judgement of the modelling work as being 'suitably conservative'. The opportunity was also taken to obtain dose measurements of the fuel, to feed activity models of the fuel.



Schematic of Export Cell trial arrangement



Thermal image of trial arrangement

Challenge:

Provide further confidence that SSBs can be used to store legacy uranium fuel from FGMSP

Solution:

Thermal imaging measurements

Benefits:

This work supports the strategy to store legacy uranium fuel in SSBs as the project moves into the active commissioning phase of ISF

Status:

The trial is complete but the equipment remains available for use as required

TRL change:

No change in TRL because thermal cameras are an established technology and equipment used was COTS. Novel use was in measurement of fuel temperature in an active environment

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Waste treatment, conditioning and packages IRT

There is a requirement for radioactive waste producers to convert higher active wastes (HAW) into a safe passive form and this has usually been achieved by encapsulation in a cement based matrix. With advances in immobilisation technology and as the mission at Sellafield evolves with a wider range of wastes generated there is an opportunity to consider credible alternatives to encapsulation including:

- Thermal technologies
- Alternative low temperature processes such as geopolymers, polymers and novel inorganic cements

There is also an opportunity to benefit from new manufacturing techniques for waste containers and an R&D programme has been considering an improved range of cost-effective waste container options. An IRT has been established to deliver the coordinated waste treatment, conditioning and packages R&D programme through a research team drawn from technical expertise within Sellafield Ltd, NNL and the supply chain.

Thermal treatment

The Thermal Treatment Integrated Project Team (IPT) is a Nuclear Decommissioning Authority (NDA) led study programme, managed by Sellafield Ltd, to develop thermal treatment processes in the UK to the degree that they can be considered a technically credible option for the treatment of waste across the NDA estate and beyond. The IPT comprises representation from the NDA, Sellafield Ltd, NNL and RWM and also liaises with key non-Sellafield agencies such as Atomic Weapons Establishment (AWE), Problematic Waste IPT, Environment Agency (EA), Scottish Environment Protection Agency (SEPA), Office for Nuclear Regulation (ONR) and others.

During 2016/17 an independent strategic data quality objectives exercise was undertaken to identify the wastes to be included within the scope of the project. The output from this was then used in 2017/18 to identify a number of wastes to be studied in more detail, these were:

- SIXEP sand and clinoptilolite
- FGMSP sludge
- Plutonium contaminated material (PCM) waste

The criteria used to identify these wastes included the Sellafield Ltd key decision calendar. The study focussed on the technical underpinning of thermal treatment of these three wastes together with an economic review of their treatment compared with a conventional grout treatment process. In parallel with this, an active demonstration programme was carried out by NNL in the Central Laboratory with a series of non-active and active trials completed using a range of wastes. The project findings in 2017/18 confirmed the strategic intent and direction of the project and supported future scope for the IPT.

Active thermal treatment facility in NNL's Central Laboratory

Challenge:
Alternative treatment options for future waste challenges

Solution:
Thermal treatment

Benefits:
Reduction in the volume of conditioned waste consigned to interim storage and subsequent disposal. Delivering significant lifetime cost savings for the disposal of wastes across the NDA estate.

Status:
Thermal treatment is now being considered as a key area for development for the treatment of key ILW.

TRL change:
The active demonstrations progressed the TRL from 2/3 to 5/6.

Delivery partners:
Nuclear Decommissioning Authority, National Nuclear Laboratory, Radioactive Waste Management, Atomic Weapons Establishment, TÜV SÜD Nuclear Technologies, Galson Sciences Ltd, University of Sheffield, Banah UK Ltd., Nuclear Advanced Manufacturing Research Centre

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Encapsulants

The aim of this programme is to generate key chemical and physical data on selected low temperature encapsulants performance against identified key waste types e.g. sludges, oils, ion-exchange resins and reactive metals in order to assess if benefits can be achieved when compared to baseline Portland cement technology. These benefits are expected to include improved waste/matrix compatibility, increased waste loadings over baseline cements and processing benefits that may be achieved during product manufacture.

The work in 2017/18 principally involved undertaking a detailed review of previous work to define encapsulants for the treatment of problematic and/or hazardous wastes. It identified the following systems for study in the on-going programme:

- Geopolymers
- Calcium aluminate cements (high alumina and calcium sulfoaluminate cement)
- Magnesium phosphate cement (MPC)

These systems have been selected for their hydration chemistry, reactant products, improved waste compatibility and retention characteristics, when compared with Portland cements. Formulations have been produced with low viscosity that may infiltrate wastes with tortuous pathways, or yield improved mixing characteristics with viscous wastes.

Preliminary practical studies have been ongoing over recent years on geopolymer systems at NNL Workington Laboratory in collaboration with studies undertaken at the University of Sheffield. Two baseline formulations have been developed at small scale under low shear conditions incorporating predominantly one metakaolin powder source activated with a potassium silicate/potassium hydroxide solution. The acceptable ratios of components were as follows:

- Si/Al =1.4, K/Al = 1, H_2O/K_2O =13.2
- Si/Al =1.0, K/Al = 1, H_2O/K_2O =13.0

These formulations:

- included a potential corrosion inhibitor
- had high fluidity
- set within 24 hours with zero bleed
- showed acceptable compressive strength and dimensional stability up to 90 days testing

These formulations were used in two small scale studies to assess the potential for immobilisation of flooded clinoptilolite and CMS. The products from these trials can be seen in the images.

Geopolymer product with 70 vol % clinoptilolite waste loading.

40 wt% CMS sludge at 60 vol % loading in (left) geopolymer and (right) 4.5:1 BFS/OPC @w/s 0.35. The difference in mixing viscosity can clearly be seen.

A further, commercial geopolymer cement has also been identified through consultation with Banah UK Ltd. This cement was also found to display similar characteristics to the formulations developed with Sheffield.

The preliminary studies discussed in this report have indicated that low viscosity geopolymer systems can be formulated, that may enhance waste loadings for viscous wastes. The next phase of the project, in 2018/19, will focus on compatibility studies with further optimised geopolymer formulations and the development of formulations for the other encapsulation materials.

Challenge:

Alternative treatment options for future waste challenges

Solution:

Alternative low temperature processes such as geopolymers, polymers and novel inorganic cements

Benefits:

Increased waste loading and therefore a reduction in the volume of conditioned waste consigned to interim storage and subsequent disposal.

Status:

Work is in preliminary stages and ongoing. Planned work includes:

- Compatibility studies with further optimised geopolymer formulations
- Development of formulations for the other identified systems
- Scale-up trials for each identified encapsulant.
- Geopolymer formulations developed under the IRT have undergone preliminary optioneering studies for ion exchange media and sludge

TRL change:

Work in preliminary stages – small scale geopolymer formulations developed and bench scale compatibility trials are at TRL 1-2

Delivery partners:

University of Sheffield, Banah UK Ltd.

National Nuclear Laboratory

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Alternative container design

The current cost of disposal containers for decommissioning waste is high due to the high quality of construction materials, stringent design and operational constraints. The design of containers has evolved over time and there is an opportunity to take advantage of modern manufacturing designs, materials and techniques, to review the current approach and work with the supply chain to produce cheaper, fit-for-purpose container solutions without compromising environmental and operator safety.

The container programme is in its early stages and the focus for 2017/18 was the production of a technology road map for alternative container design with key dates identified so that technologies can meet the requirements of the waste producers. In parallel with this and initiated by the Game Changer programme (see Enabling functions for more detail on Game Changers), three proof-of-concept projects are ongoing, seeking innovative solutions to meet the safety requirements of waste containment with increased efficiency and reduced cost. These projects will challenge the “one size fits all” philosophy by examining the requirements of both wasteforms and packages.

Challenge:

Efficient storage of a range of decommissioning wastes

Solution:

Fit-for-purpose containers

Benefits:

Reduced costs, whilst maintaining high safety standards and operator safety

Status:

Ongoing – the planning stage is almost complete and the programme is moving towards delivery of concept and development stages.

TRL change:

The work is in early or proof of concept stages

Delivery partners:

National Nuclear Laboratory, Nuclear Advanced Manufacturing Research Centre

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Condition monitoring and inspection IRT

Condition monitoring and inspection (CM&I) is an essential activity that enables Sellafield Ltd to demonstrate control of a variety of interim stored nuclear product and wastes. There are a number of CM&I strategies covering the range of nuclear product and waste types that have either been produced, or will be produced over the coming decades. Underpinning these strategies are technologies and techniques for acquiring many different types of information such as hydrogen evolution and waste container deformation, some techniques are mature whilst others require development. It has been recognised across the CM&I community that there is significant value in bringing together the CM&I approaches, technical knowledge and development activities into a single R&D programme, managed by an IRT, that aims to ensure continued safe storage of nuclear wastes. The aims of the IRT are to:

- Develop a single CM&I R&D programme that aims to mitigate the risks of long term interim storage of nuclear waste through the understanding of the evolution of the storage system (storage containment and the store) over time.
- Maximise the utilisation of internal and external resources to drive intelligent application and value for money in the development of CM&I solutions.
- Provide a knowledge base and sharing of best practice for the Sellafield Ltd CM&I community.

This report presents the progress made during 2017/18 on a number of key areas of the CM&I R&D programme. It covers some of the technologies under development as well as the review of the various approaches adopted on the site.

Collating the Sellafield CM&I strategies and techniques

A package of work, delivered by NSG Environmental Ltd., collated the CM&I approaches adopted or expected to be adopted for waste storage facilities on the Sellafield site. The output provided the current CM&I picture across the site identifying commonalities, risks, assumptions, gaps and needs associated with the facilities. Building on this a workshop was held with CM&I stakeholders, a key output of which included a roadmap showing the logical steps involved in delivering key pieces of work to address the needs.

CM&I technology review

A technology review was carried out by NNL to identify and appraise potential CM&I technologies for six aspects of measurement, associated with interim storage of waste and product packages. These were:

- Temperature and relative humidity measurement
- Water level measurement
- Measurement of waste package deformation
- Visual measurement of container surface
- Identification of content of legacy containers
- Hydrogen measurement

The results of this review provide a basis for CM&I practitioners to identify candidate technologies when further developing CM&I strategies and plans.

High accuracy inspection of modern SNM stores

Maintaining the condition of the interim store is an essential component of the overall storage system for SNM. Stores will corrode over time and therefore it is important that degradation is monitored effectively so that timely remedial action can be taken if necessary. Some storage configurations are comprised of a series of racks that enable the product to be naturally air-cooled. There is a requirement for better quantitative data from inspections to demonstrate that the plant will meet the design lifetime.

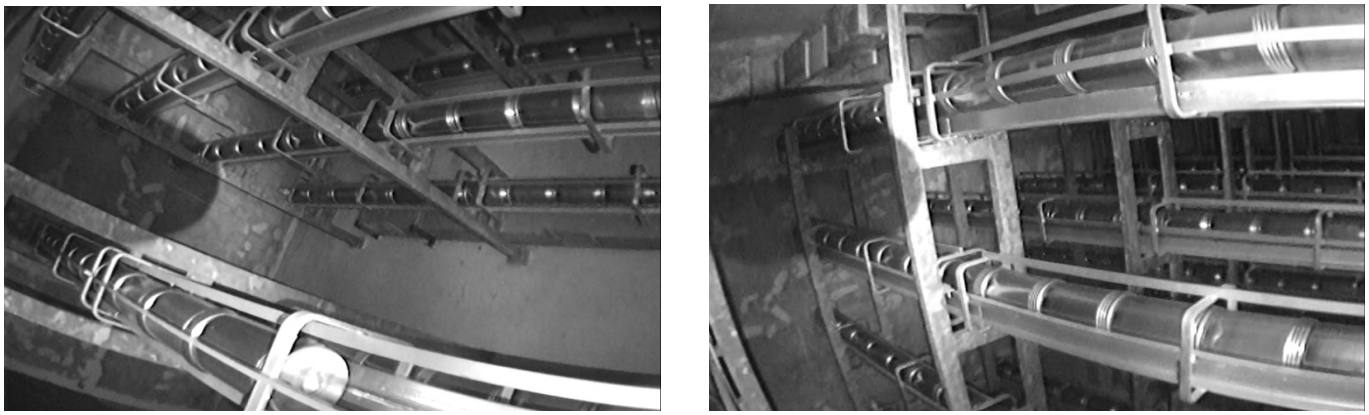
Following a tender exercise in 2017/18, ABS Consulting and the National Physical Laboratory (NPL) were chosen to develop a new inspection system, with key parameters including:

- Automated operation
- Self-contained unit
- Utilisation of digital image correlation and analysis techniques to identify areas of change
- Ability to generate quantitative data on the progression of corrosion within the store

The aim of the project is to use RolaTube technology (RTL Materials Ltd, trading as RolaTube Technology) to deploy a camera system to capture positional data together with visual images of the store (enabling repeatability and analysis between subsequent inspections). A key feature under development is the automated digital image correlation of data sets acquired by a moving camera. The project is ongoing and consists of 2 phases:

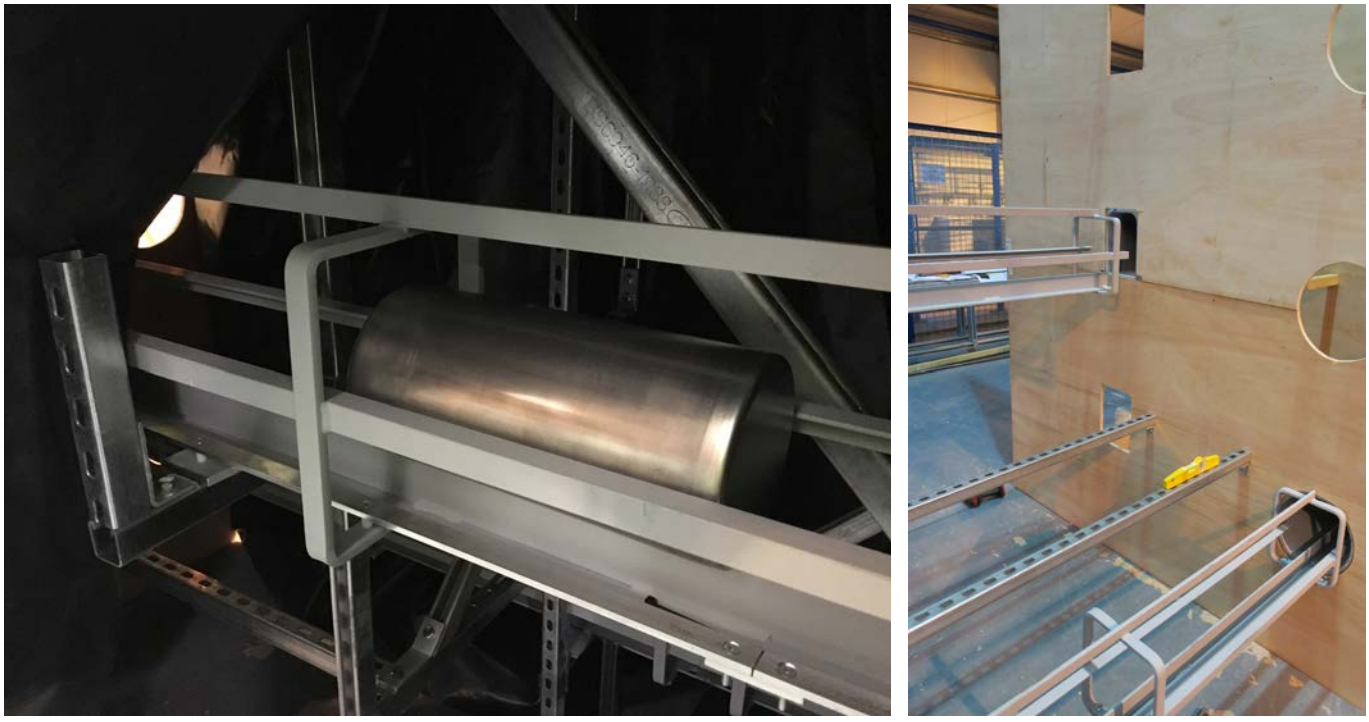
- Phase 1 - Prototype development and demonstration during 2018/19
- Phase 2 – Continued development of the prototype to a final visual inspection system with the device expected to be ready mid-2020.

The prototype uses a commercial-off-the- shelf AXIS V5914 PTZ HD Camera



Endoscope images of the internal spaces in a store, the packages can be seen in open racks

Completed North Store Test Rig: The completed rig replicates the physical constraints of the store in the dark environment



Views of the test rig

High accuracy inspection of older SNM stores

The current means of inspecting the older SNM storage system (the store and the product containers) is either through ex-situ inspection or in-situ endoscopic inspection (this is non-repeatable and has low surface coverage).

During 2017/18 James Fisher Nuclear Ltd., was commissioned to design an inspection system (*see the previous page for images of the rig*). Phase 1 was completed in 2017/18 with the construction of a North Store Test Rig (NSTR), this replicates the configuration and constraints in one of the older stores. Phase 2 is ongoing and is the development and testing of a prototype deployment system that will carry a high definition inspection camera to any package regardless of its position within the array. On completion of phase 2, phase 3 will focus on the design and construction of a complete inspection system, North Stores Inspection Equipment (NSIE) which can automatically deploy instrumentation into any store and channel. Phase 4 is the ongoing development of innovative sensors for the in-situ inspection of package characteristics such as internal pressure, corrosion and weld quality.

Container vent temperature measurement using infra-red and phosphor thermometry

Nuclear wastes from reprocessing are encapsulated in drums and stored in ventilated stores. A method to further improve how waste evolution is monitored has been trialled. A project was undertaken to determine whether internal container temperature can be inferred from the temperature of the drum's filter. If the temperature of the drum filter can be measured this would be a good indication of the actual drum internal temperature, from which levels of chemical reaction may be inferred. During 2017/18 two measurement techniques were used to measure internal drum temperature and the results compared, these were:

- Infra-red
- Phosphor thermometry

The trials were carried out at NPL on 500l drums and these produced the following results:

- Both the infra-red and phosphor thermometry techniques measured temperatures that were consistent across the range of measurement angles
- The techniques produced very similar results
- There was little measurement error in both techniques
- It was concluded that there is a relationship between the internal drum temperature and the measured vent temperature for both conventional infra-red measurement and phosphor thermometry
- Phosphor thermometry can be used for non-contact underwater temperature measurements

Game Changer programme

At a Game Changer (see Enabling functions for more detail on the Game Changer programme) event in December 2017, Sellafield Ltd articulated CM&I challenges through a series of presentations and discussions describing the storage system (the waste, the package and the store). Attendees were invited to submit applications for funding to develop their ideas. These have since been received and assessed with some being awarded funding for further development.

For more information on the IRT please contact the programme lead:

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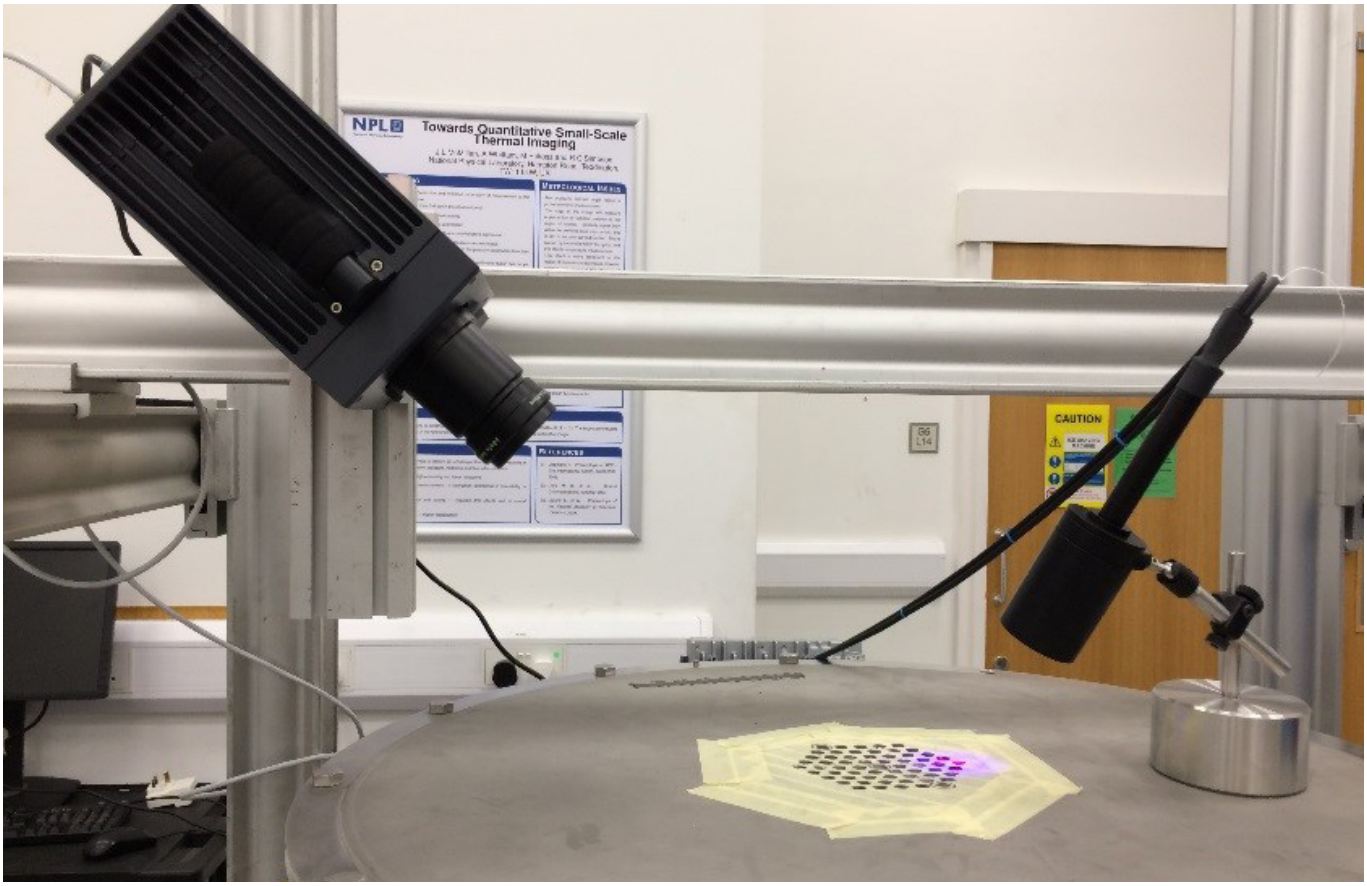

Phosphor thermometry experimental set up: This technique provides a robust method to remotely determine the temperature of a surface. A thin coating of thermographic phosphor is sprayed on the surface to be measured, this is excited with ultra violet light. The phosphorescence decay is then measured and the decay time determined, this is directly related to temperature through calibration

Challenge:

Remote measurement of internal drum temperature

Solution:

Phosphor thermometry and infra-red measurement

Benefits:

- A non-contact measurement system that can be used at a range of angles to provide consistent results
- An improved estimate of internal drum temperature can be made compared with surface measurement
- Can be used on other waste container vents or other surfaces for temperature measurement
- Phosphor thermometry can be used for non-contact underwater temperature measurements

Status:

Ongoing with proof of principle demonstrated, there is potential for further work on other containers and filters

TRL change:

Infra-red: TRL 9

Phosphor thermometry: TRL 6. This is a novel application of an engineering measurement technology and would require further development for application of this material to objects requiring thermal measurement in the nuclear industry

Delivery partners:

National Physical Laboratory

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Enterprise wide and enabling research and development

Most of the R&D presented in this report has been carried out to meet a specific need but sometimes R&D is required to meet a wider application across the Sellafield site for example:

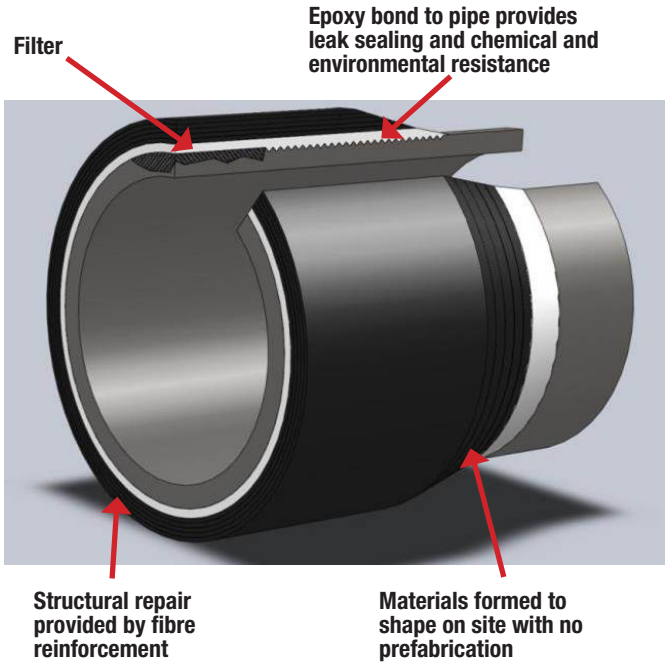
- Engineered composite repairs
- Developing an agent based evacuation modelling architecture
- Machine learning and artificial intelligence
- Novel analytical techniques
- Environmental monitoring and assessments beach monitoring tool
- Geographic information system to produce a web-based master planning tactical land request tracker
- Innovative method using a geographic information system to present master planning concepts

Engineered composite repairs

As Sellafield infrastructure ages, more maintenance and repair is needed for continued safe operations. The normal approach to repairs in pipes and pipelines is removal and replacement of the section requiring attention. Composite repairs offer an attractive proposition both technically and financially to avoid the need to take plant out of service for a long period to perform the repair. External to Sellafield these repair techniques are used satisfactorily for non-safety related equipment and the life of these repairs is variable. This shared research project looks at how to apply repairs to more onerous and safety critical applications with confidence. The project has been initiated and is being run by the Health and Safety Executive (HSE), it is a multi-industrial project with representatives from nuclear, oil and gas, gas transmission and distribution and the energy sectors, as well as in kind support from non-destructive testing (companies and consultants) and composite wrap producers.

This project is ongoing and during 2017/18 a number of decommissioned repairs were retrieved for durability analysis and non-destructive tests (NDT). A draft good practice guide was produced and this will be updated throughout the project and ultimately form part of the HSE guidance for the use, inspection and approval for use of defined life composite repairs. This project aims to establish good practice for a composite repair, from the design, installation, inspection, performance assessment and lifetime prediction. It is covering the following key elements:

- Quality assurance and integrity management
- Inspection and the criticality of defects
- In service performance
- Fire performance
- Repair installer proficiency scheme



Typical repair methodology – (picture courtesy of Furmanite)

Challenge:

Maintenance of Sellafield's infrastructure

Solution:

Composite repairs to pipes and pipework

Benefits:

This project aims to establish good practice for a composite repair, from the design, installation, inspection, performance assessment and lifetime prediction.

Status:

Ongoing

TRL change:

Composite repairs are currently used at high TRL for non-critical applications. This project aims to achieve high TRL for safety related and critical applications

External publications/press releases/ weblinks:

http://press.hse.gov.uk/2017/hse-launches-shared-research-project-on-engineered-composite-repairs/

Delivery partners:

The work is being run by the Health and Safety Laboratory and the sponsoring industrial partners are:

- National Grid
- TAQA
- Shell
- Nexen
- EDF Energy
- Total
- ConocoPhillips
- Centrica
- SGN
- Sellafield Ltd
- Health and Safety Executive
- Apache

In addition to this there are in kind support functions provided by composite suppliers:

- Metalyte Pipeworks Ltd
- Neptune Research Inc
- Team Furmanite
- IMG
- Clock Spring
- Walker Technical
- Belzona Polymerics Ltd.
- Henkel

Additional in kind and technical support is being provided by NDT companies, plus there is an independent expert advisory group, links to on-going comparative work with National Physical Laboratory, DNV-GL and HOIS plus dialogue with verification bodies who will use the output to inspect and assess repairs in service such as Lloyds Register, Bureau Veritas and DNV-GL.

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Developing an agent based evacuation modelling architecture

The aim of this project was to review and improve the current strategy for the evacuation of staff, across the Sellafield site, in the event of a "controlled site release" of personnel due to adverse weather conditions, for example. There are more than 11,000 personnel on the site during a normal working day and therefore the project needed to consider this, together with the aim of reducing the amount of vehicle congestion across the site, and queuing onto the A595 to achieve a safe and efficient evacuation of the site.

Saker Solutions Ltd. developed a methodology to create an agent based modelling architecture within a discrete based simulation environment, with the aim of modelling large scale evacuation scenarios (more than 10000 people). Working in partnership with Saker Solutions Ltd., Sellafield Ltd used this methodology to simulate the evacuation of the Sellafield site, taking into account shifts, staffing levels, building locations, staff travel preferences, car parking, exit routing, as well as modelling agent interactions and congestion from vehicle use.

This model can now be used to examine and evaluate different scenarios, in which the order that buildings release their population can be varied and experimented on. It can also be used to understand the effect of various unplanned situations and impacts, such as road or gate closures on site emptying times. Scenarios can be combined with different operating assumptions to investigate the impact of varying event timings and staffing profiles.

The model provides a mechanism to test different release order strategies, planning and evaluation without disrupting staff with time consuming evacuation drills. Further, with the ability to run so many different test scenarios, a much greater understanding of how evacuations could unfold, provide planning staff with the tools they need to identify problems and find solutions in the event of a real-life event driven release and therefore identify the most effective plan for the site.

Both vehicles and pedestrians were modelled to understand depth of interaction

Understanding traffic flow is key to a well-managed release strategy

The extent to which pedestrians interacted with traffic was previously unknown

Challenge:

Improvements to the evacuation strategy for staff at the Sellafield site

Solution:

Agent based modelling architecture

Benefits:

Scenario modelling that avoids staff disruptions. It can be used to identify problems and find solutions

Status:

The model was used to assess the impact of different evacuation strategies. Work is ongoing to improve both the methods used to create the model, and the overall scope it covers, to allow for greater levels of interactions between agents while maintaining simulation speed, performance and accuracy of results

Delivery partners:

Saker Solutions Ltd.

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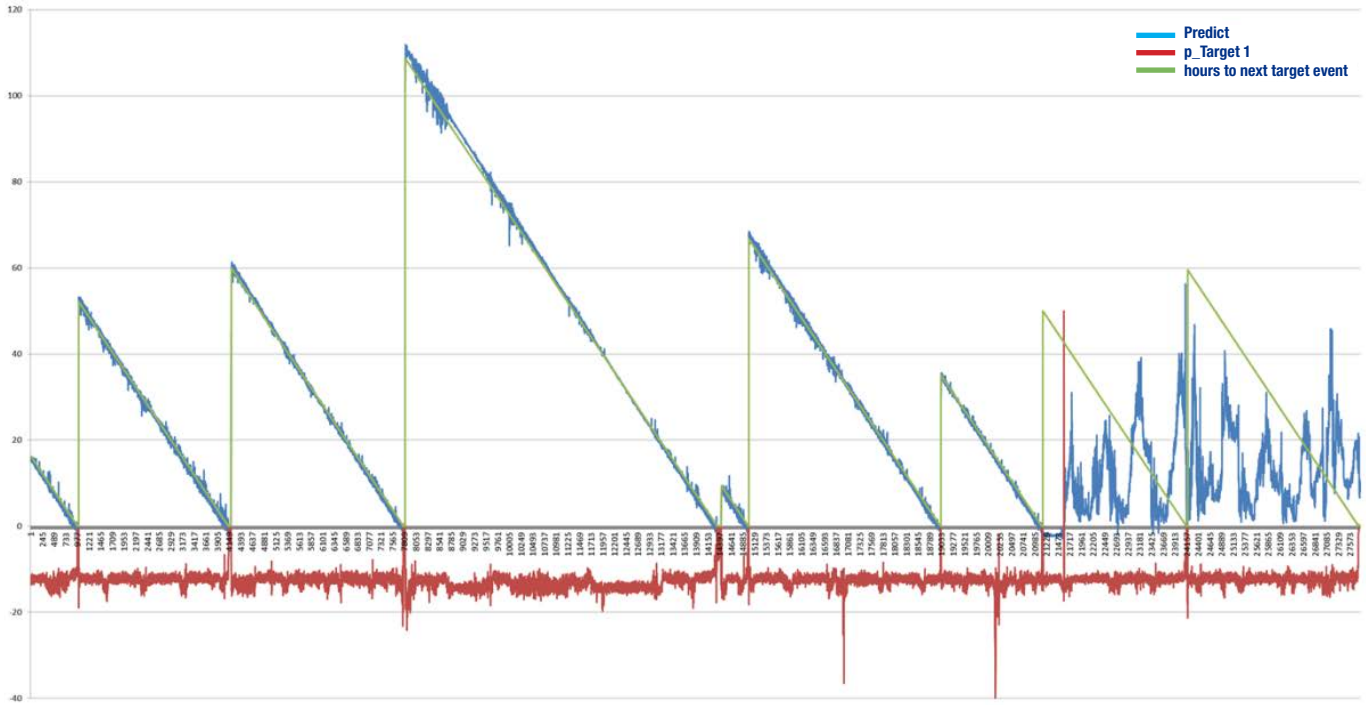
Machine learning and artificial intelligence

Machine learning (ML) is an application of artificial intelligence (AI) that provides systems with the ability to automatically learn and improve through experience, without being explicitly programmed. Machine learning focuses on the development of computer programs that can access data and use it to "learn" for themselves.

Sellafield Ltd has been exploring potential uses for machine learning within the business, as part of the creation of a wider "Business Analytics" capability. One of the first applications for ML was in examining container life, and trying to determine if there were patterns to container failure rates within the data.

In a machine learning environment, models are developed using the "R" language, and then fed a "training" data set. Each time the model correctly identifies a target variable or condition, the user "informs" the model that it has correctly scored or found the intended outcome. This cycle is repeated until there is a high degree of confidence in the ultimate model.

Machine learning is a fast moving and ever-changing environment, with numerous developments occurring, the latest of which is AutoML. AutoML seeks to further enable the spread of the practice, through automatic generation of the model code and structure without the same degree of user intervention as before, and is currently being tested in some initial experiments.



Predictive analysis from machine learning experiment around plant blockages

Challenge:

Feasibility of machine based learning in Sellafield Ltd's business

Solution:

Experiments with real diverse datasets

Benefits:

Improved insight and analysis of data for problem solving and decision making

Status:

The first case studies on container life and plant blockages have demonstrated the viability of the practice and further case studies are planned.

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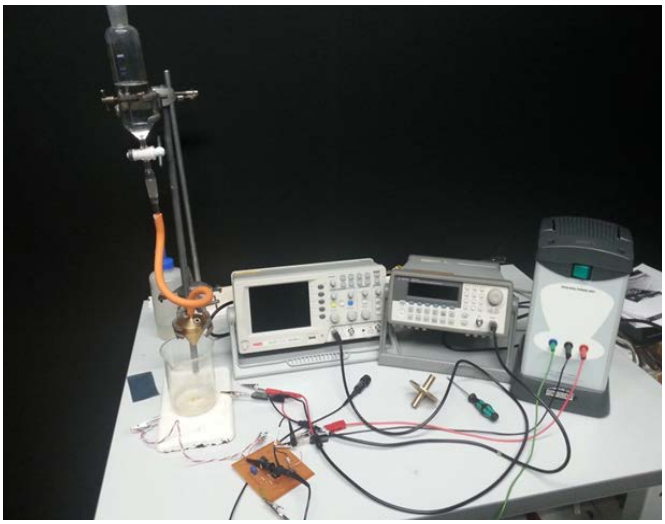
Novel analytical techniques

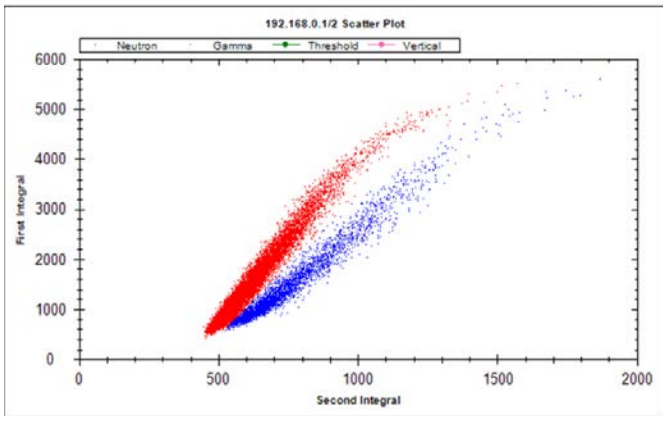
Analytical Services is currently undergoing a period of transformation from supporting reprocessing to moving towards wider decommissioning operations. This will lead to a shift from routine sample analysis to a greater emphasis on scheduled samples requiring bespoke analysis. As part of this, current operations in Analytical Services Laboratory will be phased out and the majority of future work will be performed in the NNL Central Laboratory. During this period of transformation there is the opportunity to exploit the latest technology developments to improve safety, efficiency and quality of analytical work.

During 2017/2018 the Novel Analytical Techniques (NAT) IRT programme ran an event through the Game Changers programme (see Enabling functions for more information on Game Changers). A number of submissions are now being explored further with the aim to achieve proof of concept. These submissions range from novel laboratory instrumentation to innovative in-situ technology.

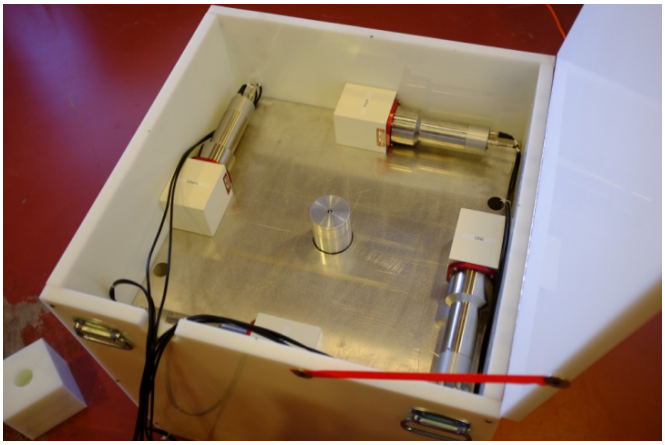
As the Sellafield site gathers increasing momentum in its decommissioning mission the search for more flexible, responsive and fit-for-purpose analytical tools and technologies to support the complex challenges ahead is crucial to delivering the site's future requirements safely and effectively.



Development of an acoustic technique for liquor analysis



Development of a novel technique for neutron detection analysis of fissile material



Challenge:
Evolution of the Sellafield mission and its impact on Analytical Services

Solution:
Fit-for-purpose analytical solutions

Benefits:
Flexible, responsive, fit-for-purpose delivered safely and effectively

Status:
Ongoing – Delivery of submissions through the Game Changers programme and the scoping of future activities

TRL change:
The work is currently in early or proof of concept stages

Delivery partners:
National Nuclear Laboratory

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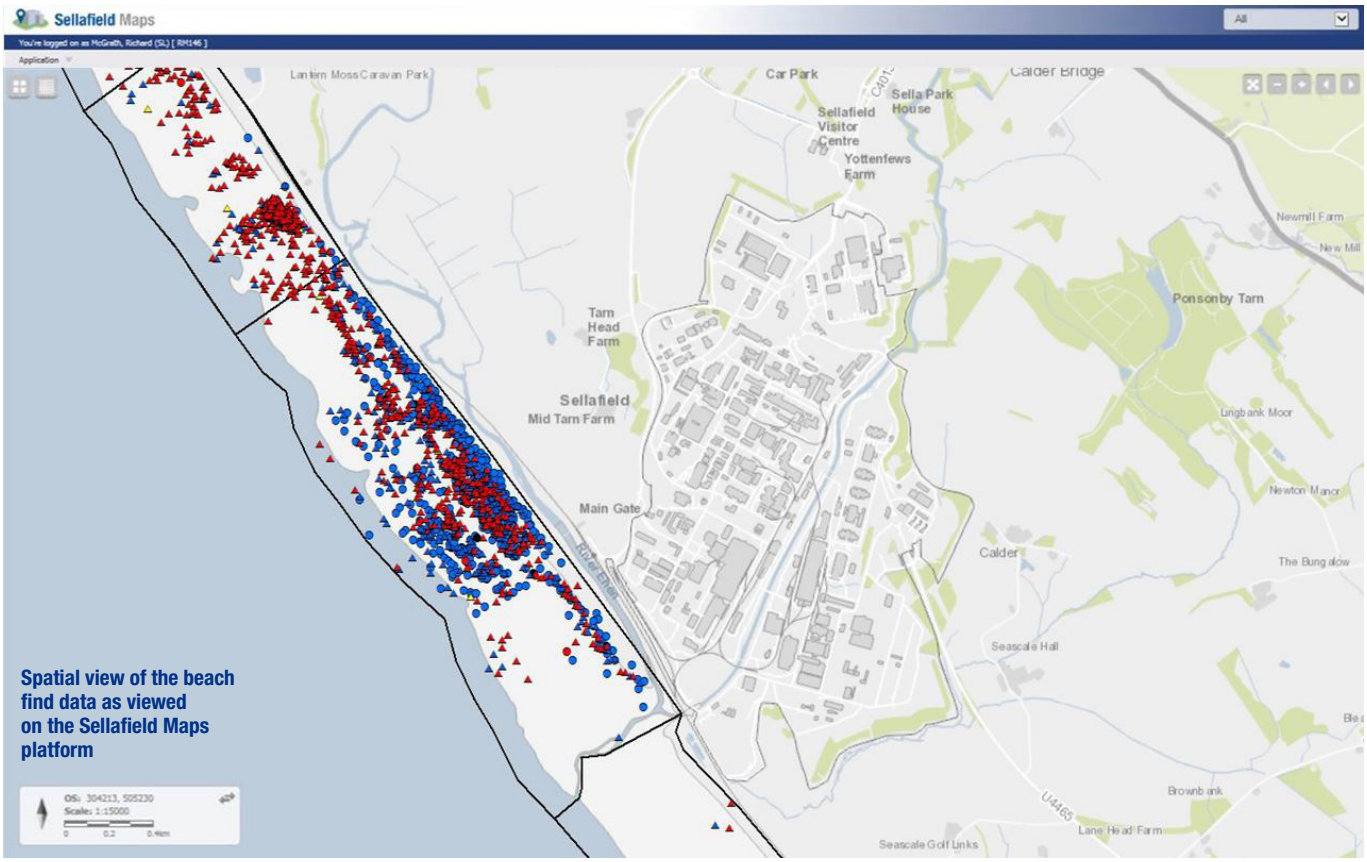
Peter Kinsella peter.kinsella@sellafieldsites.com

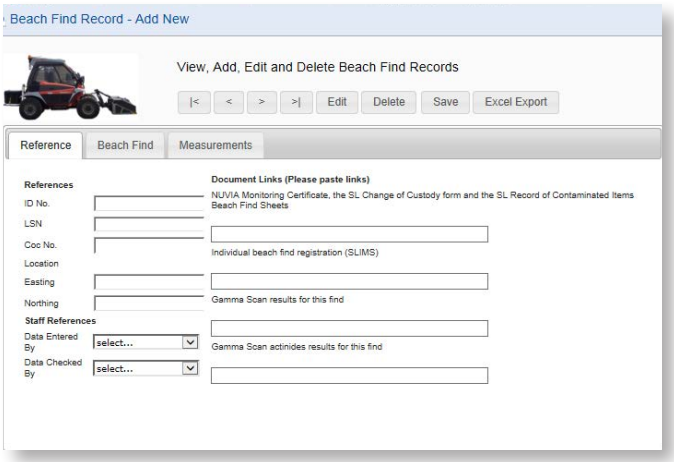
Environmental monitoring and assessments beach monitoring tool

The Sellafield site has an environmental permit under the Environmental Permitting (England and Wales) Regulations 2010 which requires the company to perform large area beach monitoring to detect and recover radioactive particles. In order to deliver this requirement, a vehicle mounted detection array system is deployed, equipped with a high-resolution GPS to provide information on the specific areas of the beach that have been monitored and the location of any beach finds. Data are logged by this system at 1 Hz generating very large spatial datasets that require processing and analysis.

Desktop-based GIS software has been used by Sellafield Ltd for a number of years to view and manage the statutory beach monitoring programme available to a limited number of personnel with the specialist skills. Due to an increase in business demand, the GIS capability at Sellafield has grown significantly in recent years and in 2013 a web-based map platform (Sellafield Maps) was made available to the business to view spatial data. The Sellafield Maps web platform has been modified to allow dissemination of the beach monitoring data, permit data entry and management and online analysis to a wider controlled audience of Sellafield Ltd staff. This tool is now in use and is a key enabler to manage the statutory collection, management and analysis of beach monitoring data. This has improved efficiency by freeing up resources to carry out other tasks.



Spatial view of the beach find data as viewed on the Sellafield Maps platform



The application allows the user to view, add and edit beach find data via a simple form

Challenge:
Dissemination of beach monitoring information

Solution:
Expansion of existing Sellafield Maps platform to reach a wider audience

Benefits:
Improves efficiency and manages knowledge

Status:
Complete and in use at Sellafield

Delivery partners:
Jacobs (via Design Services Alliance)

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Geographic information system to produce a web-based master planning tactical land request tracker

Site Licence Condition 16 covers site plans, designs and specifications and it is the responsibility of Sellafield Ltd to ensure that the day-to-day management of land is consistent with this. Land use and/or development vary and may include a new bus shelter, electricity sub-station or a major project such as a new build waste storage facility. Land use requests are managed centrally within Sellafield Ltd and in 2017/18 the process used, was reviewed and revised to improve efficiency.

The first part of the project was to consolidate the data into one file and to introduce a function so that a land request can be tracked through the application process. A second aspect of the work was to identify a means to disseminate the spatial information to a wider audience. Using a web-based map system, a 'land request tracker' application was developed. This system allows personnel to view:

- where a land request is in the land allocation process,
- what parcel of land has been allocated and,
- importantly, what neighbouring land is being used for.

For example, a land request might be in the strategic optioneering phase where multiple sites may be being considered, in the early stages of a single identified site or at a detailed design level. This information is available at a glance, using a dynamic and appropriately symbolised web-map.

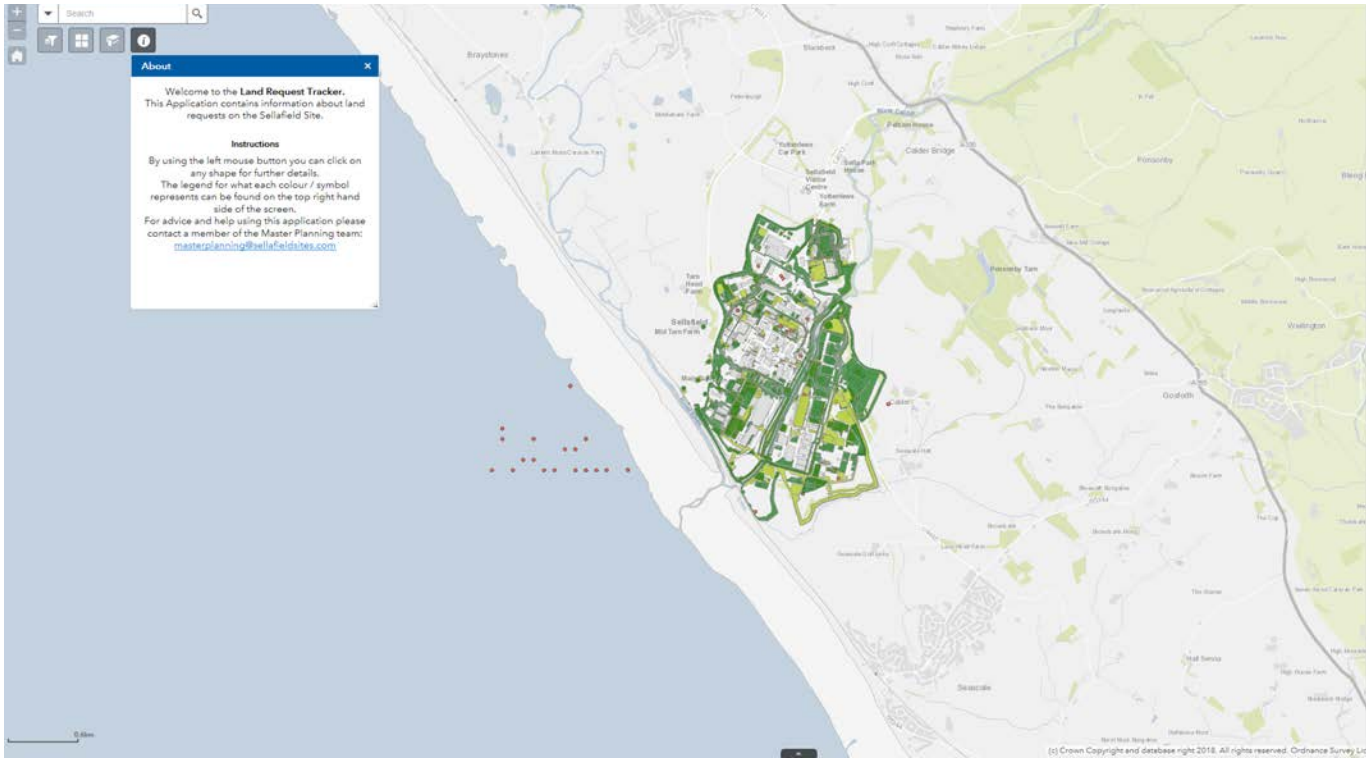

Image of the land request tracker application symbolised in colours related to what phase of the land allocation process a land request is

Challenge:
Management of land request applications

Solution:
Land request tracker application via a web-map solution

Benefits:
Improves efficiency, communication and planning and provides transparency in the land allocation process

Status:
Complete and in use at Sellafield

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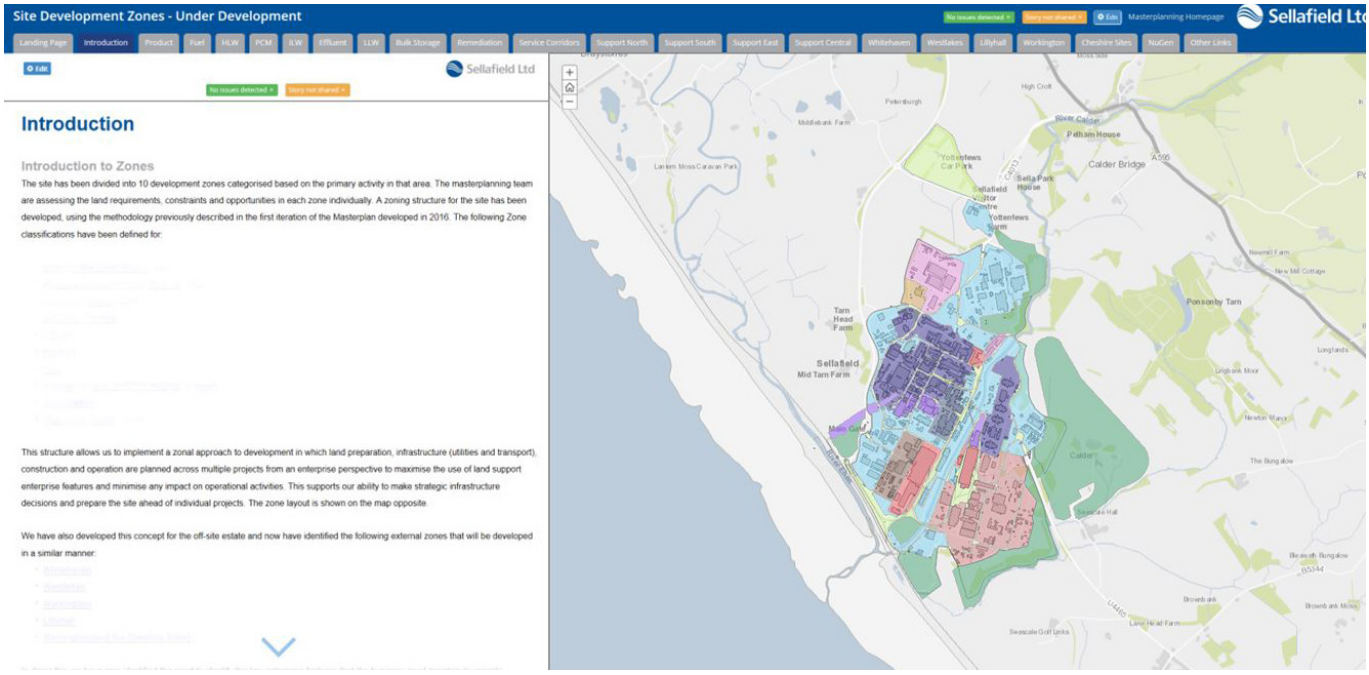
Innovative method using a geographic information system to present master planning concepts

Sellafield Ltd has a master planning process that enables the business to spatially manage operations across the Sellafield site in an efficient manner. A function that is vital to the business particularly as the site evolves from reprocessing to clean-up and decommissioning operations. Activities which require spatial planning include:

- New build locations
- Infrastructure corridors
- Demolition and decommissioning
- Transport and logistics
- Accommodation and welfare
- Spoil management

Each of these elements is integrated to create a master plan for the Sellafield site. The site has been divided into ten zones based on the primary activity in that area, this allows a zonal approach to development in which land preparation, infrastructure, construction and operations can be planned across multiple projects to maximise the use of land, while minimising the impact on operational activities. By sharing master planning concepts, this innovative approach supports the Sellafield mission by providing senior management with the information required to endorse the vision for the site. It also assists with management of the spatial environment, while planning for the future, for example in delivery of new facilities on the site.

An interactive web-browser based platform was used for the presentation of spatial data, via a map and supporting text. This offers significant benefits over conventional paper-based documents where often maps are presented in appendices. The tool is always up to date, because the underpinning data are live and part of business-as-usual operations.



An image showing the layout of the solution which replaces the conventional paper-based document

Challenge:
Dissemination of master planning concepts and ideas for each development zone on the Sellafield site.

Solution:
A web-based interactive solution combining spatial 'map' data with related text

Benefits:
Planning and decision making across the Sellafield site.
Improved communication

Status:
The tool is live and in use in the business

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Enabling functions

Centres of Expertise, university engagement and collaborations are examples of the mechanisms in which Sellafield Ltd supports the delivery of R&D to underpin ongoing operations, decommissioning and waste treatment. A diverse portfolio of skills and expertise are required with Sellafield Ltd engaging the supply chain, universities and experts to solve problems and develop new technologies. This section provides some examples of these:

- Centres of Expertise
- Integrated innovation in nuclear decommissioning competition
- University engagement
- Game Changers

Centres of Expertise

The Centres of Expertise (CoEs) are home to Sellafield Ltd's subject matter experts in various scientific areas providing support and technical expertise to programmes and projects across the site and their input features though out this report. Dr Penny Rathbone is the CoE lead for Polymeric Materials for the Sellafield site and provides support to other nuclear sites through collaboration and by working with the supply chain.

The CoE is an informal network of internal and external subject matter experts in the area of polymers. Penny's duties include being the central point of contact and providing guidance on materials selection, material analysis, failure analysis, peer review, innovation, research and development, standards and assurance and decommissioning activities. Penny is responsible for making sure there is an ongoing strategy for provision of polymeric capability in the company. Penny has had a varied and interesting career in the nuclear industry, spanning more than 20 years.

Penny graduated from the University of Liverpool with a BEng in Materials Science and joined the National Westminster Bank on the fast-track management scheme. After a year of this, she left to carry out a PhD back at the University of Liverpool in Auxetic Materials. Penny was offered a bursary to work for Unilever in 1994 but decided to take a job at the Company Research Laboratory (CRL) of British Nuclear Fuels Limited (BNFL) at the Springfields site, Preston. She worked in the advanced materials group looking at "blue sky" research, managing PhDs and other projects. She also took on the day-to-day running of the microscopy lab and the polymer projects being run from the CRL. After five years at Springfields, she went on a secondment to the Sellafield site for three months in 2000, to help with commissioning and maintenance shutdown activities. She has had numerous roles since then, including microscopy, condition assessment and inspection of site wide systems, general materials support, alpha containment materials specialist and programme management for facilities rationalisation, moving active laboratories between buildings.

In addition to her role as CoE lead, Penny is involved in science, technology, engineering and mathematics (STEM) activities with schools in the local area to encourage science as a career and she lectures a module on the Nuclear Materials and Engineering degree course at the University of Cumbria. She became a member of the Fellow of the Institute of Materials, Minerals and Mining (IOM3) in 2014, she is also a member of the Women's Engineering Society and Women in Nuclear.

> "Being part of a CoE provides the company with centralised specialist resources to focus on resolving issues and providing innovative and practical solutions as well as giving the members of the CoE support in their specialist area to deliver work and to continue their education through continuing professional development training and a supportive peer group".
>
> **Penny Rathbone CoE lead Polymeric Materials**

There are currently 24 CoEs in Sellafield Ltd covering a wide range of subject matter including:

Centre of Expertise	Centre of Expertise
AGR Dismantling	Maths & Statistics
Alpha Processing & Storage	Modelling & Simulation
Analytical Chemistry	Nuclear Physics
Autonomous Intelligent Systems	Polymers
Cement Chemistry	Safeguards
Contaminated Land & Ground Water Management	Sludge
Decontamination	Spent Fuel Storage
Effluent Technologies	U/Pu Chemistry & Processing
Highly Active Liquor	Uranium & Reactive Metals
Flammable Gas & Radiolysis	Thermal Treatment Technologies & Vitrification
Magnox Decanning	Waste & Facility Characterisation
Material Science	Waste Segregation & Compaction

For further information on CoEs please contact:

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Integrated innovation in nuclear decommissioning competition

As reprocessing operations on the Sellafield site cease, decommissioning, waste management and site remediation will become increasing priority and there are many opportunities to do things faster, more safely and at a reduced cost.

A significant proportion of nuclear facilities at Sellafield are associated with both historic and recent reprocessing operations with rooms (cells) containing complex networks of vessels, pipework and structural steel offering a number of challenges:

- The hazardous, congested environment and the difficult access mean that decommissioning and dismantling the radioactive cells is a complex task.
- Remote solutions have, in the past, been bespoke and very costly, yet unreliable. Manual decommissioning, however, is hazardous for the operator and extremely time-consuming.
- The waste generated as a result of nuclear decommissioning can be highly variable and span a wide range of classifications.
- The cost associated with treating, handling, packaging and disposing or storing of nuclear waste increases dramatically with classification. This means that the financial and environmental benefits of optimising waste treatment and routing are significant.

In 2017 Sellafield Ltd provided end-user support to the Nuclear Decommissioning Authority (NDA), Innovate UK and the Department for Business Energy and Industrial Strategy (BEIS) to put together a funding opportunity called “integrated innovation in nuclear decommissioning”. This competition opened in January 2017 with the application deadline on 26th April 2017.

The call invited applications for funding for projects that integrate technologies into a single system (or systems) that can demonstrate multiple tasks for demonstration in a non-active environment by the end of September 2019. The key objectives for innovation included:

- Reduce human intervention
- Increase productivity
- Optimise waste treatment, packaging and routing

Brokerage events were held across the country in February and March which engaged over 200 companies:

- 35 consortia submitted applications and 15 of these were awarded phase 1 contracts to produce 3-month feasibility studies.
- Phase 2 contracts were awarded to 5 projects (projects ranged in size, up to a total cost of £1.5 million) to progress innovations to non-active demonstration by September 2019.

During 2017/18 Sellafield Ltd also undertook preparation work for potential demonstrations of suitable new technologies. These activities included the identification and characterisation of possible locations for demonstration and initial quantification of the potential benefits, from these innovative approaches, over the current baseline decommissioning scheme.

Delivery partners:
Nuclear Decommissioning Authority, Innovate UK, BEIS

External publications/press releases/ weblinks:
https://www.gov.uk/government/news/3-million-dragons-den-style-competition-shortlists-ideas-to-clean-up-old-nuclear-plants
https://www.gov.uk/government/news/robots-compete-in-nuclear-decommissioning-challenge

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University engagement

Introduction

Over many years, Sellafield Ltd, together with the NDA and NNL, has supported R&D in universities, particularly underpinning science, proof of concept and basic principles. Working with universities has significant benefits:

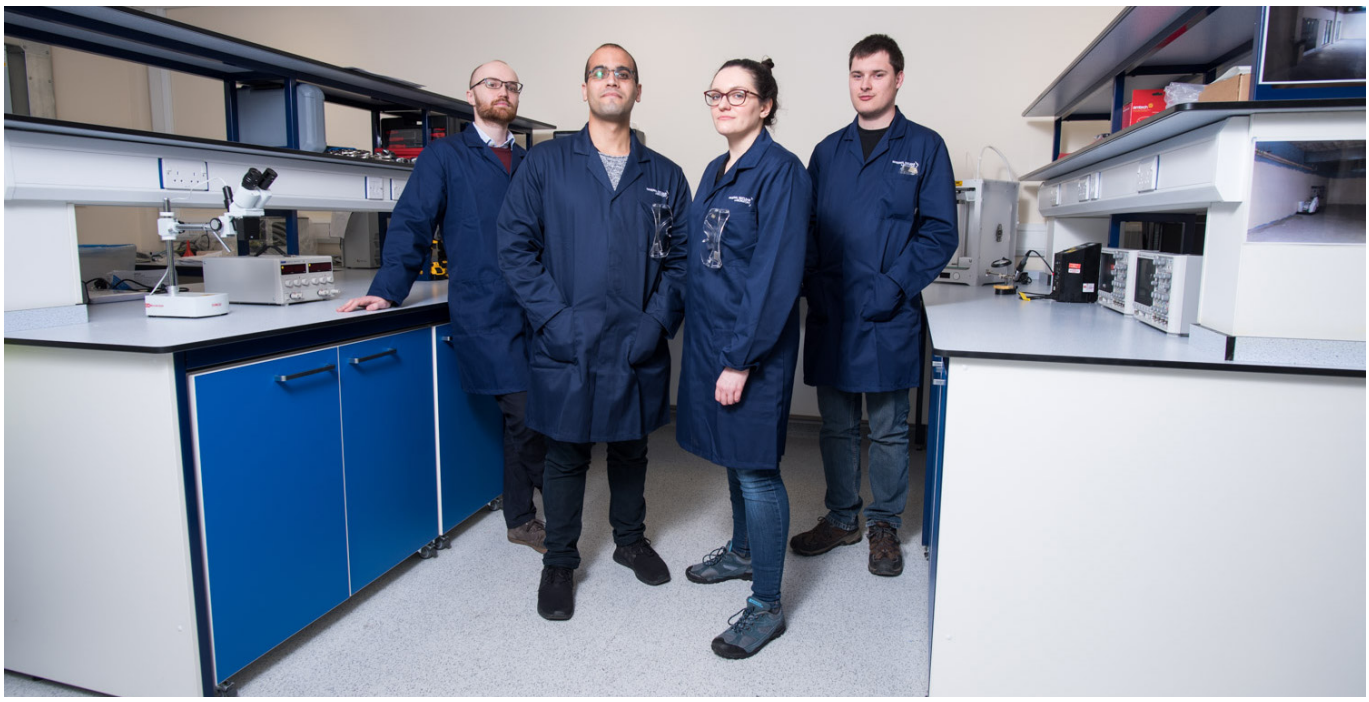
- Bringing new ideas and emerging technologies to underpin the mission at Sellafield
- Mitigate risks, uncertainties and gaps in knowledge related to Sellafield Ltd operations
- Pipeline of future scientists, engineers and nuclear leaders
- Peer review capability
- Specialist knowledge and facilities
- Encourages efficient access to multiple funding sources

Sellafield engages with universities in national programmes and in strategic partnerships, some of which are discussed below. There are also specific targeted projects to support the site mission.

Centre for Innovative Nuclear Decommissioning

Sellafield Ltd continues to support the Centre for Innovative Nuclear Decommissioning (CINDe), an industry-focussed centre for postgraduate research based at NNL Workington Laboratory. Jointly funded by Sellafield Ltd and NNL, there are currently 10 PhD students from the Universities of Manchester, Lancaster and Liverpool working alongside NNL supervisors to deliver innovative R&D for the Sellafield mission. During 2017/18, a dedicated research laboratory was commissioned to provide students with a facility to support bench scale electronics development as well as an area for wet chemistry and analysis.

During 2018/19, a third cohort of students will be recruited and additional equipment purchased for the laboratory. Closely aligned with the full-scale rigs at Workington, this will strengthen the links between academic research and higher TRL development, smoothing the flow of innovative solutions for the Sellafield site.



Research laboratory for postgraduate research at NNL Workington Laboratory

Next Generation Nuclear Centre for Doctoral Training

Sellafield Ltd continues to support the Engineering and Physical Sciences Research Council (EPSRC) Centre for Doctoral Training in Nuclear Fission - Next Generation Nuclear, which began in September 2014, by sponsoring PhDs together with other organisations from which Sellafield Ltd shares the learning. The mission is to develop future research leaders to support the UK's strategic nuclear programmes including nuclear legacy clean-up, new build power stations and, defence and security.

This programme is a partnership which includes The University of Manchester, Lancaster University, the University of Leeds, the University of Liverpool and the University of Sheffield and works with all of the UK's major industrial and regulatory bodies. In 2017/18 Sellafield Ltd supported three new research students on the programme researching topics such as groundwater monitoring on nuclear sites and characterisation and corrosion behaviour of product storage cans.

An initial proposal for a follow-on Centre for Doctoral Training has been submitted and the consortium has been invited to submit a full proposal. This will be called GREEN (Growing skills for Reliable, Economic Energy from Nuclear).

For more information see:

http://www.nextgennuclear.manchester.ac.uk/

DISTINCTIVE

The DISTINCTIVE (Decommissioning, Immobilisation, and Storage soluTIons for NuClear wasTe InVEntories) programme is a research collaboration between the UK nuclear industry and key universities that have a nuclear specialism. It is a five-year EPSRC, university and industry funded programme which began in 2014 and is now in its final year. Sellafield Ltd, NNL and the NDA collaborated with a consortium of ten universities on projects covering four key themes:

- AGR, Magnox and exotic spent fuels
- Plutonium dioxide (PuO_2) and fuel residues
- Legacy ponds and silo wastes
- Structural integrity

The collaborative approach taken has ensured that research has been aligned to the needs of the industry with output contributing towards improved interpretation of plant behaviour and informing plant design. The research projects have been supporting activities across the NDA estate, whilst providing a new generation of suitably educated and experienced graduates that are able to approach the technical challenges in the nuclear industry in the coming decades. The industrial partners of the consortium also recognise the importance of the academic community to the technical challenges across the NDA estate and its maintenance in the future.

See the website for more information, the universities involved in the programme and project details:

http://distinctiveconsortium.org/

Further information on DISTINCTIVE can be found in a recently published paper:

Angus, M., Cooney, A., Short, R., Orr, R., Hambley, D., Graham, J., Banford., A. March 2018. An industrial perspective on research within the DISTINCTIVE programme – 18045. WM2018 conference, March 18 -22, 2018, Phoenix, Arizona, USA.

In January 2018 the EPSRC announced a call for proposals seeking investment from its Energy programme. One area of investment will include decommissioning, immobilisation and management of nuclear waste. In response to this and building on the success of the DISTINCTIVE programme already described, Sellafield Ltd, has committed to support a proposed programme based on the 4 NDA strategic themes:

- Spent fuel management
- Nuclear materials
- Site decommissioning and remediation
- Integrated waste management

University links

To support key technical capabilities Sellafield Ltd identified areas where core skills and knowledge needed to be strengthened and as a result established the university links programme:

- Sludge with the University of Leeds
- Uranium at the University of Bristol
- Decontamination and effluent management at The University of Manchester
- Flammable gases with London South Bank University

These links support more focussed projects by funding academic activities in key technical areas, whilst developing understanding of Sellafield challenges by academia and by expanding the knowledge of Sellafield Ltd staff. They also facilitate credibility with stakeholders and regulators.

University Interactions Working Group

Sellafield Ltd and other parties from the Nuclear Waste and Decommissioning Research Forum (NWDRF) take part in the University Interactions Working Group (UIWG). The group reviews learning from working with academia across the NDA estate and provides coordination of future work. Via the NWDRF Sellafield Ltd takes part in the selection process for the NDA bursary scheme which funds further PhDs of benefit to the NDA estate. These PhDs are also of direct benefit to Sellafield Ltd or they complement other academic work.

Details of the scheme can be found on the following sites with updates on an annual basis inviting new applications:

http://www.nnl.co.uk/news-media-centre/news-archive/nda-phd-bursary-2018/
https://www.gov.uk/guidance/apply-for-phd-bursaries-related-to-nuclear-decommissioning

For further information on university engagement contact:

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GAME CHANGERS

Game Changers is a Sellafield Ltd sponsored initiative focused on encouraging innovation, from businesses, academia and individuals, to address complex nuclear decommissioning challenges. As the Sellafield site prepares for increased decommissioning activity, innovative tools and technologies are identified as a key enabler to efficient decommissioning and waste management.

The programme objectives are to:

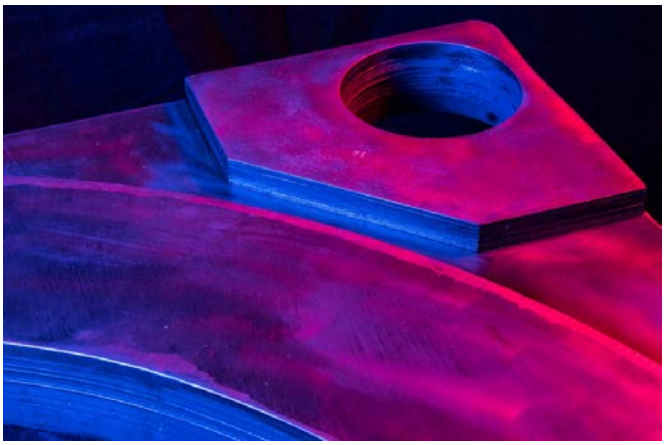
- Discover and capture specific technical decommissioning challenges identified by Sellafield Ltd, defined in close consultation with internal teams.
- Publish and communicate calls for innovation to both nuclear and non-nuclear audiences including industry, SMEs, universities, R&D departments and other supply chain organisations.
- Provide technical and commercialisation support for the development of early stage technologies.
- Provide support for the development of early TRL projects, whilst maintaining dialogue with Sellafield Ltd to identify potential applications in the business.
- Support and develop a portfolio of "de-risked" mid-TRL projects to proof of concept stage that will add value to the Sellafield Ltd business and have the potential to attract further investment.
- Achieve interaction and alignment with Sellafield technical teams. Enable and facilitate an innovation culture across Sellafield.

Technologies may already be in use in other industries, but have the potential for development for use in the nuclear sector.

The Bismuth Plug, developed by Rawwater Engineering for sealing oil and gas wells during decommissioning, is a metal alloy with a composition that can be tailored to expand when it solidifies, potentially a novel system for containment of radioactive surfaces (www.rawwater.com)

During 2017/18, the programme ran challenge-led events across the UK, these focussed on waste containers, knowledge management, analytical services, and condition monitoring and inspection. Each event included presentations and workshops from Sellafield Ltd experts, with attendance from 80 and 200 delegates from diverse industry sectors. Further events are planned for 2018/19 and will included topics such as POCO.

To date the programme has received over 160 applications, 70 of which have received initial grants to articulate their project and produce a business plan for review, with 9 such projects progressing to proof of concept stage. By return, the project has leveraged over £1m external funding.



Heatric proof-of-concept project investigating manufacture of a diffusion bonded top flange suited to Sellafield's waste containers, addressing a potential weak point in current manufacture at reduced cost (www.heatric.com)

Delivery partners:

National Nuclear Laboratory, FIS360

External publications/press releases/ weblinks:

https://www.gamechangers.technology/

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Frank Allison frank@fis360.com

Abbreviations and acronyms

AGR	Advanced Gas-cooled Reactor
AGRSP	AGR Storage Pond
AI	artificial intelligence
AVEXIS	Aqua Vehicle Explorer for In-situ Sensing
AWE	Atomic Weapons Establishment
BEIS	Department for Business, Energy and Industrial Strategy
BEP	Box Encapsulation Plant
BEPO	British Experimental Pile 0
BET	Brunauer-Emmett Teller
BNFL	British Nuclear Fuels Limited
BFS	blast furnace slag
BSV	buffer storage vessels
CARMA	Continuous Automated Radiation Monitoring Assistance
CCTV	closed-circuit television
CFD	computational fluid dynamic
CINDe	Centre for Innovative Nuclear Decommissioning
CM&I	condition monitoring and inspection
CMS	corroded Magnox sludge
CoE	Centre of Expertise
COTS	commercial-off-the shelf
CRL	Company Research Laboratory
D:EEP	Estimating Entrained Products
DF	decontamination factor
DISTINCTIVE	Decommissioning, Immobilisation, and Storage soluTIons for NuClear wasTe InVEntories
DSC	distributed simulation controller
DQO	data quality objective
EA	Environment Agency
EARP	Enhanced Actinides Removal Plant
EASD	Electrically Assisted Surface Decontamination
ECG	electrocardiogram
ECV	Effluent Collection Vessel
EDX	Energy-dispersive X-ray
ELENDES	Electrochemical Enhancement of Nuclear Decontamination Solutions

Abbreviations and acronyms

EPS-WTR	Encapsulated Product Store - Waste Transfer Route
EPSRC	Engineering and Physical Sciences Research Council
EPR	Environmental Permitting Regulations
ESEM	environmental scanning electron microscopy
FGMSP	First Generation Magnox Storage Pond
FGRP	First Generation Reprocessing Plant
FHP	Fuel Handling Plant
FIB	focussed ion beam
GC	gas chromatography
GDF	Geological Disposal Facility
GIS	geographic information system
GPS	global positioning system
GREEN	Growing skills for Reliable, Economic Energy from Nuclear
HALES	Highly Active Liquor Evaporation and Storage
HAW	higher active wastes
HP&S	health physics and safety
HSE	Health and Safety Executive
ILW	intermediate level waste
IOM3	Institute of Materials, Minerals and Mining
IPT	Integrated Project Team
IRT	Integrated Research Team
ISF	Interim Storage Facility
LiDAR	light detection and ranging
LLW	low-level waste
MBGW	miscellaneous beta-gamma waste
MDF	MOX Demonstration Facility
MIRRAX	Mini Robots for Restricted Access Exploration
ML	machine learning
MOX	mixed oxide
MPC	magnesium phosphate cement
MSSS	Magnox Swarf Storage Silo
NAT	Novel analytical techniques
NDA	Nuclear Decommissioning Authority

Abbreviations and acronyms

NDT	non-destructive tests
NNL	National Nuclear Laboratory
NPL	National Physical Laboratory
NSIE	North Stores Inspection Equipment
NSTR	North Store Test Rig
NWDRF	Nuclear Waste and Decommissioning Research Forum
OPC	ordinary Portland cement
ONR	Office for Nuclear Regulation
PBTF	Package to Box Transfer Facility
PCM	plutonium contaminated material
PF&S	Plutonium Finishing and Storage
PFSP	Pile Fuel Storage Pond
POCO	post operational clean out
PPE	personal protective equipment
R&D	research and development
RDP	Radiation Depth Profiler
RoMaNS	Robotic Manipulation for Nuclear Sort and Segregation
ROV	remotely operated vehicles
RST	Residual Sludge Tanks
RWM	Radioactive Waste Management
SEM	Scanning electron microscopy
SEP	Silo Emptying Plant
SEPA	Scottish Environment Protection Agency
SIXEP	Sellafield Ion Exchange Effluent Plant
SLC	Site Licence Company
SME	small and medium-sized enterprise
SMF	Silos Maintenance Facility
SNM	special nuclear material
SPP1	Sludge Packaging Plant 1
SRF	Swarf Retrieval Facility
SRP	Silo Roof Plugs
SSA	specific surface area
SSB	Self-Shielded Box
STEM	science, technology, engineering and mathematics

Abbreviations and acronyms

TDA	The Decommissioning Alliance
Thorp	Thermal Oxide Reprocessing Plant
TRL	technology readiness level
UIWG	University Interactions Working Group
UTG	Uranium Technical Guide
VLLW	very low-level waste
WAGR	Windscale Advanced Gas-cooled Reactor
WAMAC	Waste Monitoring and Compaction plant
WRATs	waste requiring additional treatments
XRD	X-ray diffraction

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