Sellafield Ltd

The 2016/17
Technology Development and Delivery Summary

Contents

Foreword

Sellafield is the largest UK nuclear site with a unique and diverse range of complex challenges arising from 60 years of varied nuclear operations.

Many new technologies are required to meet the decommissioning and waste treatment challenges. These challenges arise from both the existing hazard reduction programme associated with the site's legacy waste and from future decommissioning projects. The need for innovation is of critical importance to drive down costs to increase value to the UK tax payer by completing programmes more efficiently while maintaining high standards of safety. The complexity of Sellafield drives the need for the nuclear provision to be regularly revisited as new information becomes available. Over the long timescales, plans will be affected by technology improvements, changes in government policy, economic circumstances and environmental issues.

Sellafield Ltd recognises that investment in research and development (R&D), and the active identification of technology transfer opportunities is critical to the successful delivery of its mission to safely operate, clean up and decommission the Sellafield site.

Our parent the Nuclear Decommissioning Authority (NDA) and our stakeholders which include our local communities and the UK taxpayer have rightly placed an expectation on us to discharge these responsibilities efficiently, effectively, and above all safely.

As we move forward with our transformation plan we will continue to encourage innovation, developing future options that make the most of our capabilities and strengthen our supply chain. Our investment in R&D and our determination to seek new innovative solutions will help us to deliver on our promises. By sharing some of our successes via this report, we hope to demonstrate that not only is tangible progress being made in all key areas, but also the discharge of these responsibilities is in safe hands.

This report demonstrates the extent of R&D on the Sellafield site. It also provides examples of key technology successes to provide an overview of the key projects delivered by the technical community.

We would encourage interested parties to contact us should they see an opportunity for collaboration and/or coordination of research, development, or technology transfer in one of our key challenge areas.

Rebecca Weston
Strategy & Technical Director

Vision

A world leader in solving complex nuclear challenges

Mission

Safely and securely remediate the Sellafield site to benefit the industry, nation and region

Sellafield Technical Challenges

- Support to continued operations - to end of reprocessing
- Support to design, build and operation of legacy pond and silo treatment facilities
- Preparation for post operational clean out activities
- Bring forward innovative technology for broad front decommissioning

Overview

Research and development is critical for the success of many of our activities to deliver our mission, we support fundamental research and early development, lab and pilot scale demonstrations through to full operation at Sellafield.

Neil Smart
Chief Scientist, Strategy and Technical Directorate

The purpose of this document is to:

- Present representative examples of the ongoing R&D to deliver the Sellafield Ltd mission.
- Communicate the Sellafield technical challenges and the benefits of supporting relevant R&D.
- Provide a focal point for engagement with the technical community including other Site Licence Companies, academia and the supply chain.

Sellafield Ltd has a long history with the National Nuclear Laboratory, our partner, which is featured in almost half of the projects and articles in this review. In January 2017 a unique agreement was formalised between Sellafield Ltd and the National Nuclear Laboratory who pledged to work together to deliver value for UK taxpayer. As the site drives forward its one hundred year decommissioning programme, it is in the public interest for the companies to work more closely together to ensure hazard reduction on the Sellafield site is done safer, quicker and cheaper, as more innovative solutions are developed.

Sellafield Ltd's mission is very diverse and requires support from a wide range of technology suppliers and hence collaborations with the broader supply chain and academic community are essential for Sellafield Ltd's success. In 2016/17 the review features more than 30 universities and 50 organisations, including small and medium-sized enterprises (SMEs), national and international companies and national institutes. A number of collaborative programmes which illustrate how we engage with universities and share expertise are featured in this year's review including DISTINCTIVE (Decommissioning, Immobilisation and Storage soluTIons for NuClear wasTe InVEntories) and the university link programme on effluents and decontamination with The University of Manchester. Sellafield Ltd works with universities ensuring alignment between UK Research Council funded nuclear programmes and the technology end user.

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.

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:

http://www.sellafieldsites.com/

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
future.decommissioning@sellafieldsites.com

Projects included in this report

Project	Delivery partners
Managing the R&D portfolio	
University engagement	Various universities, National Nuclear Laboratory
DISTINCTIVE programme	Various universities, National Nuclear Laboratory, Nuclear Decommissioning Authority
Effluents Centre of Expertise	National Nuclear Laboratory, The University of Manchester
Flammable Gases Centre of Expertise	London South Bank University, Dalton Cumbrian Facility
Sludge Centre of Expertise	AMEC Foster Wheeler, MMI Engineering Ltd., National Nuclear Laboratory, NSG Environmental Limited, University of Leeds (direct and via the DISTINCTIVE consortium)
Game Changer programme	Innovus, National Nuclear Laboratory, FIS360
Spent fuel management and nuclear materials	
Magnox container ullage performance investigation	James Fisher Nuclear Ltd.
Lead container trials enabling pH 9 dosing of Thorp Receipt and Storage	
PuO_2 analysis performed at the National Nuclear Laboratory Central Laboratory in support of plutonium storage and retreatment	National Nuclear Laboratory, The University of Manchester
The Meteor Monte Carlo nuclear criticality code	
Site decommissioning and remediation	
Alternative intermediate level waste approach for managing Magnox Swarf Storage Silos waste	Cavendish Nuclear, DBD Ltd., Exova Corrosion Centre, Stainless Metalcraft (Chatteris) Ltd., Fauske & Associates, National Nuclear Laboratory, London South Bank University, Amec Foster Wheeler, Mirion Technologies
Magnox Swarf Storage Silos liquor and effluent management	DBD Ltd., National Nuclear Laboratory, WF Senate, ERIKS UK, CH2M, Quintessa Ltd., Eden Nuclear and Environment Ltd.
Pile Fuel Storage Pond dewatering trial: Temporary lowering of the pond level by 23cm for concrete characterisation and decontamination trials	Cavendish Nuclear, REACT Engineering Ltd., Createc, Costain
Research and development to underpin the impact of legacy waste retrievals on the First Generation Magnox Storage Pond effluent stream	National Nuclear Laboratory
Highly Active Liquor Evaporation and Storage radiometric characterisation	Cavendish Nuclear, Rovtech Solutions Ltd.
Gamma imaging for dose mapping	REACT Engineering Ltd., PHDS Co.
Unmanned aerial vehicles	James Fisher Nuclear Ltd., WYG
Alpha camera	CEA
Activity depth profiling in concrete	Createc, Costain, Cavendish Nuclear, Canberra UK
ViridiScope	Viridian Consultants Ltd., Amec Foster Wheeler
Waste estimation	Nuvia, Canberra UK, Createc, REACT Engineering Ltd.
AVEXIS: a remotely operated mini-submarine for the exploration of facilities with restricted access	The University of Manchester, Forth Engineering Ltd.
DEMplus® modelling demonstration	ATKINS, REACT Engineering Ltd., OREKA SOLUTIONS
Strippable coatings and fixatives waste disposability and performance assessment	Low Level Waste Repository Ltd., Radioactive Waste Management, The University of Manchester, Shepley Engineers Ltd.

MIRRAX: a robotic platform for the deployment of characterisation tools in facilities with restricted access	The University of Manchester
LaserSnake2	OCRobotics, The Welding Institute, National Nuclear Laboratory, Laser Optical Engineering Ltd., ULO Optics
Integrated waste management	
Thermal Treatment Integrated Project Team	Nuclear Decommissioning Authority, National Nuclear Laboratory, Atomic Weapons Establishment, Radioactive Waste Management
Encapsulation Integrated Innovation Team	National Nuclear Laboratory, Banah UK Ltd., Lucideon Ltd., University of Sheffield
Production of an Enhanced Actinide Removal Plant test rig	National Nuclear Laboratory, Axium Process Ltd.
Accepting decontamination liquors in the Enhanced Actinide Removal Plant	National Nuclear Laboratory
Electrochemical Enhancement of Nuclear Decontamination Solutions (ELENDES)	C-Tech Innovation Ltd., National Nuclear Laboratory
Application of graphene oxide materials in the nuclear industry	National Nuclear Laboratory, University of Cambridge, The University of Manchester
Test rig work to support Evaporator D commissioning	National Nuclear Laboratory
Robotic arm mounted condition monitoring and inspection instrumentation for waste package inspection	Graham Engineering Ltd., The Technology Partnership, Bristol University, York University, National Physical Laboratory, Hiden Analytical, Kromek Group plc
Vitrified Product Store – Debris Removal Hatch inspection	National Nuclear Laboratory
SonicH_2: a micro-sensor for hydrogen sensing	The Technology Partnership plc
Enabling technologies	
3D printing capability for the Sellafield site	Atomic Weapons Establishment, partnership with external 3D print bureau's and lease companies to be established.
Wireless instruments	Yokogawa® UK Ltd.

Managing the R&D portfolio

A diverse range of skills and expertise is required to deliver our R&D with Sellafield Ltd engaging the supply chain, universities and experts to solve problems and develop new technologies.

The Centres of Expertise (CoEs) are home to Sellafield Ltd's subject matter experts in various scientific areas and provide support and expertise to programmes and projects across the site. The CoE structure gives a focused point of contact for technical support for internal and external queries.

This section provides some examples of the ways in which R&D is managed:

- University engagement
- DISTINCTIVE programme
- Effluents Centre of Expertise
- Flammable Gases Centre of Expertise
- Sludge Centre of Expertise
- Game Changer programme

University engagement

Introduction

Sellafield Ltd, together with the National Nuclear Laboratory, has worked extensively over many years with universities on R&D and strategically supporting key scientific capabilities. There are several different routes to working with universities including Research Council funded programmes such as DISTINCTIVE. Sellafield Ltd also funds collaborations with key universities to develop core skills and knowledge specific capabilities, for example sludge with the University of Leeds and decontamination and effluent management at The University of Manchester. Working with universities has a number of 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
- Academic advocacy
- Encourages access to multiple funding sources

DISTINCTIVE

The 5 year Engineering and Physical Sciences Research Council (EPSRC), university and industry funded DISTINCTIVE programme began in 2014. Sellafield Ltd, the National Nuclear Laboratory and NDA have collaborated with a consortium of 10 universities on projects covering 4 key themes:

- Advanced Gas-Cooled Reactor (AGR), Magnox and exotic spent fuels
- Plutonium dioxide (PuO2) and fuel residues
- Legacy ponds and silo wastes
- Structural integrity

Each project is supervised by either Sellafield Ltd or the National Nuclear Laboratory and there are some good examples of learning from academic projects on effluent treatment, the performance of plutonium dioxide during storage and measuring sludge using an acoustic backscatter technique (see the next article for more about the programme's successes). The programme is now maturing well and initial discussions are taking place on its successor. DISTINCTIVE itself is a successor programme to DIAMOND (Decommissioning, Immobilisation And Management Of Nuclear wastes for Disposal).

See the website for more information and the universities involved in the programme, project details are also provided: **http://distinctiveconsortium.org/**

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 capability development by funding academic activities in key areas for Sellafield Ltd and work alongside the more fundamental work arising from DISTINCTIVE. Individual contributions on these links are included in this chapter for sludge, decontamination and effluents and flammable gases.

Centre of Innovation in Nuclear Decommissioning

The Centre of Innovation in Nuclear Decommissioning (CINDe), established in 2016, is a new collaboration between the National Nuclear Laboratory, Sellafield Ltd and a consortium of universities which were selected following a competition for academic partners, these are:

- The University of Manchester
- University of Liverpool
- Lancaster University
- University of Cumbria

The centre is based at the National Nuclear Laboratory facilities in Workington which allows easy collaboration between Sellafield Ltd, National Nuclear Laboratory staff and students and also benefits from the use of existing facilities and rigs at Workington.

Three students were recruited in 2016/17 and are working on characterisation techniques (laser-induced breakdown spectroscopy (LIBS) and Raman spectroscopy), wireless communications and a pond wall cleaning remotely operated vehicle (ROV). A further 5 are planned to be recruited in 2017/18 and work is planned to improve the facilities for students at Workington.

Next Generation Nuclear Centre for Doctoral Training

Sellafield Ltd continues to support the EPSRC Centre for Doctoral Training in Nuclear Fission - Next Generation Nuclear (NGN) 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.

NGN is a partnership which includes The Universities 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.

For more information see:
http://www.nextgennuclear.manchester.ac.uk/

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 these PhDs can be found on:
https://nda.blog.gov.uk/wp-content/uploads/sites/165/2016/02/NDA-PhD-Research-Seminar-for-NDA-Sponsored-PhD-Projects-2016-Abstracts-Booklet.pdf

Details of the 2017 scheme can be found on:
http://www.nnl.co.uk/news-media-centre/news-archive/nda-phd-bursary-2017/

Other programmes

Sellafield Ltd supports individual PhDs and industry/ academia collaborations such as the Research Centre for Non-Destructive Evaluation (RCNDE).

The RCNDE is an EPSRC-sponsored collaboration between industry and academia to coordinate research into non-destructive evaluation (NDE) technologies, and to ensure research topics are relevant to the medium to longer-term needs of industry. RCNDE continues to be funded on the guiding principles of world-class scientific research and industrial application. The Centre's vision is to see NDE transform into a fully integrated part of the engineering life cycle and the aim is to progressively link up with other disciplines, particularly structural integrity, materials science and engineering design. Details of the RCNDE can be found on the National Nuclear Laboratory website.

http://www.nnl.co.uk/science-technology/rcnde/

University partners of Sellafield Ltd can apply for EPSRC grants to address the needs of the company. These are often accompanied by a letter of support from Sellafield Ltd offering in kind and sometimes financial support. Grants awarded in 2016/17 include:

- Robotics for nuclear environments - EPSRC award to The University of Manchester.
- Assessment of gamma radiation on the properties of concrete - EPSRC award to The University of Manchester.
- Rad-hard diamond detectors for civil nuclear applications - Science and Technology Facilities Council (STFC) award to the University of Bristol.
- Corrosion of cladding - EPSRC award to the University of Liverpool.
- Laser-driven multi-modal probe beams for nuclear waste inspection - STFC award to Queen's University Belfast.
- Long-lived radionuclides in the surface environment (LO-RISE) - mechanistic studies of speciation, environmental transport and transfer - Natural Environment Research Council (NERC) award to The University of Manchester.
- Predicting long-term performance of cement disposal systems for radionuclide loaded zeolite and titanate ion exchangers - EPSRC award to the University of Sheffield.

Summary

The activities described in this report contribute to a healthy academic portfolio; Sellafield Ltd works collaboratively with the NDA, The University of Manchester and the National Nuclear Laboratory, to maintain and communicate a comprehensive overview of the longer-term R&D activities relevant to decommissioning at Sellafield. The portfolio is maintained, monitored and quantified with key metrics drawn from the data. At the end of 2016/17 the portfolio contained 345 projects with total annual funding of ~£25M split across a number of sources including: Sellafield Ltd, National Nuclear Laboratory, NDA, EPSRC, InnovateUK, universities and business. Just over 40% of these projects are academic such as PhDs and postdoctoral research associates (PDRAs) in a significant number of universities across the UK.

Delivery partners
Various universities, National Nuclear Laboratory

Contact
Andrew Cooney (Strategy & Technical)
andrew.s.cooney@sellafieldsites.com

DISTINCTIVE

DISTINCTIVE is the academic programme co-funded by the EPSRC with support from industry partners from the nuclear sector. The purpose is to carry out internationally leading science and engineering research in an area of decommissioning and nuclear waste management with Sellafield Ltd providing technical supervision and direction.

Highlights

- **17 PDRAs and 21 PhD researchers are being trained across the entire project, as well as a further 22 PhD students associated with the project.**
- **To date researchers have published 57 peer-reviewed papers, 36 in journals and 21 in conference proceedings.**
- **139 engagement activities have taken place (to audiences of academics, industrialists and members of the public).**
- **There have been 27 awards and recognition given to consortium members, in terms of prestigious advisory positions, and research prizes and keynote speaker invitations**
- **16 new grants have been awarded based on work undertaken within DISTINCTIVE totalling just under £3M.**

There are four key themes:

- AGR, Magnox and exotic spent fuels
- PuO2 and fuel residues
- Legacy ponds and silo wastes
- Structural integrity

The following sections explain the progress and the research carried out in each theme.

AGR, Magnox and exotic spent fuels

- Work on transitioning spent AGR fuel from wet to dry storage to inform drying and transitioning of legacy materials from current aged storage facilities, to be retrieved and repackaged for ongoing storage at Sellafield, assisting development of fuel handling operations. Investigations into behaviour of fuel and cladding materials.
- Fuel material behaviour included uranium, uranium carbide and uranium dioxide (UO2), with novel use of thin films to examine behaviour of fuels in water and moist atmospheres (i.e. transition from submerged pond storage to dry storage). Thin film surfaces directly comparable to surfaces on bulk crystals and hence provided test substrate for mimicking spent nuclear fuels.
- Detailed empirical and modelling work has given improved understanding of the oxidation of uranium carbide fuel from the Dounreay Fast Breeder Reactor, a critical step to enable its disposition.
- For cladding materials, work has resulted in better understanding of corrosion behaviour, quantifying extent of microstructure damage, and developing automated drying techniques. Some of this research has contributed to a change in the way intermediate level waste (ILW) material from silos at Sellafield will be packaged and it will feed into long term storage strategies for spent fuel being developed by the NDA and Sellafield Ltd.

PuO_2 and fuel residues

- Strategy proposed for de-risking of the plutonium management policy in the UK by adoption of a dual track approach, with any remaining plutonium not converted into MOx fuel, or otherwise reused, to be immobilised and treated as waste for disposal. Findings were presented at the House of Commons, All Party Parliamentary Group on Nuclear Energy.
- Input into process design, operational and safety aspects of Sellafield Product and Residue Store Retreatment Plant for retreating and/or repackaging historic plutonium and residues for consolidation into store.
- First-in-the-UK early career researcher experiments with PuO_2 powders using active glove box facilities at the National Nuclear Laboratory Central Laboratory leading to improved understanding of PuO_2 behaviour during out of specification storage, i.e. when in presence of water or contaminated with chloride.
- Detailed atomic-level understanding of interaction of water with stoichiometric and defect PuO_2 surfaces – work was selected as a highlight for Materials Chemistry Consortium's 2016 report to the EPSRC.
- Development of glass-ceramic and formulations, and hot isostatic pressing (HIP) process, for immobilisation of UK plutonium stockpile, supported by hands-on Pu-239 validation at the Australian Nuclear Science and Technology Organisation (ANSTO).
- Unique facility and capability developed for HIP of actinides.
- New methodology for determination of very slow dissolution kinetics of actinide glass-ceramics through ultra-high resolution optical interferometry and atomic force microscopy (AFM) techniques, providing quantitative input data for disposal system safety assessment.

- Launched world's first long duration synchrotron experiment at Diamond Light Source to investigate, in situ, kinetics of hydration of cement hydrate phases known to sequester plutonium and other actinides within cement-encapsulated plutonium-contaminated material wastes.
- Successful trials on UO_2 and thorium dioxide (ThO_2) (as PuO_2 simulants) of nanogravimetric device for direct measurement of water entrainment in plutonia powders and subsequent determination of heats of adsorption; the instrument is being transferred to the National Nuclear Laboratory for analogous measurements on PuO_2 powders.

Legacy ponds and silo wastes

- Prototype non-intrusive acoustic backscatter measurement technique for monitoring suspended sediment particles in water being installed in legacy fuel storage pond at Sellafield to allow improved design of waste processing options. Modelling and measurement work on slurry transport and deposition also providing input to process design.
- Technical advice given regarding design of a new SIXEP (Sellafield Ion eXchange Effluent Plant) Contingency Plant for waste slurry discharges based on slurry modelling and experimental work performed.
- Gas hold-up work informing case and operational planning at Sellafield for raw waste storage, with follow-on work planned. Seen as fundamental to maximising store capacity pending geological disposal and underpins waste monitoring strategy. Work has potential to avoid generation of several hundred waste packages.
- Image recognition techniques developed being considered as possible method for (partial) characterisation of mixed waste as it is being retrieved or whilst in pond storage. If successful this would significantly reduce the effort required to catalogue inventories of thousands of waste boxes.
- Development of improved understanding of corrosion behaviour of partially immersed glass waste forms and of glass/crystal composite waste forms through experimental and modelling work.
- Successful knowledge transfer of slag formulation development for treatment of plutonium-contaminated materials (PCM) to industry, and validation of vitrified products from pilot scale melter experiments.
- Development of new non-zeolite inorganic ion exchange materials for caesium (Cs) and strontium (Sr) removal from effluent with high capacity and direct conversion routes to ceramic waste forms.

Structural integrity

- Developed model of silica grout gelling that enables control of grout gel time from minutes to tens of hours. Model accounts for in-situ soil and groundwater conditions and will provide flexibility for innovative grout use, e.g. injection of horizontal barriers requiring much longer gel times.
- Validated the grout gelling model via lab-based colloidal silica injection into fine sands at a meter scale.
- Case submitted to the Australian nuclear regulator - Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) and gained approval to conduct colloidal silica-based field trial for grouting legacy waste trenches at Little Forest Legacy Site, Sydney. Mock waste trench will be constructed and then grouted in-situ with colloidal silica. Results of trial will be used to underpin future options for long-term site management.
- Determined the engineering properties of colloidal silica grouted soils: shear strength, compressibility, water retention, hydraulic conductivity.
- Developed novel repair strategies for degraded concrete infrastructure. Repair strategy is based on application of silica nanoparticles to repair cracks in cement storage ponds. The aim is to restore strength and inhibit water seepage.
- Demonstrated that cement structure (C-S-H gel) can be tailored to sorb radionuclides into the cement matrix.

Delivery partners

Various universities, National Nuclear Laboratory, Nuclear Decommissioning Authority

Contact

Andrew Cooney (Strategy & Technical)

andrew.s.cooney@sellafieldsites.com

Effluents Centre of Expertise

The challenge

As the Sellafield site transitions from reprocessing operations to hazard and risk- reduction activities and post operational clean out (POCO), a number of challenges and opportunities emerge. These include improving the understanding of effluent systems and accelerating decommissioning activities. Notable examples include assessing of the routing of effluents from waste retrieval operations through the SIXEP and the optimisation of the Enhanced Actinide Removal Plant (EARP) to process new post-reprocessing feed streams. Successful management of effluent routings will be critical to enable hazard and risk reduction missions and in the realisation of opportunities during POCO. Considerable progress has been made in effluent management through interaction between the Sellafield Ltd technical teams, The University of Manchester and the National Nuclear Laboratory.

Background

For 5 years Sellafield Ltd and The University of Manchester have sponsored and supervised 12 PhD researchers in partnership with the National Nuclear Laboratory via the university link scheme established by the company. Through this investment and related gearing, it has been possible to develop a research community bridging across academia and industry of more than 40 people. The research programme was defined and shaped to provide underpinning information to complement and enhance the applied research that is conducted by the National Nuclear Laboratory and sponsored by Sellafield Ltd.

Why?

The aim of the research programme is to provide fundamental understanding of the underlying processes impacting on effluent management. In doing so, this has clearly enhanced the process capability on site which in turn provides direct cost savings and risk reduction and therefore increases stakeholder confidence in operational activities.

How?

Interactions between academic research groups, representatives from Sellafield Ltd plant and technical departments, and researchers at the National Nuclear Laboratory have facilitated an unprecedented exchange of information and allowed research findings to be directly implemented within plant operations and planning. Examples include:

- Refinement of the operations within EARP leading to reduced radionuclide discharges.
- Refinement of operations in the First Generation Magnox Storage Pond (FGMSP) leading to optimised management of effluent during sludge movement.
- New high level skills, techniques, research gearing and translation to industry.

PhD student Josh Weatherill

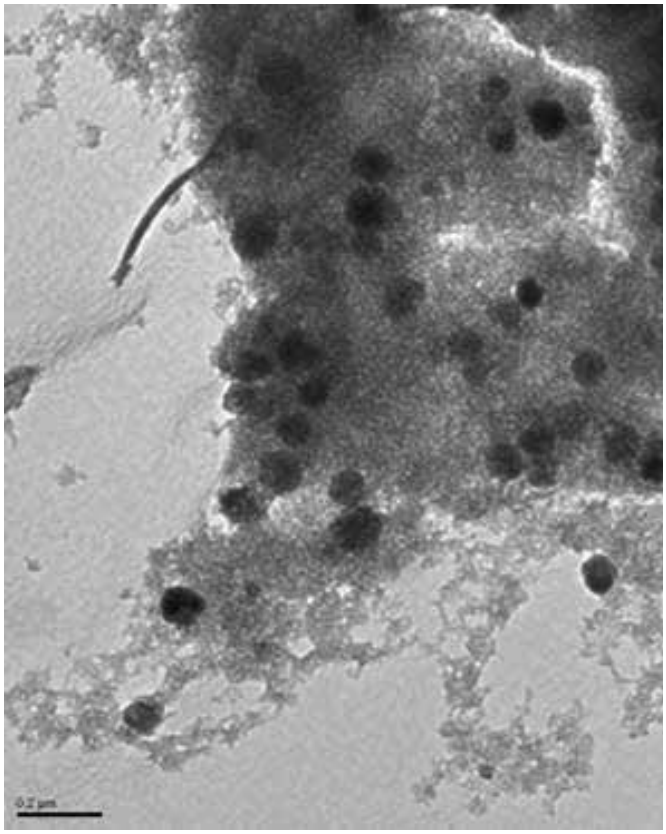
A summary of EARP research

EARP rig at The University of Manchester

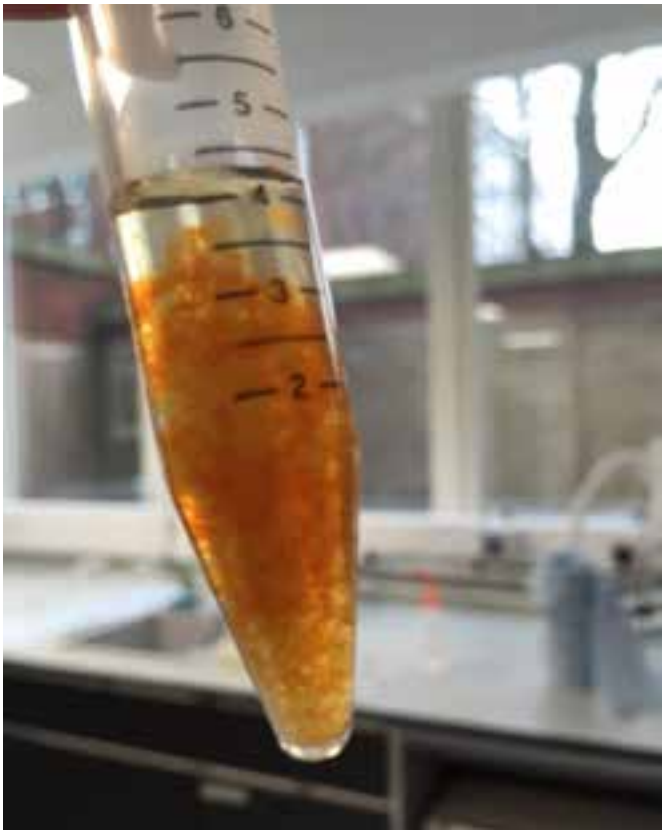
The EARP plant operates by raising the pH of the acidic iron-rich effluent stream to approximately pH 9, inducing precipitation of a ferric iron floc. Radionuclides such as americium, uranium and plutonium become associated with the floc via a range of sorption mechanisms and thus removed from the aqueous phase. This floc is then dewatered by ultrafiltration and encapsulated for long-term storage. The research at The University of Manchester has utilised a novel, bench-scale rig to mimic the EARP processes in the lab.

Evidence from the Sellafield site suggests that the ferric floc forms between pH 2 and 3 during the caustic dosing process. However, recently published work using small angle X-ray scattering at the Diamond Light Source shows that iron metal centres begin to form nanoparticles at very low pH (0.1 – 1), much earlier in the process than previously thought. This has led to an improved understanding of the abatement of americium on site.

The academic research has greatly improved understanding of the floc's physical and chemical properties. X-ray diffraction shows that, initially, a poorly crystalline ferrihydrite phase forms and over time this transforms into a mixture of hematite and goethite, which could be filtered differently. Low levels of non-active components in the feed can slow or completely halt this transformation process and work is ongoing to define these systems more fully.

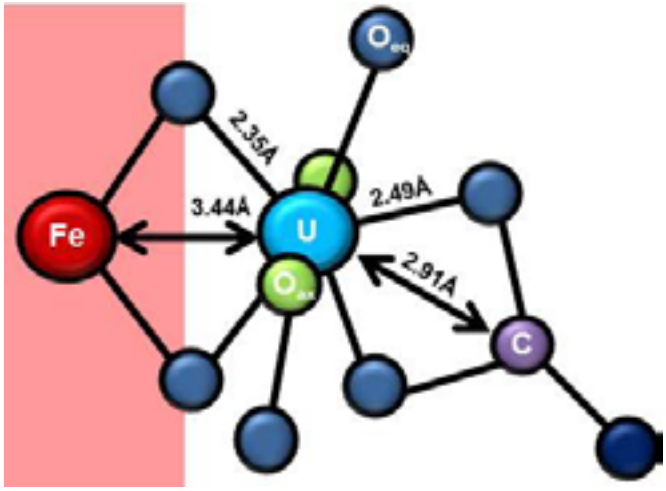


Ferrihydrite with hematite particles

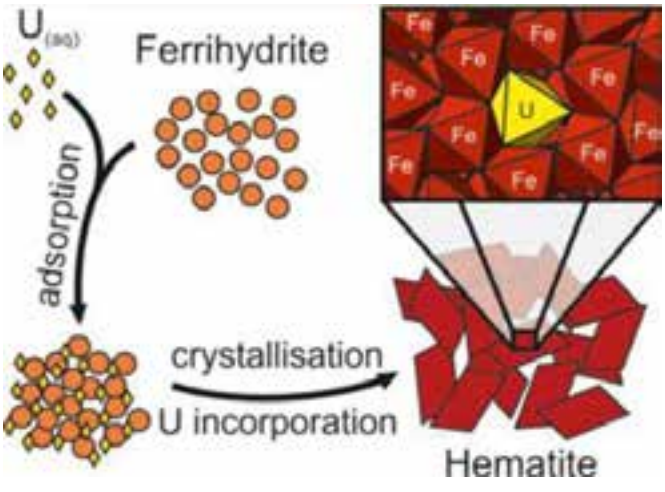


Ferric floc

It is now known that uranium is removed in the process initially by chemical association with the floc's surface. With time, however, ageing and crystallisation of the floc results in some incorporation of uranium via bonding within the iron oxide structure. This could be significant in the long term retention of the floc. Further work is planned to study the behaviour of different radionuclides in the treatment process.



Uranium inner sphere sorption to ferrihydrite



Uranium sorption and incorporation

A summary of ponds and silos research

The sludges within the legacy ponds and silos are mainly comprised of corroded magnesium-based fuel cladding, with smaller amounts of uranium fuel present. We now know that this corroded uranium plays an important role in controlling the chemistry of caesium and strontium, key radionuclides in these effluent systems.

Uranium is typically highly insoluble under these conditions and the solution concentration is generally low. However, it can form very small particulates (known as colloids) that remain suspended in solution. These colloids could challenge downstream effluent treatment plant by enhancing the mobility of uranium and other radionuclides, which interact with the colloids. Research is being undertaken to understand their structure, reactivity and the conditions under which they form. Work performed at The University of Manchester using spectroscopic analysis of the colloids in simulated effluents has led to a greater understanding of their structure and highlighted the role played by silica in stabilising these colloidal phases.

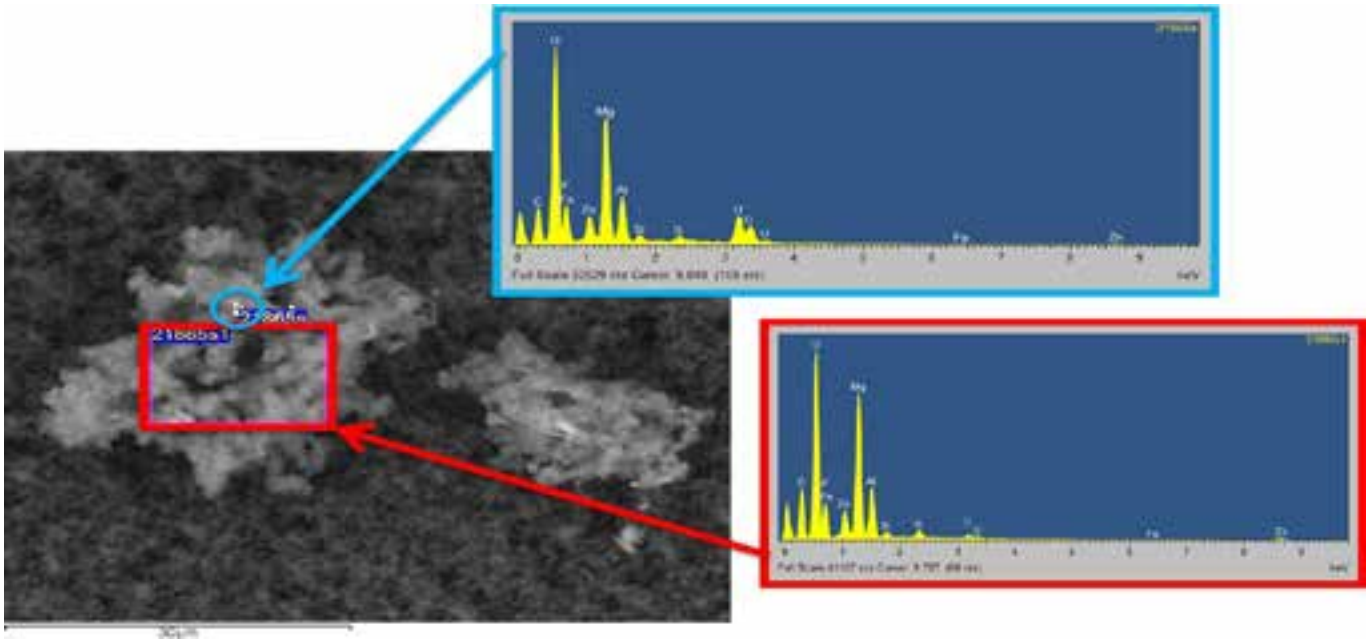


Image of uranium colloid, inset with elemental data

A number of legacy ponds have exhibited seasonal microbial activity, often referred to as “algal blooms” during which visibility within the ponds is impaired, potentially hindering waste retrieval efforts. Previously, little was known about the ponds’ biological content, but a recent DNA sequencing study of samples from the FGMSP at The University of Manchester has indicated the presence of a photosynthesising cyanobacterial species that displays tolerance to radiation and alkaline pH. This knowledge will be crucial in developing approaches for controlling the blooms. The interaction of radionuclides with the microbial cells and their breakdown products has been studied to understand the impact of these biological species on radionuclide abatement in the ponds.

Cyanobacteria found in pond water samples (Courtesy of The University of Manchester’s Dalton Nuclear Institute)

FGMSP contains a range of degraded organic components arising from, for example, leaves, plant matter and bird guano, etc. Experiments using humic material to represent this heavily degraded organic content have shown varied effects on caesium and strontium behaviour, with results being largely dependent on the bulk solid material present and the pH.

Impact of the university link

- The research has already been applied to optimise operations in EARP and ponds and silos.
- Advanced analytical techniques have been accessed via The University of Manchester providing unique insights into fundamental processes which translate into industry challenges.
- New skills and techniques have been developed.
- Publications and research presentations have been generated which raises the profile of the research interaction between Sellafield Ltd and The University of Manchester.
- Continuing research has been awarded and the partnership is continuing.

A research team meeting at The University of Manchester

"Working closely with industrial contacts during my PhD has enabled me to investigate underlying scientific concepts whilst still being able to keep my project relevant to industry."

Researcher Ellen Winstanley

"Having been able to visit the Sellafield site and meet with key people has enhanced my understanding of the issues Sellafield faces, and the wider context in which my research sits."

PhD Student Hollie Ashworth

"As a PhD student it has been exciting and rewarding to see my research being applied to real world scenarios. The opportunity to investigate fundamental scientific processes that are then being integrated into the wider understanding of on-site operations has been a very positive experience."

PhD student Thomas Neill

"The research and skills partnership we have developed has allowed our research teams to gain unprecedented insights into the challenges on site. This has allowed us to tailor our research to provide optimal underpinning information which is directly impacting site operations."

Professor Katherine Morris, The University of Manchester.

"I have been impressed with the advances in knowledge that have been achieved through the close working partnership between Sellafield Ltd, National Nuclear Laboratory and the University".

Luke O'Brien (NNL Laboratory Fellow)

Delivery partners

The University of Manchester, National Nuclear Laboratory

External publications/press releases/web links

Weatherill, J., Morris, K., Bots, P., Stawski, T., Janssen, A., Abrahamsen, L., Blackham, R., Shaw, S. (2016). Ferrihydrite formation: the role of Fe13 Keggin clusters. Environmental Science and Technology, 50(17), 9333–9342. http://dx.doi.org/10.1021/acs.est.6b02481

Contact details

Simon Kellet (Decommissioning Strategy and Technical) simon.kellet@sellafieldsites.com

Luke O'Brien (National Nuclear Laboratory) luke.o'brien@nnl.co.uk

Katherine Morris (The University of Manchester) katherine.morris@manchester.ac.uk

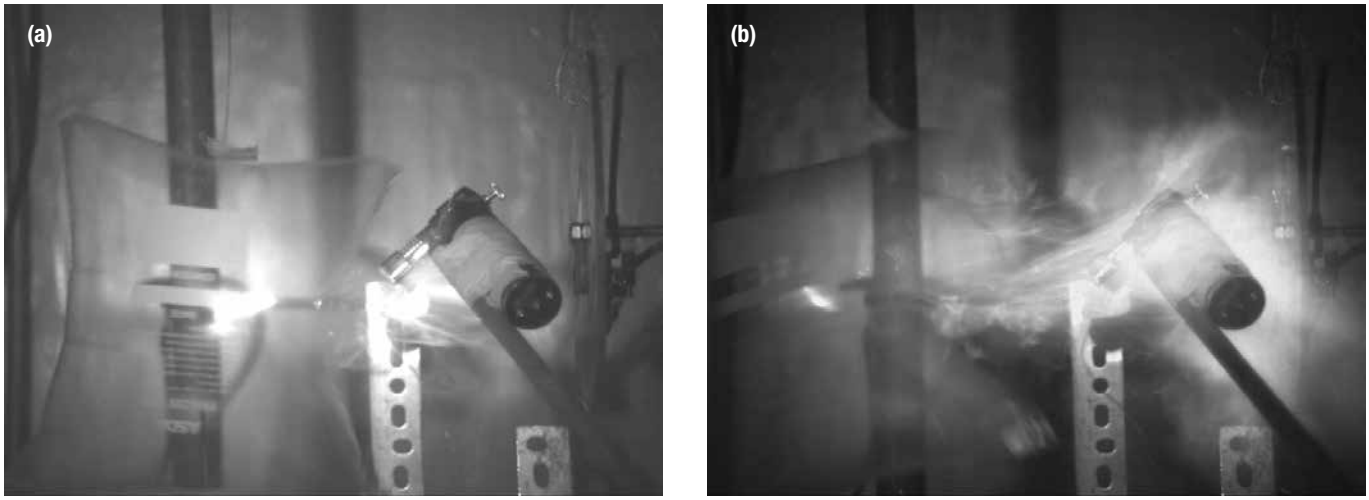
Flammable Gases Centre of Expertise

Hydrogen is generated in many facilities on the Sellafield site and over twenty years ago the Hydrogen Working Party (HWP) was formed to generate common guidance and act as a focal point for advice on hydrogen related issues. The work of the HWP has now been encompassed within the Flammable Gases CoE (FGCoE), led by Phil Vesey. The FGCoE actively collaborates with projects and plants to develop 'fit for purpose' solutions to the many hydrogen (or other flammable gas) challenges and also directs research work with our 'independent experts' at London South Bank University (LSBU) with whom we have a partnership arrangement. We also have close ties and shared memberships with related technical groups particularly the Reactive Metals, Sludge and Radiation Science CoEs. Here are some of research activities that have been carried out this year to support the FGCoE.

Experimental work to improve understanding of the potential consequences of the ignition of small volumes of hydrogen

The delivery of the Sellafield site mission is increasingly requiring operational intervention rather than remote, engineered systems. Increased 'hands on' operations mean that conventional/personal safety management becomes more important and in some cases may become equivalent scale to nuclear hazard. The consequence of exposure to ignition of small volumes of localised flammable hydrogen (for example, leaks or release to air scenarios) is difficult to estimate theoretically and there is little industrial evidence. Experimental test work has therefore been carried out at LSBU, in support of the Sellafield Ltd FGCoE, to better understand the potential consequences of the ignition of small flammable volumes of hydrogen in terms of the near field thermal effects, over-pressures etc.

The experimental test work programme has examined the effect of igniting balloons and plastic bags containing small volumes (a few litres) of flammable hydrogen-air mixtures over a range of different concentrations (including lean, stoichiometric and rich). Explosion tests were filmed with a high speed video camera to allow the effects of the explosion to be analysed. An instrumented space, fitted with thermocouples and a pressure transducer, positioned in close proximity to the ignited hydrogen volume, has also allowed the potential consequences (temperature, pressure wave) of the explosion to be assessed. The thermocouples were used to record any heating effects and allow the potential for burn injuries to be examined. The pressure transducer was used to record the peak pressure levels to allow the effect of explosion overpressure on hearing and risk of hearing damage to be examined.

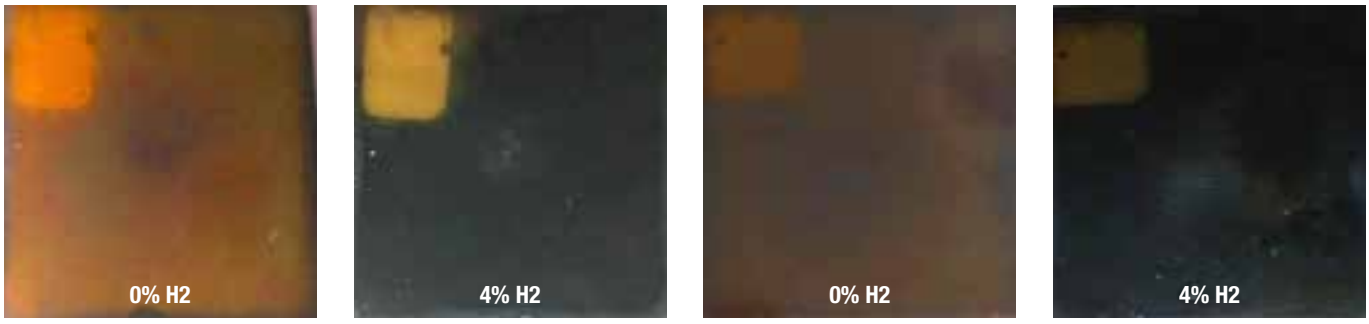


Images illustrating the explosion following the ignition of a small volume of hydrogen in a plastic bag: (a) the ignition source is positioned next to the plastic bag containing hydrogen; (b) the hydrogen mixture in the bag is ignited resulting in an explosion

Development of hydrogen sensitive coatings for nuclear safety applications

The detection of hydrogen gas is essential in ensuring the safety of nuclear plants. However, events at Fukushima Daiichi Nuclear Power Plant highlighted the vulnerability of conventional detection systems to extreme events, where power may be lost. Herein, chemochromic hydrogen sensors have been fabricated using transition metal oxide thin films, sensitised with a palladium catalyst, to provide passive hydrogen detection systems that would be resilient to any plant power failures. The Pd-V2O5 thin film sensors were synthesised via sol-gel deposition of V2O5 followed by electron beam deposition of palladium catalyst. To assess their viability for nuclear safety applications, these sensors have been gamma-irradiated to four total doses (0, 5, 20, 50 kGy) using a cobalt 60 (Co-60) gamma radioisotope at the Dalton Cumbrian Facility. Optical properties of both un-irradiated and irradiated samples were investigated using UV-Vis diffuse reflectance spectrometry to compare the effect of increased radiation dose on the sensors resultant colour change. The results suggest that gamma irradiation, at the levels examined (>5 kGy), has a significant effect on the initial colour of the thin films and has a negative effect on the hydrogen sensing abilities. The rate of colour change on exposure to 4% hydrogen decreases as the gamma ray dose is increased from 5 kGy to 50 kGy which suggests that irradiation generates defects in the bulk structure of V2O5 altering the gas-sensing abilities of the films. A paper describing this work is going to be presented in September 2017 at the International Conference on Hydrogen Safety in Hamburg.

Co60 gamma irradiator and inner chamber (Dalton Cumbrian Facility)



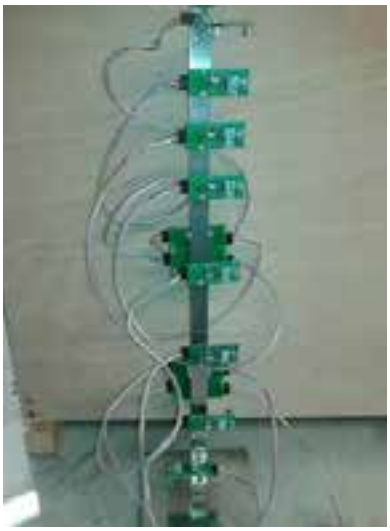
Images of un-irradiated and 50 kGy irradiated Pd-V2O5 thin films before and after exposure to 4 % H2 for 30 minutes

Passive ventilation of small scale enclosures

Developments in hydrogen fuel cell technology will see their future use in many environments and locations. Low power fuel cells will be housed in small protective enclosures, which must be ventilated to prevent a build-up of hydrogen gas, produced during normal fuel cell operation or a supply pipework leak. Hydrogen gas safety is also an issue in the nuclear industry where hydrogen can be generated via radiolysis and/or corrosion in enclosures containing nuclear waste (for example storage liners and boxes) and must be reliably removed to prevent it accumulating and reaching a flammable concentration. Mechanical ventilation is effective at managing enclosure hydrogen concentrations, but it drains power and is vulnerable to failure. In many applications (e.g. low power and remote installation) this is undesirable and reliable passive ventilation systems are preferred.

Passive ventilation depends upon buoyancy driven flow, with the size and shape of ventilation openings critical for producing predictable flows and maintaining low buoyant gas concentrations. Environmentally installed units use louvre vents to protect the fuel cell, but the performance of these vents compared to plain vertical vents is not clear. Research is being carried out into relative performance of passive ventilation arrangements including plain and louvre vents (to date, experimental work has shown that louvre vents increase average enclosure hydrogen concentrations by approximately 10% across the leak range tested). The experimental data are also being used to validate a CFD (computational fluid dynamics) simulation model to enable performance of other designs to be evaluated. A paper describing this work will be presented in September 2017 at the International Conference on Hydrogen Safety in Hamburg.

Enclosure test rig



Sensor stack

The experimental assessment of buoyant gas flow through gaps between stacked boxes for AILWA

A significant programme of experimental work has also been carried out at LSBU on behalf of the Sellafield Ltd AILWA (alternative intermediate level waste approach) project to investigate passive venting of a buoyant gas (see the article entitled: Alternative intermediate level waste approach for managing Magnox Swarf Storage Silos waste - hydrogen management in Site decommissioning and remediation).

Delivery partners

London South Bank University, Dalton Cumbrian Facility

Contact

Phil Vesey (Technical Manager PFCS) phil.vesey@sellafieldsites.com

Paul Holborn (Research Fellow, LSBU) holborpg@lsbu.ac.uk

Jim Ingram (Research Fellow, LSBU) ingramja@lsbu.ac.uk

Sludge Centre of Expertise

During 2016/17, the Sludge CoE continued to operate as a joint technical and engineering centre acting as a hub for the dissemination of experience across Sellafield Ltd. In particular as sludge retrieval activities accelerated during the year the sludge centre worked collaboratively with the Effluents CoE in sharing learning from experience associated with FGMSP operations.

The CoE continued to use the Sludge and Slurry Working Group to engage with both the commercial and academic supply chains with organisations presenting information about their capabilities both as part of routine meetings and in special interest days; in 2016/17 cross centre engagement days were held on analysis and process instrumentation.

The University of Leeds, as our academic partner, continued to provide independent advice to the work of the centre whilst continuing to develop the academic understanding of Sellafield Ltd needs. This partnership enhances the fundamental research work being hosted at the university and the undergraduate teaching and Sellafield Ltd is seeing the benefits in the quality of applicants and recruits from Leeds.

The Sludge CoE participates in a number of research activities, for example:

- A collaborative R&D programme with the University of Leeds and MMI Engineering Ltd to develop an acoustic backscatter technology. This equipment is now being deployed on plant as the last stage of its development. Part of the university contribution to this is a PhD project.
- A DISTINCTIVE PhD on gas hold up in weak sludge is now reaching a conclusion and is informing current discussions on skip fill levels for Magnox Swarf Storage Silos (MSSS) retrievals and raw waste storage (the DISTINCTIVE programme is discussed in this chapter).
- Supporting the MSSS programme in developing a risk mitigation plan for hydrogen release (hydrogen management is discussed in this chapter).
- The SIXEP Contingency Plant (SCP) study is currently attempting to resolve the appropriate design conditions for slurry transfers that need to have different conditions to the current SIXEP equivalents. Current design guidance and literature papers are recognised as inadequate and a proposal to resolve this and provide a suitable operational regime is being developed in consultation with the University of Leeds (building on work done as part of the CoE link and DISTINCTIVE research) and the Modelling and Simulation CoE.

Delivery partners

AMEC Foster Wheeler, MMI Engineering Ltd., National Nuclear Laboratory, NSG Environmental Limited, University of Leeds (direct and via the DISTINCTIVE consortium)

Contact

Geoff Randall (Sludge CoE Lead)
Geoff.x.randall@sellafieldsites.com

Martyn Barnes (Sludge CoE)
martyn.g.barnes@sellafieldsites.com

Acoustic backscatter prototype unit (courtesy of the University of Leeds)

Acoustic backscatter commercialised unit (courtesy of the University of Leeds)

Acoustic backscatter transducer deployment array - transducer mounts developed by James Fisher Nuclear Ltd.

Acoustic backscatter transducer deployment array

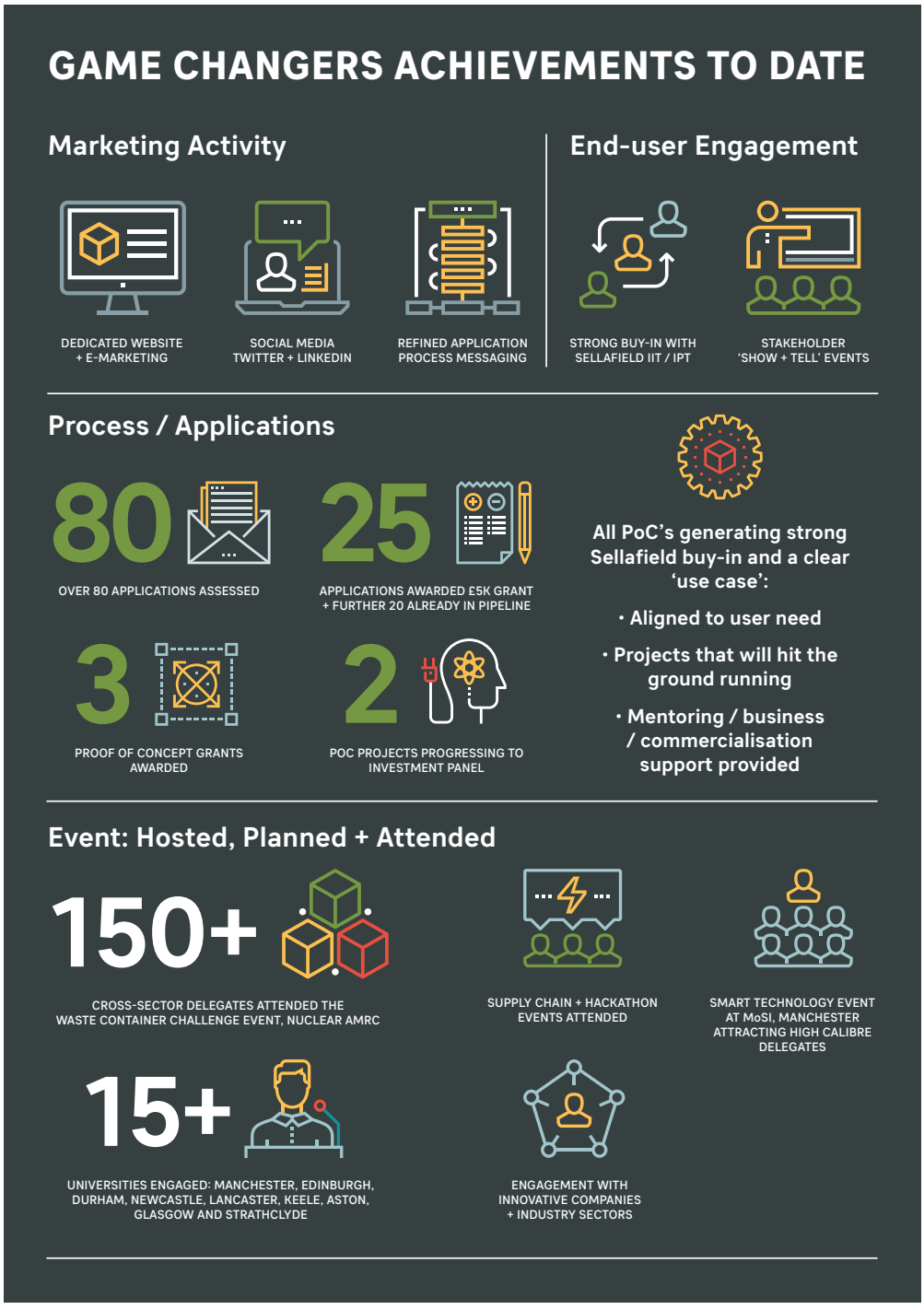
Game Changer programme

Working in collaboration with Sellafield Ltd and building on the success of its programme, Innovus invites proposals, from businesses, academia and individuals, for "Game Changers" – new ideas and technologies which can reduce cost, risk and make operations safer whilst accelerating the safe delivery of decommissioning.

There are 6 stages to the application process with guidance and feedback available throughout and more information can be found on the website at:
http://www.gamechangers.technology/

Delivery partners
Game Changers is delivered on behalf of Sellafield Ltd by the Innovus programme managed by the National Nuclear Laboratory and supported by FIS360.

Contact
Andrew Cooney (Strategy & Technical) andrew.s.cooney@sellafieldsites.com



Game Changer achievements for 2016/17

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.

Our 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).

More than 100 tonnes of plutonium dioxide are stored at Sellafield. Our storage of plutonium programme brings together the activities, facilities and associated facilities that produce plutonium dioxide and those that will be required to treat and/or repackage plutonium product and residues to facilitate the safe ongoing storage of the stock of civil plutonium at Sellafield.

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:

- Magnox container ullage performance investigation
- Lead container trials enabling pH 9 dosing of Thorp Receipt and Storage
- PuO_2 analysis performed at the National Nuclear Laboratory Central Laboratory in support of plutonium storage and retreatment
- The Meteor Monte Carlo nuclear criticality code

Magnox container ullage performance investigation

Magnox fuel is stored in containers within the Fuel Handling Plant (FHP). To minimise pond water activity the container's contents are isolated from the bulk pond water using a barometric seal provided by nitrogen in the ullage. This ullage needs to be maintained periodically and R&D is underway to understand how long it lasts and what happens when it is deteriorates, current information indicates that it lasts at least 2 years.

Magnox containers were tested in a ~50m^3 water tank within the James Fisher Nuclear Ltd facility in Egremont. The containers were set up within the tank with a nitrogen ullage in each; these were then dosed with sodium carbonate to raise the conductivity. The nitrogen ullage was then removed and the container liquor allowed to diffuse into the tank. Readings were taken to determine the conductivity within the container and the tank and it was shown that equilibrium between the two was reached after 6 days.

Understanding the deterioration of the ullage is important so that it can be replenished during storage. The experiments were undertaken to determine how quickly 'activity' could diffuse out of the container and into the bulk pond water in FHP in the event of a loss of the barometric seal provided by the nitrogen in the ullage. This project commenced in April 2014 and was completed in March 2017.

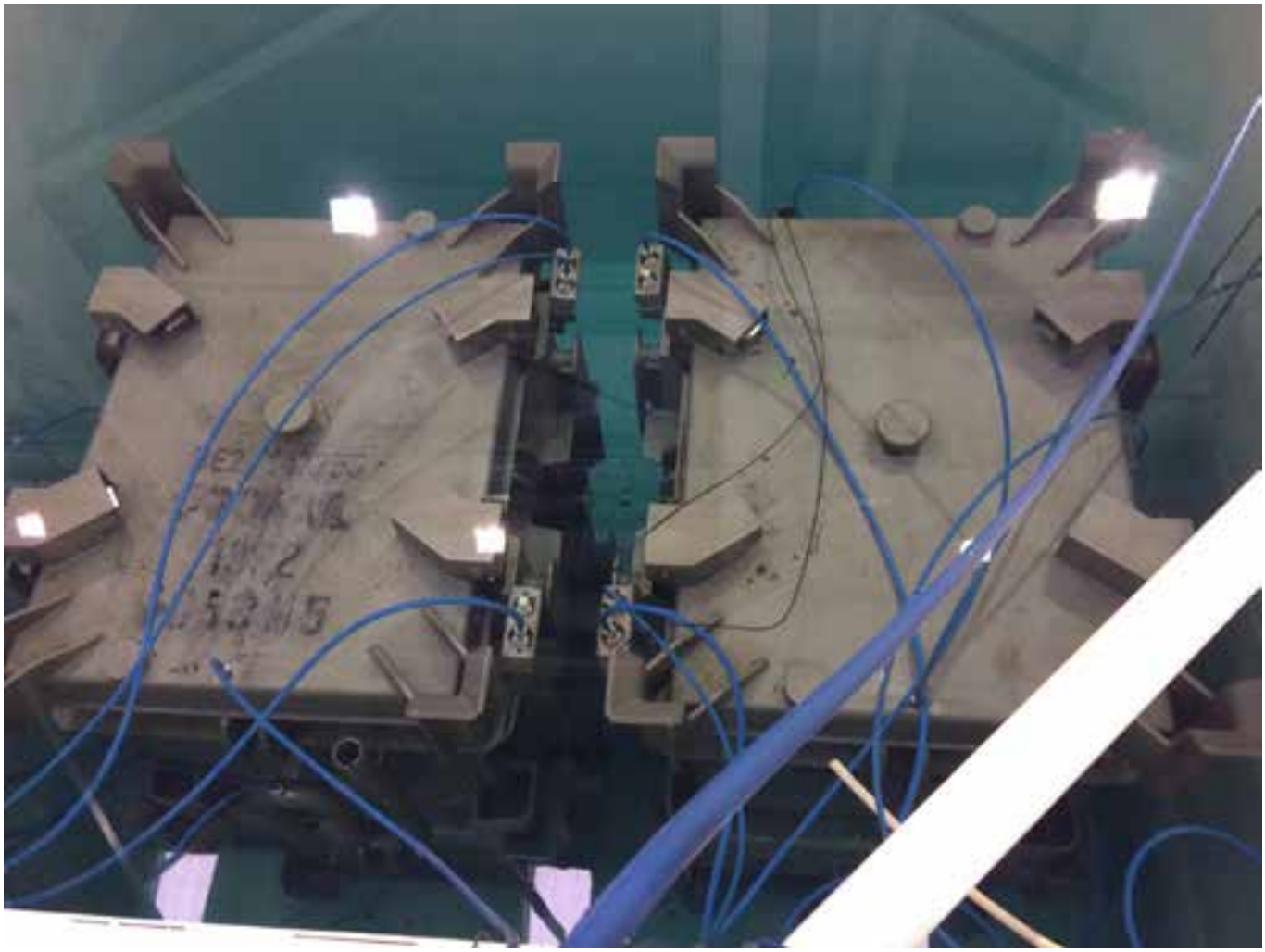
Delivery partners

James Fisher Nuclear Ltd.

Contact

Andy Hillier (SFM Ponds Technical Manager)
andy.p.hillier@sellafieldsites.com

John Rowley (SFM Ponds Technical)
john.d.rowley@sellafieldsites.com



Magnox container within the water tank

Lead container trials enabling pH 9 dosing of Thorp Receipt and Storage

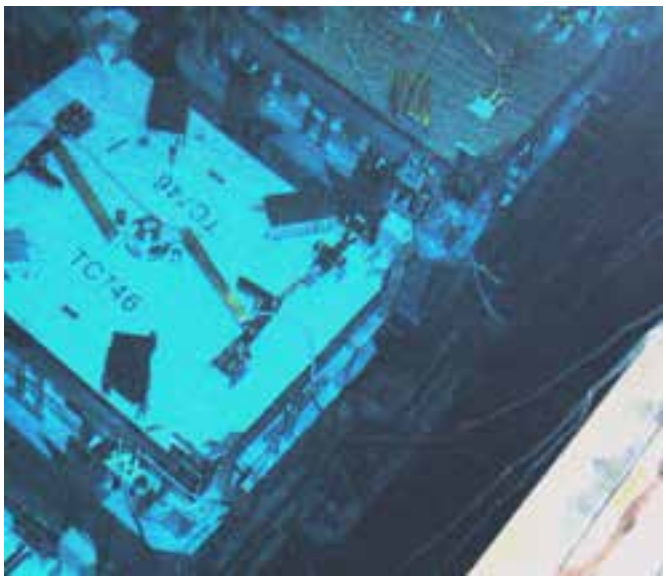
In 2018 Thorp Receipt and Storage (TR&S) pond will change from a buffer storage pond for fuel awaiting reprocessing, to an interim storage facility for AGR fuel pending disposal in the GDF. This will extend the pond storage time of fuel from ~5 years to up to 80 years. In order to ensure that the fuel will remain intact for that storage period a substantial programme of work has been conducted to understand corrosion and corrosion inhibitors. The optimum conditions for corrosion inhibition has been shown to be pH 11.4, however, pH greater than 10 causes corrosion of the Boral (boron carbide aluminium) components needed for LWR (Light Water Reactor) fuel storage. To ensure that the AGR fuel in storage has some protection from corrosion until the Boral components are either removed, or isolated in the pond, an alternative inhibitor is necessary.

An experimental programme of work was undertaken by Sellafield Ltd to investigate an alternative inhibitor using a set of isolated 'lead containers' within TR&S. These contained real fuel susceptible to corrosion. The containers were dosed with chloride to promote corrosion and an inhibitor. The trials demonstrated that use of sodium hydroxide dosing to pH 9 provided a high level of resistance to corrosion and in May 2016 dosing to this pH commenced in TR&S. This approach is now providing protection of fuel stocks ready for the change to interim storage in 2018.

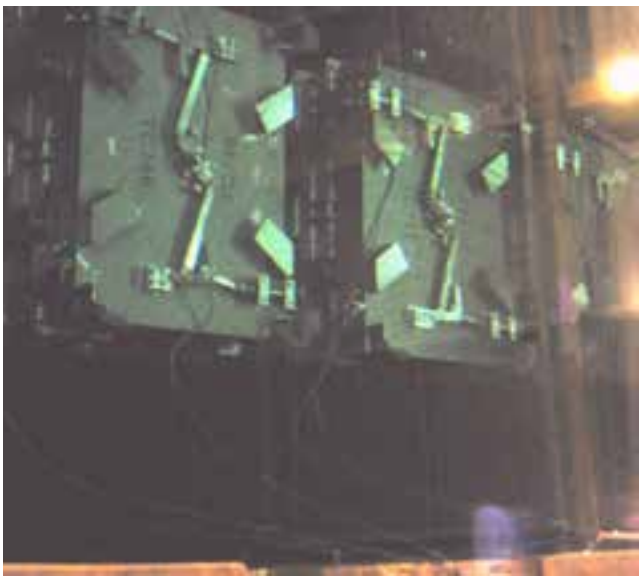
Contact
Sandra Clarke (SFM Ponds Technical)
sandra.a.clarke@sellafieldsites.com

Alex Ledger (SFM Ponds Technical)
alex.ledger@sellafieldsites.com

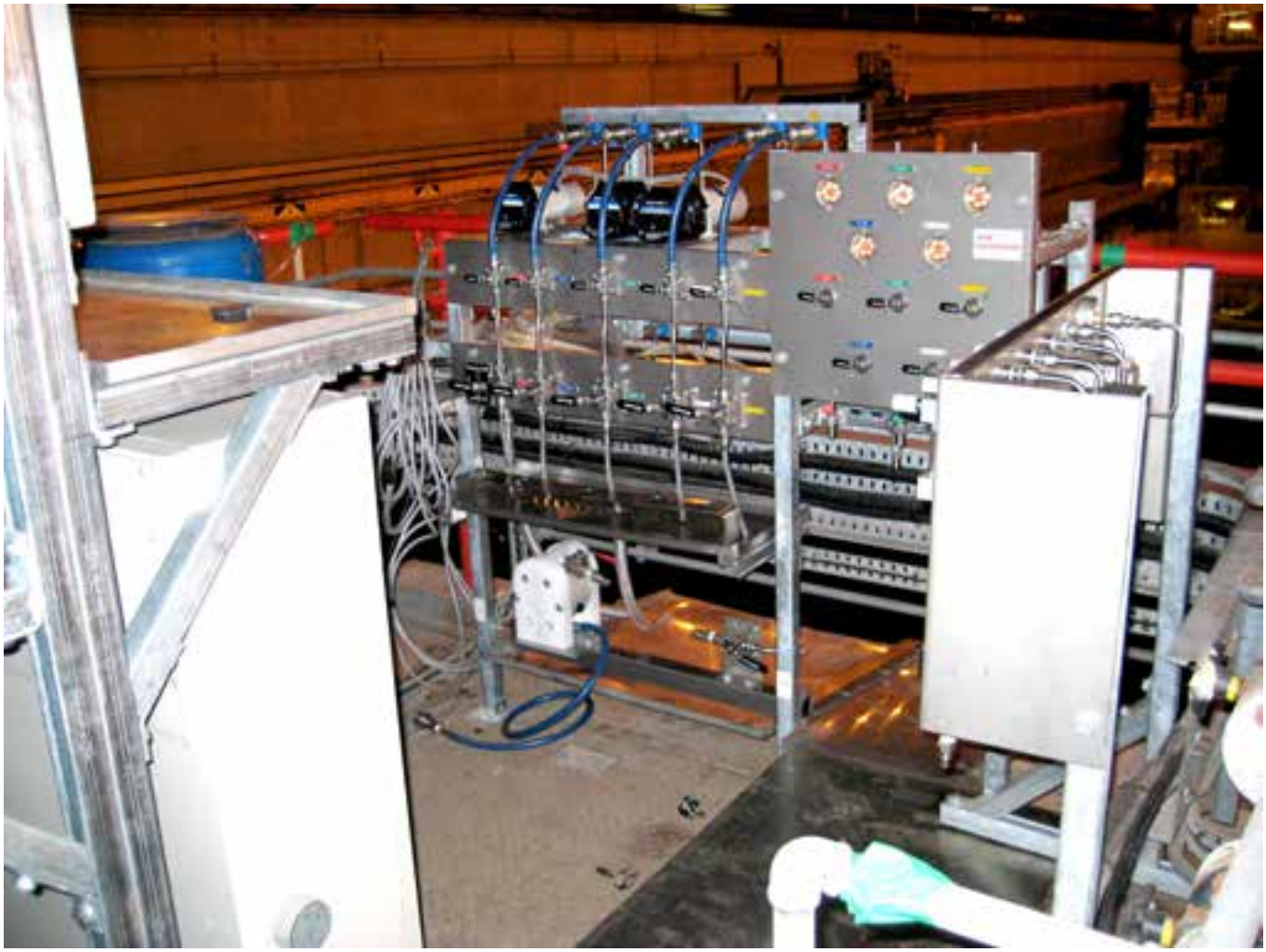
Pond hall



Containers



Container hosed up



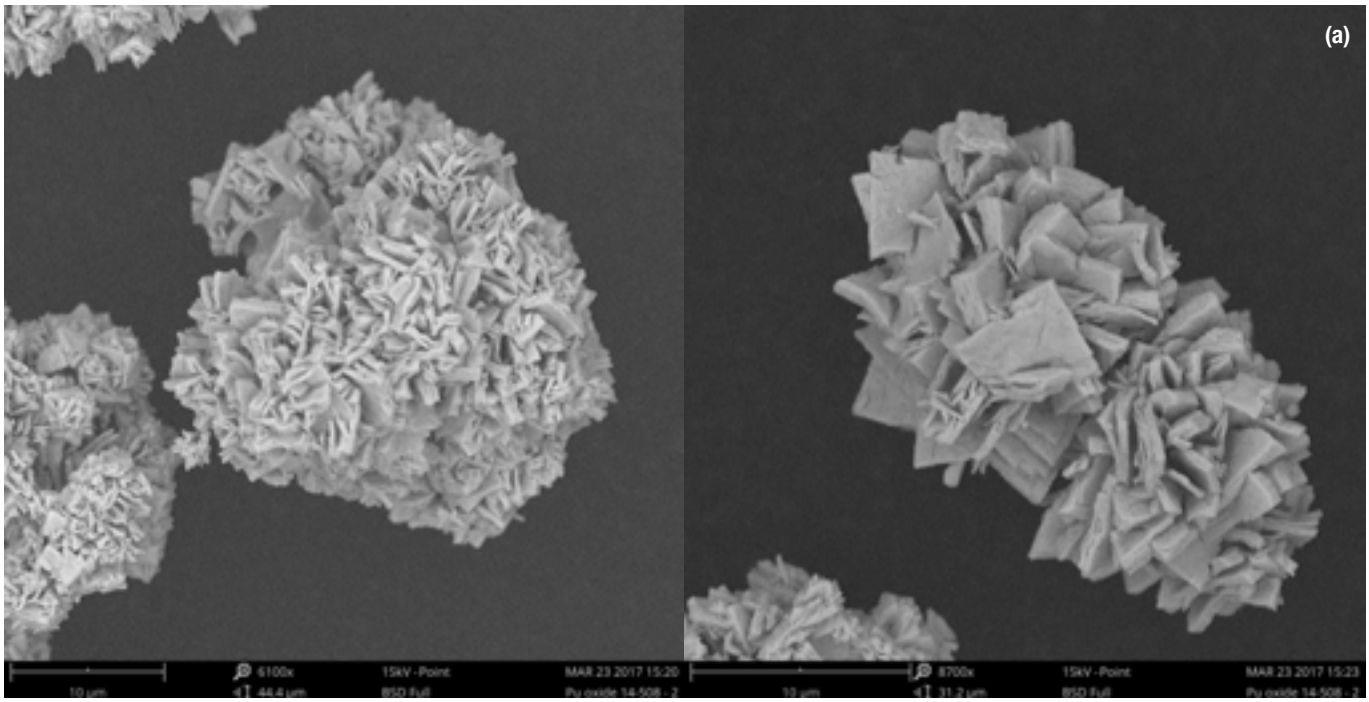
Control panel

PuO_2 analysis performed at the National Nuclear Laboratory Central Laboratory in support of plutonium storage and retreatment

PuO_2 powder has been stored on the Sellafield site for up to 40 years; over this time radioactive decay will have been ongoing with associated changes to the PuO_2 powder. To ensure the continued safe storage of the PuO_2 it is essential to understand the initial powder properties and how storage to date may have altered those properties.

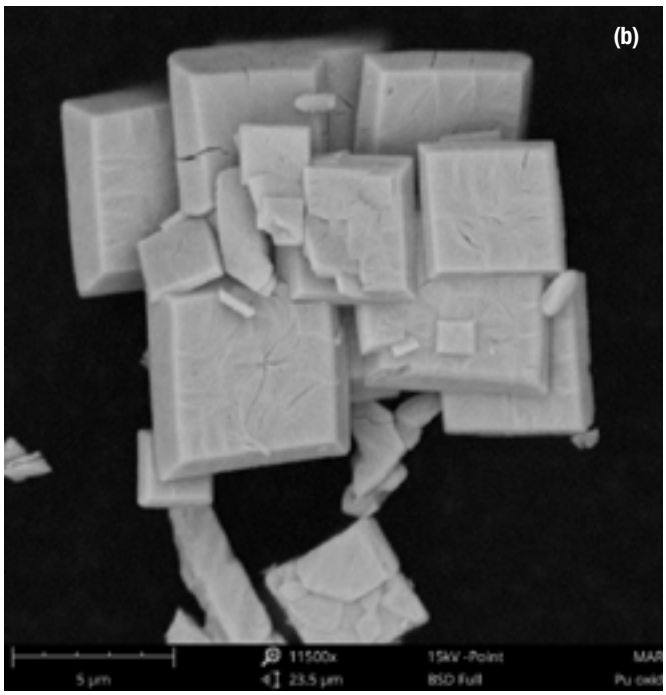
The method of powder processing and the relative stability of the different crystal cleavage planes dictate the morphology of the powder. Consequently changes to the powder morphology can be an indication of changes in surface expression, surface chemistry and associated surface areas.

A large tranche of the PuO_2 powder across the Sellafield site has never been thoroughly characterised due to lack of alpha active analytical techniques at Sellafield. Sellafield Ltd in collaboration with the National Nuclear Laboratory have funded the installation and commissioning of a Scanning Electron Microscope (SEM) at the Central Laboratory. The National Nuclear Laboratory has undertaken work to study the different morphologies of the PuO_2 powders stored across the site to create a catalogue of PuO_2 SEM images which will enable an informed position to be established on changes that have occurred as a result of long-term storage.

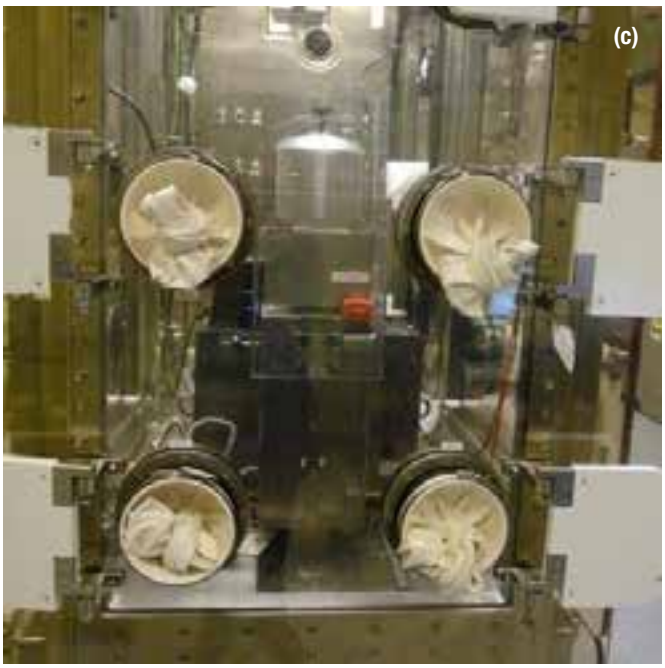


(a) SEM images obtained for low surface area PuO_2 that was prepared by calcination of Magnox PuO_2 at 950°C in an air atmosphere at two different magnifications.

Analysis of the SEM image can be used to calculate the particle agglomeration sizes. A subset of PuO_2 material stored on the Sellafield site has been contaminated by chloride and it is a requirement to remove this to ensure continued safe storage (See the 2015/2016 Technical Development and Delivery Summary for further information). SEM images of the "as received" chloride contaminated material are shown in (b), it is interesting to observe that the chloride contaminated material with respect to the low specific surface area (SSA) uncontaminated PuO_2 material (a) has less angular particles with the edges appearing to be rounded off.



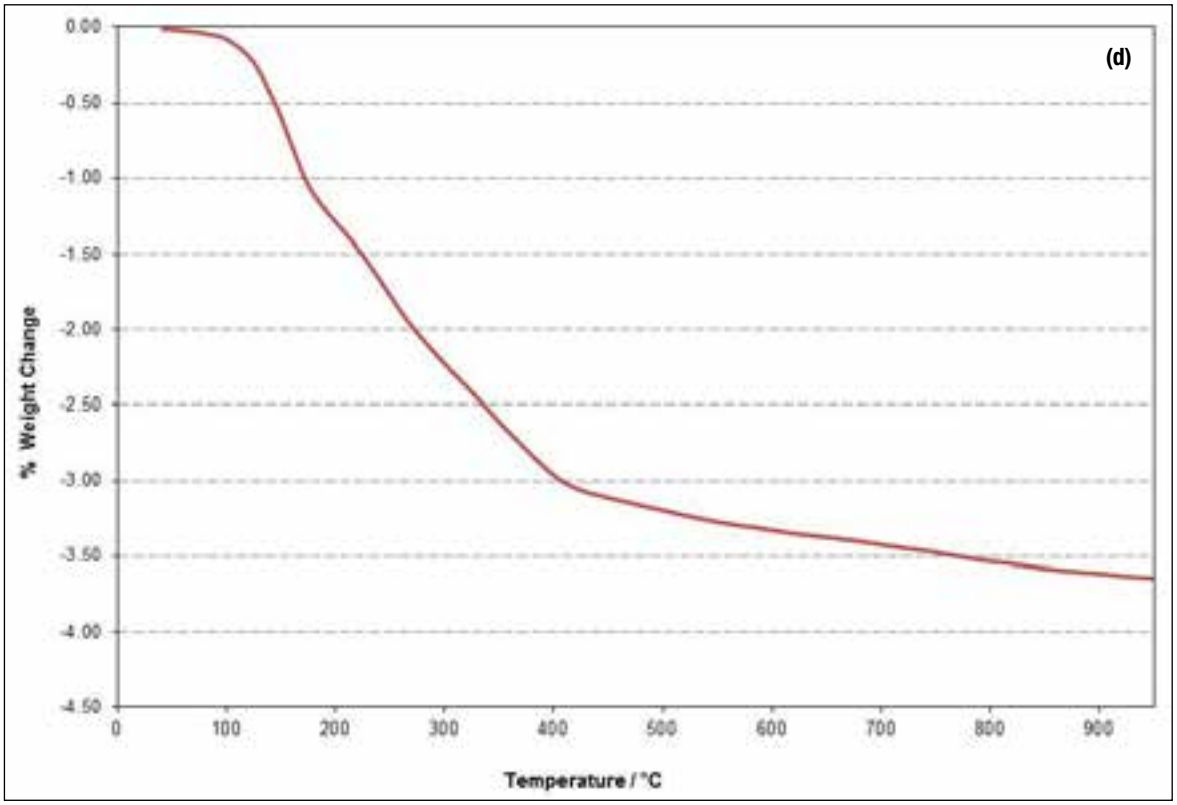
(b) SEM image of untreated Cl contaminated PuO_2



(c) Setaram TG92-18 thermobalance in a glovebox at NNL Central Laboratory

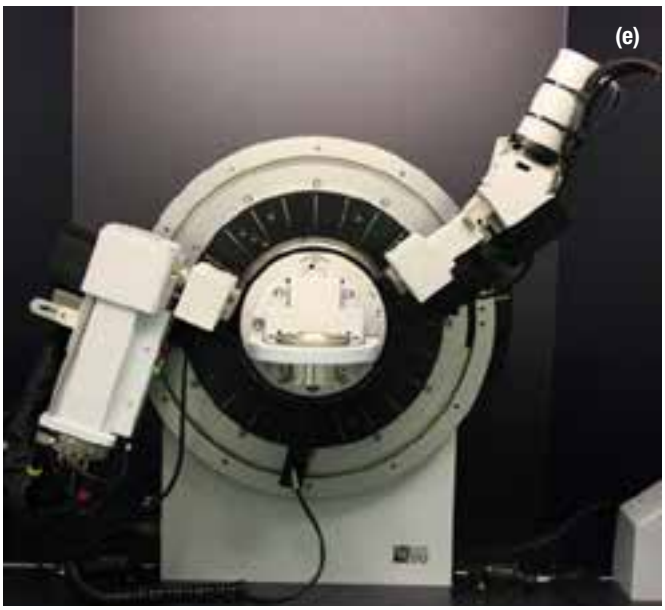
Radioactive decay during storage results in the self-heating of the PuO_2 material. Subsequently there is desorption of moisture and adsorbed gases from the PuO_2 powder surface into the internal gas space of the package. Certain contaminants and background gases can perturb or even dominate the desorption characteristics. To enable accurate prediction of gas pressures within PuO_2 storage packages, to prevent over-pressurisation, it is essential to understand the thermally driven desorption characteristics of standard production, long-stored and contaminated PuO_2 material. A Setaram TG92-18 thermobalance has been installed in the Central Laboratory (c) for thermo-gravimetric analysis (TGA) under a variety of gas atmospheres (including inert, oxidising and reducing atmospheres).

The graph below (d) shows gas desorption in terms of mass loss from the surface as a function of the PuO_2 powder temperature. It can be seen that ~50% of adsorbed mass is removed to the gas phase for a powder surface temperature of 300°C and nearly 80% for a powder temperature of 500°C.

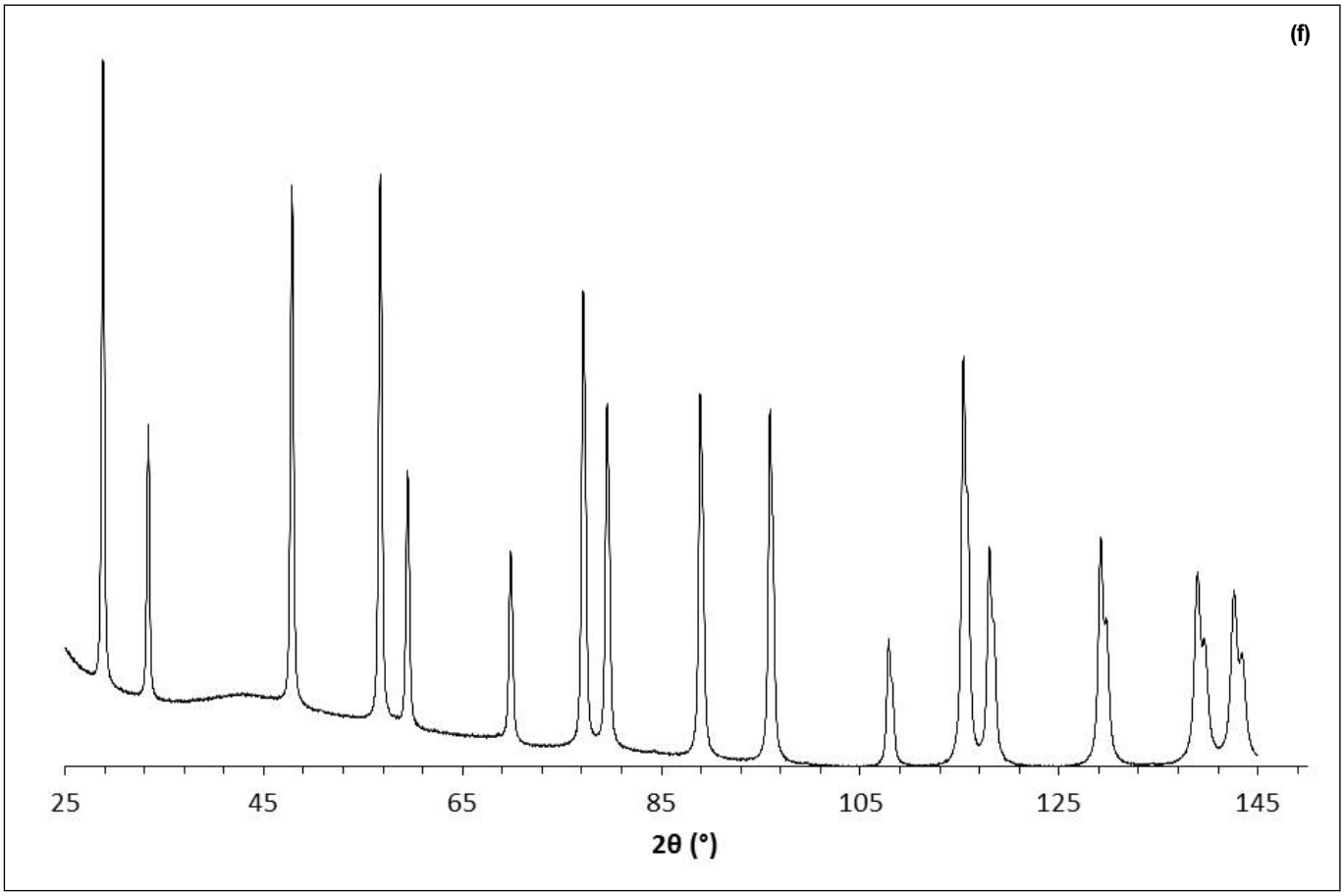


(d) TGA analysis of a PuO_2 sample exposed to a glovebox air atmosphere showing % weight change as a function of temperature

Radiation damage within the PuO_2 can perturb the crystal structure which can be monitored through changes to the lattice parameter, which is very sensitive to changes in the chemistry of the crystalline material. A Bruker D8 diffractometer (e) has been installed in the Central Laboratory and a method developed to ensure the safe analysis of plutonium dioxide powders, and other active materials. Sellafield Ltd recently funded work by the National Nuclear Laboratory to use the powder X-ray diffraction (PXRD) technique to measure the lattice parameters of a selection of PuO_2 material taken from across the Sellafield site.

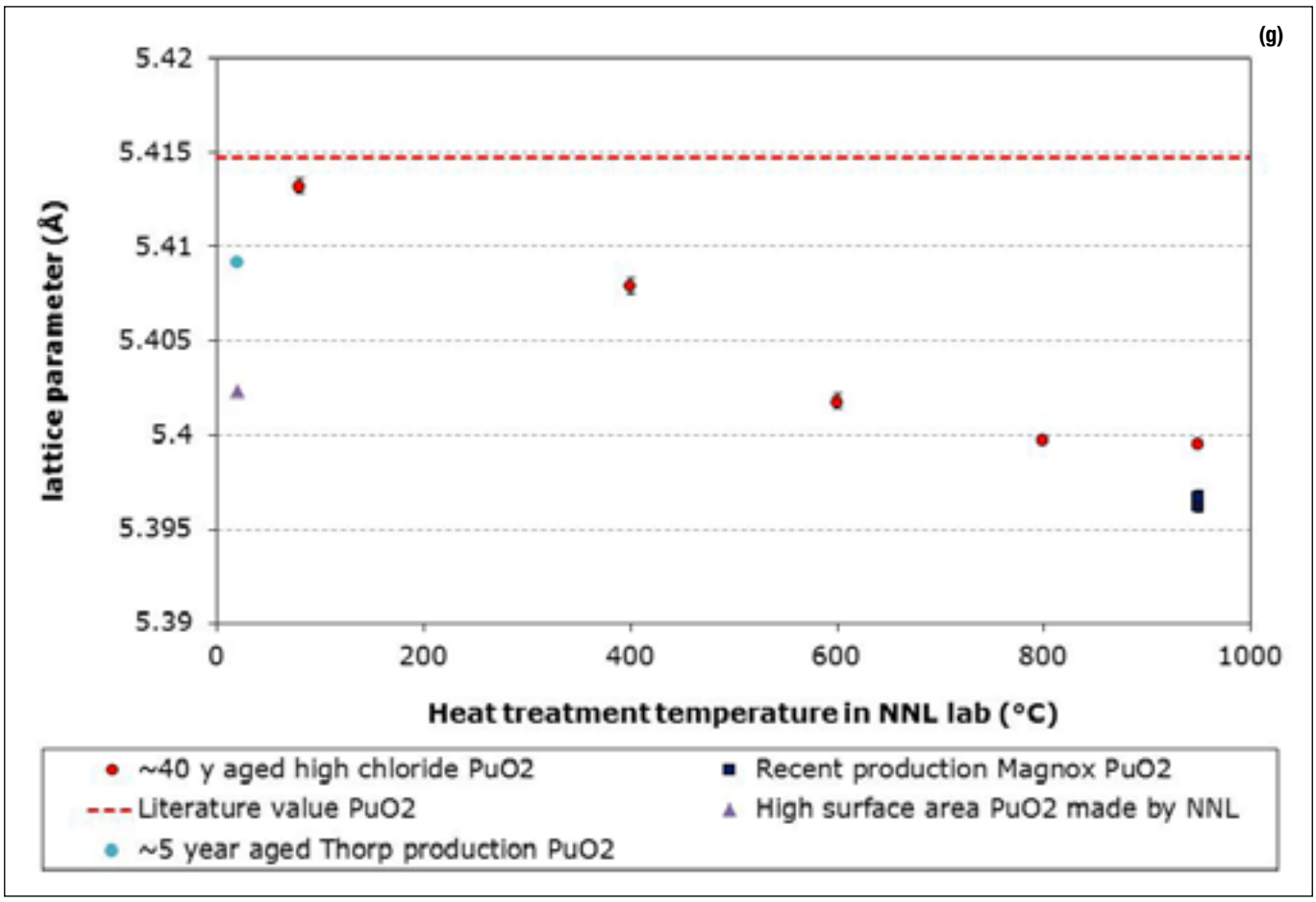


(e) Bruker D8 diffractometer



(f) Example of a PXRD plot of PuO_2 showing the expected Miller plane peaks

The PXRD patterns (f) have been taken for a range of PuO_2 samples and the lattice parameters reported, these are shown in (g).



(g) Measured lattice parameters for a range of PuO_2 samples

The new commissioned plutonium active suite of analytical techniques at the Central Laboratory enables Sellafield Ltd to obtain and collate data from across the extensive range of PuO_2 powders stored on the Sellafield site, enabling informed decisions on ongoing and future safe storage. It is expected that these facilities will be soon complemented by the availability of a glove box configured specific surface area analyser, to further characterise the PuO_2.

Delivery partners

National Nuclear Laboratory

Contact

Paul Cook; Jeff Hobbs; Jon Squire & Helen Steele (PMF Technical, Sellafield Ltd)

Michael Carrott; Colin Gregson; Robin Orr; Mark Sarsfield; Robin Taylor & Ian Vatter (National Nuclear Laboratory)

The Meteor Monte Carlo nuclear criticality code

Nuclear criticality assessment makes use of computer codes to calculate the "multiplication factor" (k-effective) of fissile systems. There is a requirement to ensure continued availability of a criticality code that is validated, underpinned, supported and recognised by all stakeholders so that the criticality safety team can continue to provide fit-for-purpose safety cases for all of the Sellafield Ltd value streams. Meteor has been developed by Sellafield Ltd as a new criticality code to fulfil this role. Meteor differs from previous criticality codes in that it can use computer aided design (CAD) models directly rather than requiring remodelling. However, Meteor remains compatible with the MONK criticality code which has been used, to date, by Sellafield Ltd.

One of the key development objectives for this code was to have a fast cycle for new releases so that updates and bug fixes are released rapidly in response to user requests. This was achieved, with two update releases of Meteor following the initial release in August 2016, and a further one planned for July 2017. Meteor is now in a consolidation phase, having been released to the Sellafield Ltd criticality team who are testing it with the aim of replacing the MONK criticality code. Meteor has already been used to provide additional confidence to a number of criticality assessments within Sellafield Ltd.

The key technical advantages of Meteor are that it provides an independent, portable criticality code that can be easily maintained and which incorporates modern ways of working, particularly centred around CAD. Meteor can use historic models, but also has new features such as Shannon Entropy and extended statistical tests for skewness and kurtosis.

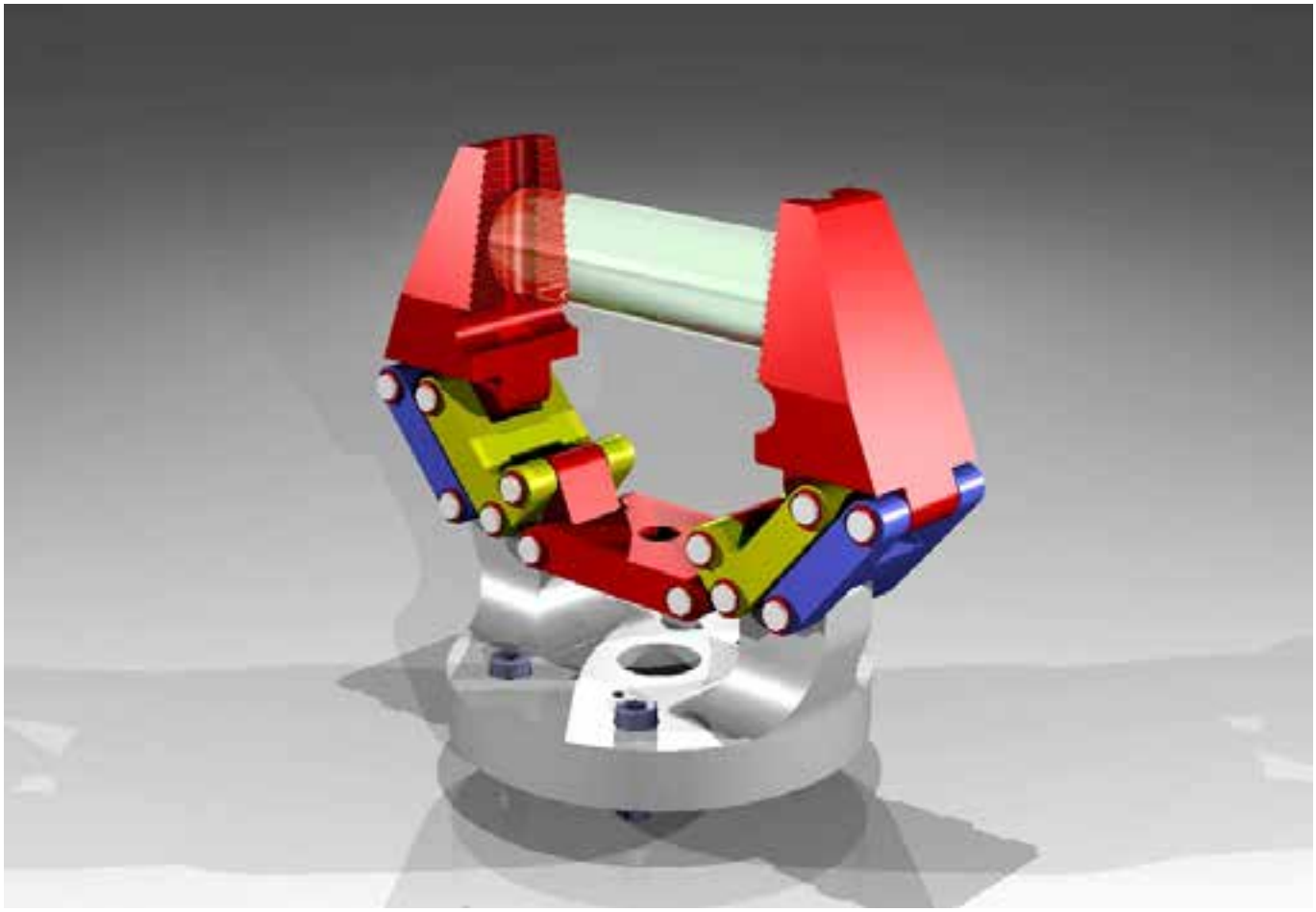
External publications/press releases/web links

Searson, K. et al, (2015), Meteor: CAD, CSG and Woodcock Models, In: Mathematics & Computations (M&C+SNA+MC 2015), Nashville, TN, ANS, pp 269-277.

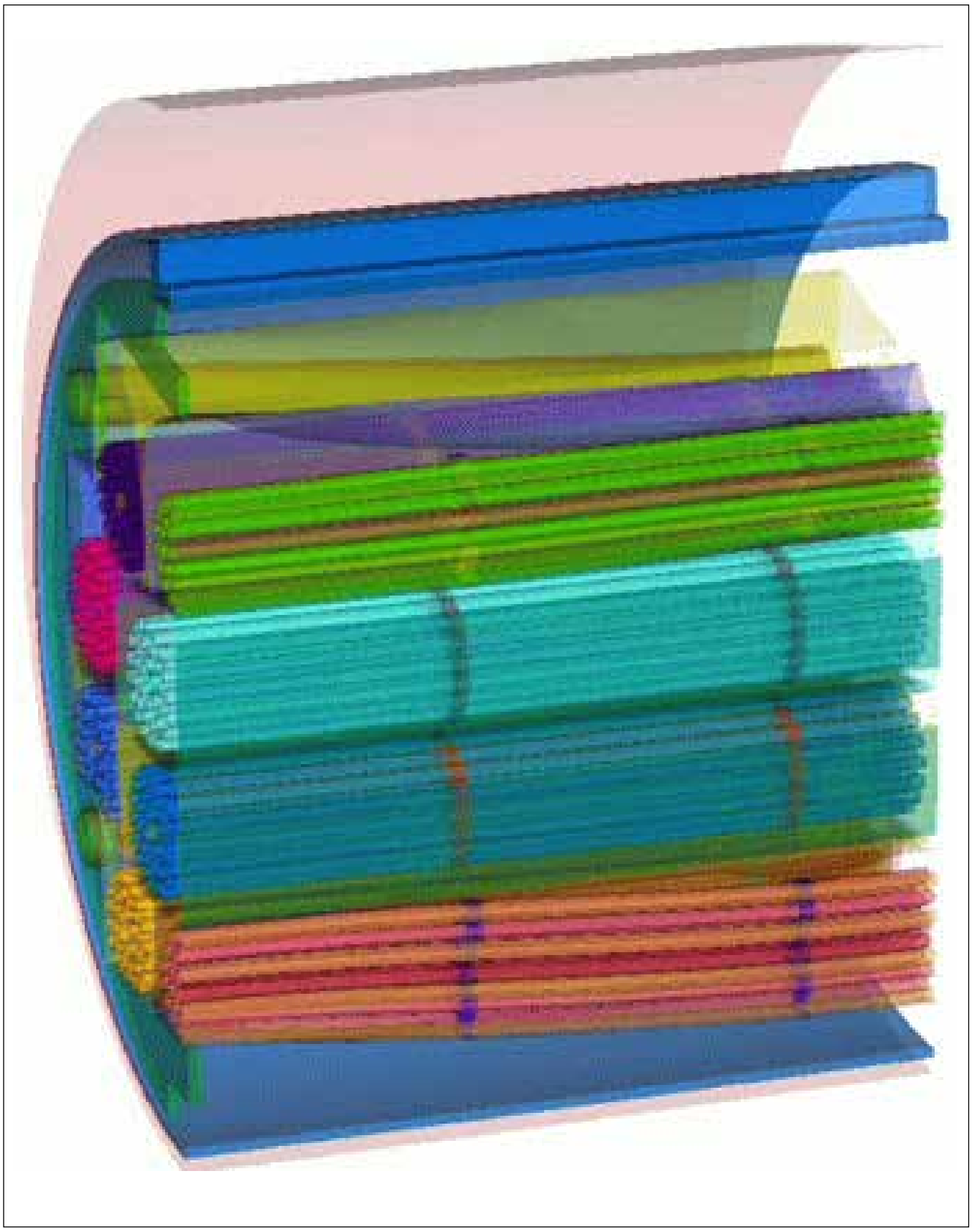
Searson, K. et al, Meteor, a CAD-Based Criticality Code, Trans. Am. Nucl. Soc. 109, pp 709 – 712.

Contact

Paul Hulse (Projects Delivery) paul.hulse@sellafieldsites.com



Model of grab ray-traced in Meteor, showing combination of CAD objects and MONK primitives



CAD model of a deformed fuel flask after impact, Meteor's CAD capabilities make the criticality assessment of this a possibility.

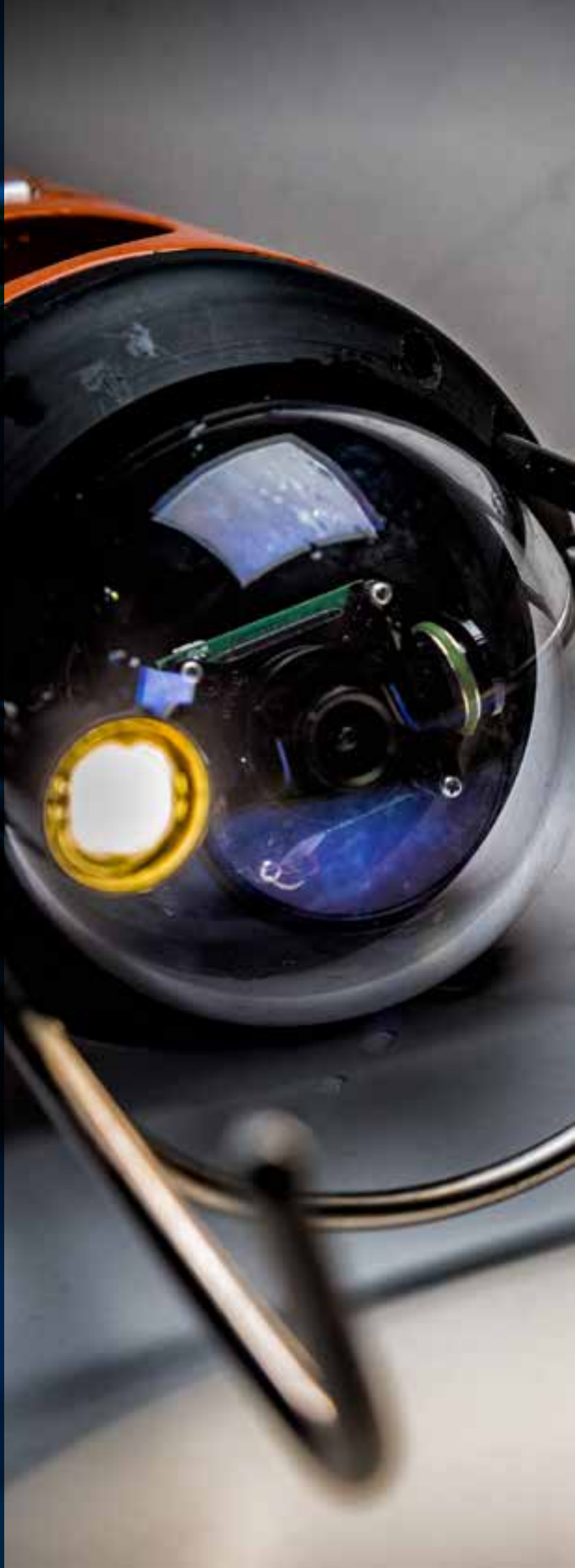
Site decommissioning and remediation

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 2016/17, on a number of R&D programmes to meet these challenges:

- Alternative intermediate level waste approach for managing Magnox Swarf Storage Silos waste
- Magnox Swarf Storage Silos liquor and effluent management
- Pile Fuel Storage Pond dewatering trial: Temporary lowering of the pond level by 23cm for concrete characterisation and decontamination trials
- Research and development to underpin the impact of legacy waste retrievals on the First Generation Magnox Storage Pond effluent stream
- Highly Active Liquor Evaporation and Storage radiometric characterisation
- Gamma imaging for dose mapping
- Unmanned aerial vehicles
- Alpha camera
- Activity depth profiling in concrete
- ViridiScope
- Waste estimation
- AVEXIS: a remotely operated mini-submarine for the exploration of facilities with restricted access
- DEMplus® modelling demonstration
- Strippable coatings and fixatives waste disposability and performance assessment
- MIRRAX: a robotic platform for the deployment of characterisation tools in facilities with restricted access
- LaserSnake2



Alternative intermediate level waste approach for managing Magnox Swarf Storage Silos waste

Introduction

The 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 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 with the waste packages consisting of skips of MSSS waste inside a $3m^3$ box with an internal concrete bund. The interim storage option is now being implemented across the MSSS stream projects, enabling acceleration of MSSS retrievals with earlier risk and hazard reduction and lifetime cost savings (MSSS bulk solid waste and liquor removal is scheduled for 2018-2046). Waste will be routed via the Encapsulated Product Store Waste Transfer Route (EPS WTR) until the Box Encapsulation Plant (BEP) becomes available. The MSSS alternative intermediate level waste approach transitional project is responsible for delivering the new baseline and consists of several key components some of these are presented in this report and will be discussed in turn:

- Understanding the impact of an alternative approach
- $3m^3$ box development
- Assessment of hydrogen release from skips (bubble counting)

Understanding the impact of an alternative approach

The implementation of AILWA will have an impact on several plants and projects within the Decommissioning Directorate and this led to a multi-discipline and multi-programme impact assessment which was carried out during 2016/17. A number of processes were first established, in order to carry out the impact assessment, these were:

- Identifying detailed impacts on individual projects.
- Managing various project impacts and cross-project/ programme interdependencies.
- Managing and communicating change.
- Identifying, sentencing and resolving emerging issues.

In addition, a sub-programme was set up to allow quick issue resolution and decision making. Through the implementation of these processes, a new baseline was established and within 6 months the following was achieved:

- Formal approval of several project functional specifications.
- Agreement for funding, where required, to support all necessary changes.
- Approval for projects to proceed with the new baseline.

The change in strategy was implemented and the new baseline adopted in 2016/17. The next phase of the project will provide detailed underpinning and delivery of the new baseline and processes remain in place to manage any ongoing changes, issues and opportunities.

The impact assessment provided the efficient delivery of a complex change to the business and ultimately identified an overall expected saving of £2.35bn. The process also identified additional opportunities to bring forward the start and end of retrievals by 2 years and 4 years respectively, ultimately providing a significantly safer environment for the waste in one of the most hazardous buildings on the Sellafield site.

Delivery partners
Cavendish Nuclear, DBD Ltd.

Contact
Richard Macnair (MSSS Strategy & Technical)
richard.j.macnair@sellafieldsites.com

$3m^3$ box development

The waste packages will consist of skips of MSSS waste inside a $3m^3$ box with an internal concrete bund. The bund is included in the package 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. Both the skip and box will be fitted with lids that will include filters to manage evolved hydrogen and control water losses. During 2016/17 the MSSS Strategy & Technical Team focussed on the following tasks:

- Construction material for the skip, box and lids.
- Filters, seals and bund materials and performance.
- Hydrogen management.

Construction material for the skip, box and lids

The aim of this task was to assess the suitability of material for construction of the box, skip and their lids by setting corrosion trials for the evaluation of pitting, crevices, welds and up to 4 weld repairs as well as other fabrication techniques likely to be used in the manufacture. During 2016/17, three phases of work were completed:

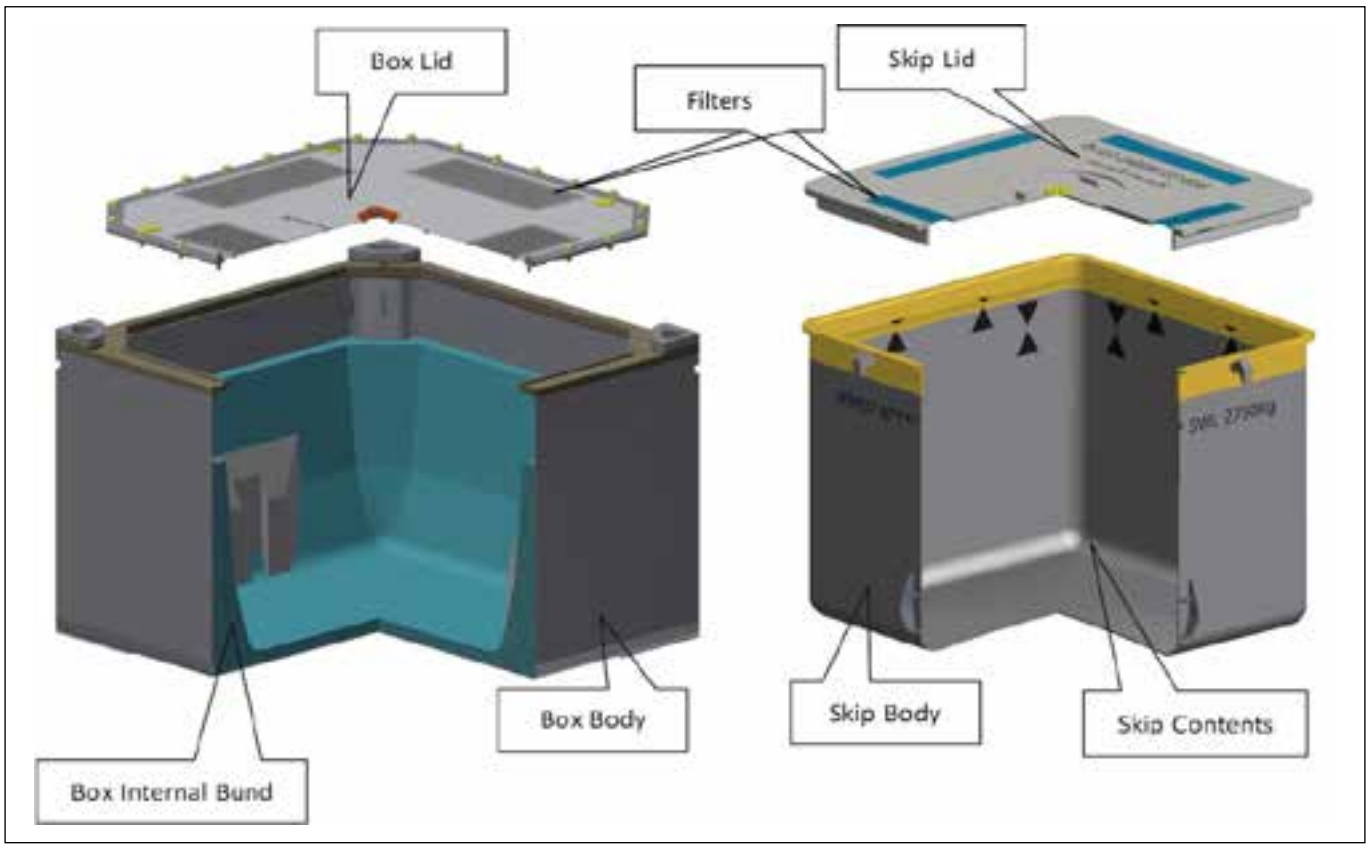
- A desktop based review was carried out to identify a shortlist of materials suitable for packaging MSSS waste including sludge, miscellaneous beta gamma waste and silo liquor and that they can withstand other contaminants such as chloride.
- Corrosion trials to confirm corrosion rates under specific conditions.
- Further corrosions trials to assess any corrosion issues associated with fabrication techniques.

The results from this work provided strong support for the use of BS EN 1.4462 duplex stainless steel for the manufacture of MSSS waste 3m^3 waste containers.

Delivery partners
Exova Corrosion Centre, Stainless Metalcraft (Chatteris) Ltd., DBD Ltd.

Contact
Sushma Davison (MSSS Strategy & Technical, Research & Development) sushma.davison@sellafieldsites.com

Frank Norton/Paul Whiteside (Inspection and Certification Group) paul.whiteside@sellafieldsites.com



Skip, box and lid designs

Filters

The purpose of the filter is to manage evolved hydrogen generated by MSSS waste and control water losses over the very long timescales of interim storage. The aim of this task was to assess the performance of new and corroded filters in order to evaluate likely performance during long storage periods. The work was carried out in four phases during 2016/17 and covered the following:

- Identification and review to produce a shortlist of potentially suitable filter materials.
- Performance testing of unused filters and comparisons with vendor specifications.
- Trials to establish corrosion/ageing of filters under defined conditions.
- H_2 diffusion performance tests on aged filters and comparison with those results obtained from the tests carried out on unused filters.

All four phases of work were completed in 2016/17 with the results providing confidence in the performance of both the new and corroded filters. Further work is planned for 2017/18 to assess the corrosion and performance of filters over longer periods of time.

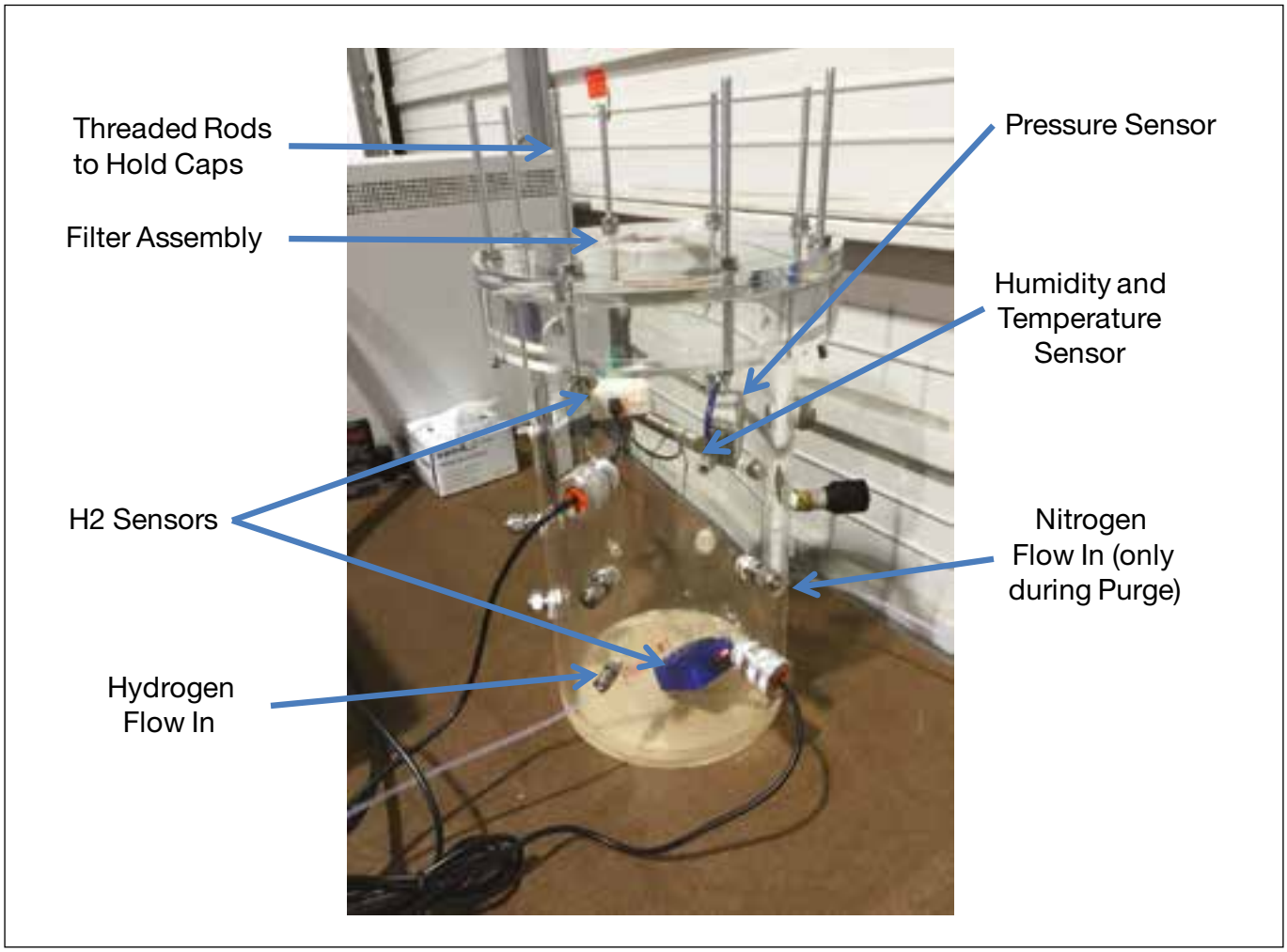
Delivery partners

Fauske & Associates, DBD Ltd.

Contact

Sushma Davison (MSSS Strategy & Technical, Research & Development) sushma.davison@sellafieldsites.com

Frank Norton/Paul Whiteside (Inspection and Certification Group) paul.whiteside@sellafieldsites.com



Experimental test setup

Seals

The box and skip seals are required to provide a safe environment within the skip and surrounding area by containing releases. The purpose of the seals is to provide preferential flow through the filter and to function effectively with low contact pressures provided by the skip lid weight. The work completed in 2016/17 included:

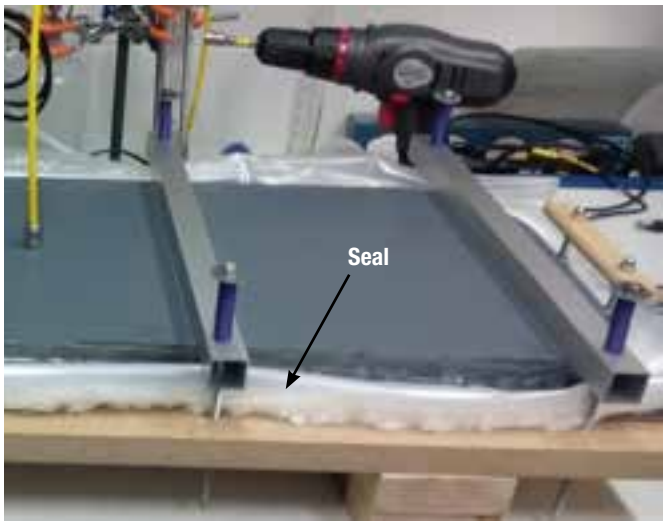
- The identification of seals available on the market.
- Application of criteria to select seals that will meet the skip and box requirements.
- Further de-selection at an expert workshop to identify the seals for testing.
- Small and larger scale experimental trials (illustrated) against a number of performance criteria.

This work identified two suitable types of seal that have the potential to meet the interim storage requirements of 3m^3 boxes over long timescales. The final phase of the work is to test the selected seals further in full scale trials.

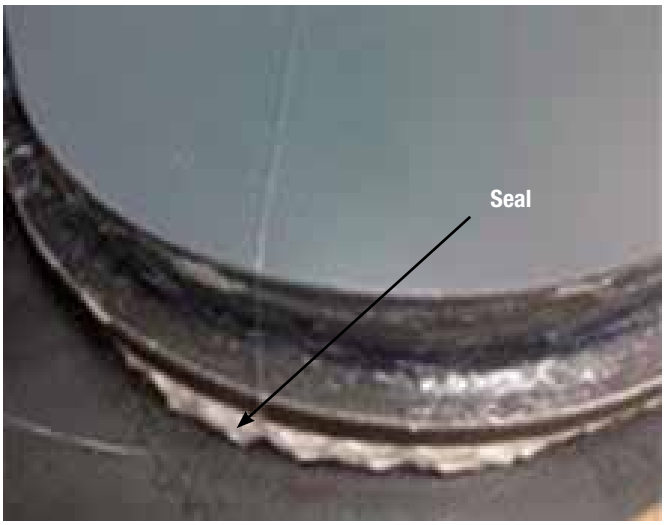
Delivery partners
National Nuclear Laboratory, DBD Ltd.

Contact
Sushma Davison (MSSS Strategy & Technical, Research & Development) Sushma.davison@sellafieldsites.com

Paul Whiteside (Inspection and Certification Group) paul.whiteside@sellafieldsites.com



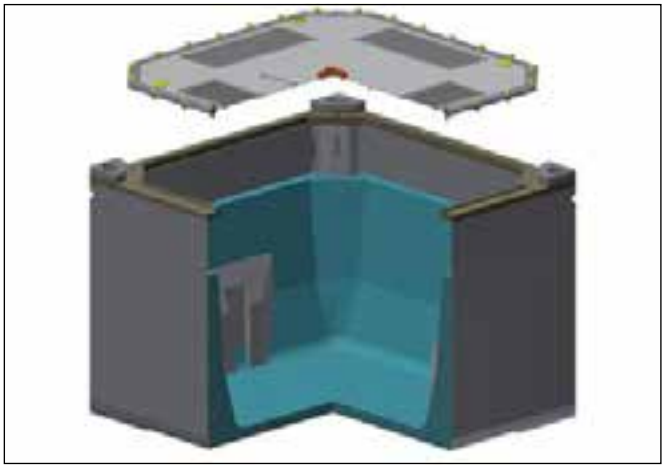
Medium scale assembly for measuring leakage through the seal being tested



Small scale assembly for measuring leakage through the seal being tested

Internal cement bund

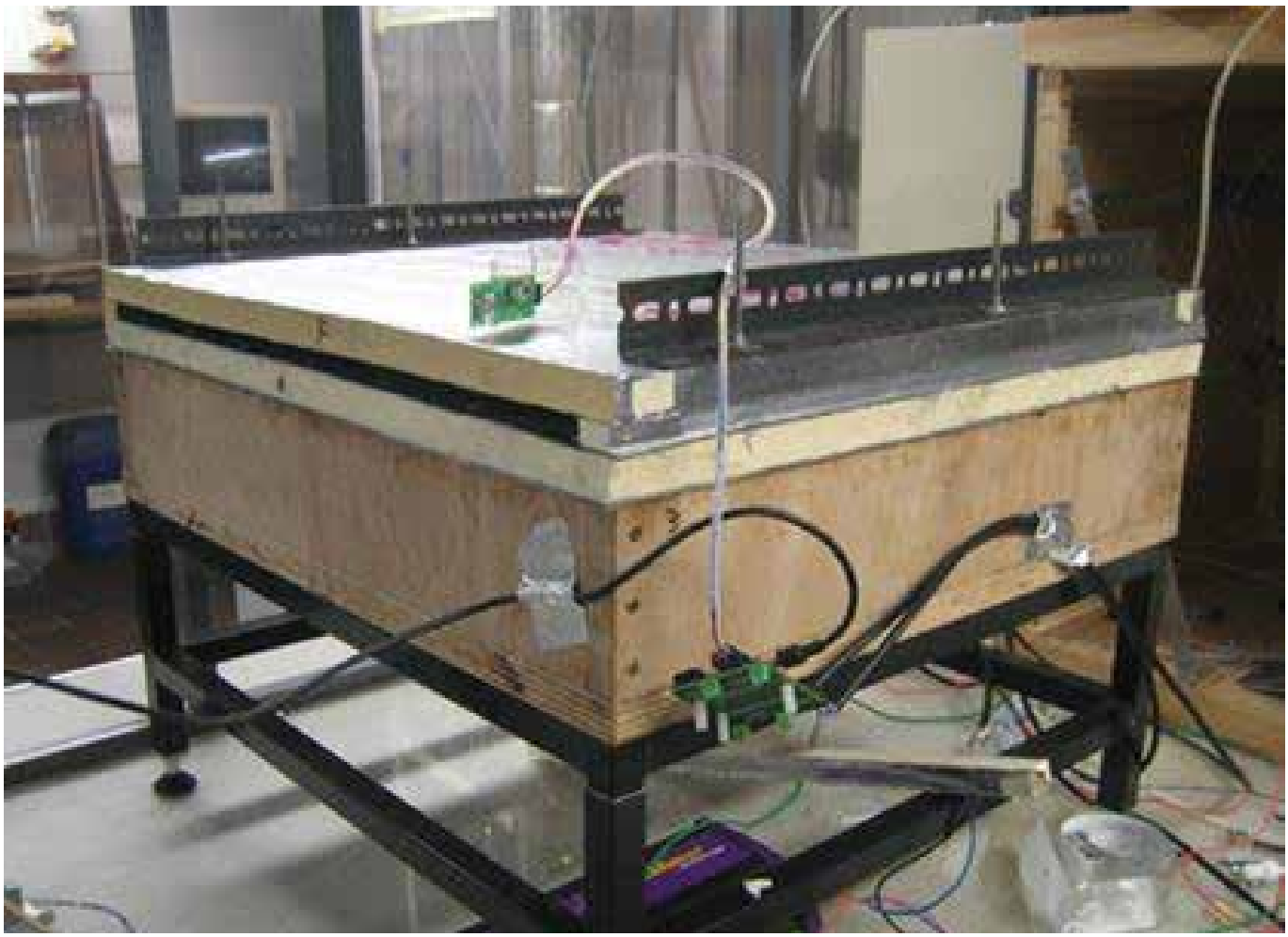
The aim of this task is to develop a suitable formulation for the cementitious bund that can meet the performance requirements for the bund over the full period of long term storage. The purpose of the bund is to mitigate the risk of skip failure, as a result of, for example, corrosion. During 2016/17, the project focussed on the identification of the bund formulation to meet various feed and performance requirements and to assess its manufacturability. Both small and large scale manufacturing trials were carried out on a number of cement formulations. In the next phase of the work these will be assessed against success criteria based on performance requirements.



Section through a 3m^3 box showing the bund profile (blue)

Delivery partners
National Nuclear Laboratory, DBD Ltd.

Contact
Sushma Davison/Ian Kettle (MSSS Strategy & Technical, Research & Development) sushma.davison@sellafieldsites.com



The 1-D experimental rig with lower box and upper gap channel

Hydrogen management

During interim storage, the boxes will be placed in stacked arrays with a small horizontal gap between the upper and lower boxes. The hydrogen released via the filters from the lower box must therefore be able to flow through the horizontal gap channel and be dispersed to maintain hydrogen concentration levels below the "lower flammable limit" to minimise the risk of a deflagration. A computer model will be used to enable Sellafield Ltd to explore multiple design options in a timely and cost efficient manner and validation of this model requires experimental data.

During 2016/17, a programme of experimental work was carried out at London South Bank University to investigate passive venting of a buoyant gas (using helium as a safe analogue for hydrogen) from a filtered box via a narrow channel. This was to provide suitable data for model validation. The filtered box was used to mimic the waste container and the channel represented the geometry between the stacked containers. Both 1-D (pictured) and 2-D rig configurations were investigated.

For narrow channels the results suggested that buoyancy driven flow along the channel is inhibited and that the gas concentration in the channel is very sensitive to the gas release rate. For both the 1-D and 2-D rigs buoyancy driven ventilation flow appears to be far more effective for channels of wider gap height, significantly reducing the maximum gas concentrations observed in both the channel and the box ullage at a given gas release rate. This work is now complete with experimental data used to validate the model.

Delivery partners

London South Bank University, DBD Ltd.

Contact

Sushma Davison (MSSS Strategy & Technical, Research & Development) Sushma.davison@sellafieldsites.com

Paul Holborn (London South Bank University) p.holborn@lsbu.ac.uk

Evaluation of an automated machine vision technique to assess hydrogen release rate from skips of MSSS waste using bubble analysis and measurement, MSSS characterisation requirements implementation

There is a requirement to measure hydrogen emission rates from skips containing Magnox sludge retrieved from the 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 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 camera video, using a bespoke machine vision software algorithm. The objective of this project is to establish credibility of the technology and to compare it against other available techniques to allow decision making for the stream.

During 2016/17 and completed in March 2017, phase 1 of the work was carried out to establish credibility of the technology. This involved trials, carried out by Amec Foster Wheeler, using a full-scale simple test rig and software development, which progressed the technology from TRL 2 to TRL 3 (technology readiness levels). The results demonstrated that bubbles can be identified, tracked, and counted on the liquor surface, and that a calibration factor can be generated which enables a volumetric gas measurement to be made to an accuracy of ± 3% (under the conditions tested). The results obtained from phase 1 suggest that the system remains a credible option.

Phase 2 (to develop the technology from TRL3 to TRL6) was defined in parallel with the delivery of phase 1 to minimise the gap between development work stages. This phase aims to assess the robustness of the system, accuracy of results in the environment(s) where it will be deployed and the variability of the wastes. Specifically, the second stage of development is to understand the effect of the variability of the waste on:

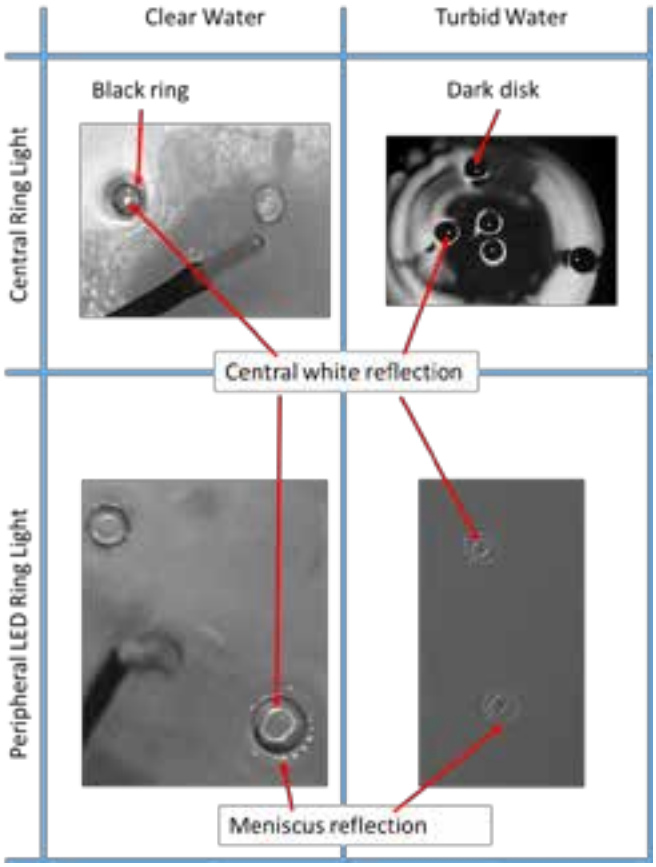
- The range/limits the technology can tolerate.
- Measurement accuracy.
- Limits of detection.

Delivery of phase 2 development is expected to be complete in financial year 2017/18 to support the decision on either proceeding to phase 3 (system installation on plant at Sellafield), or using other (conventional) options that are being assessed in parallel.

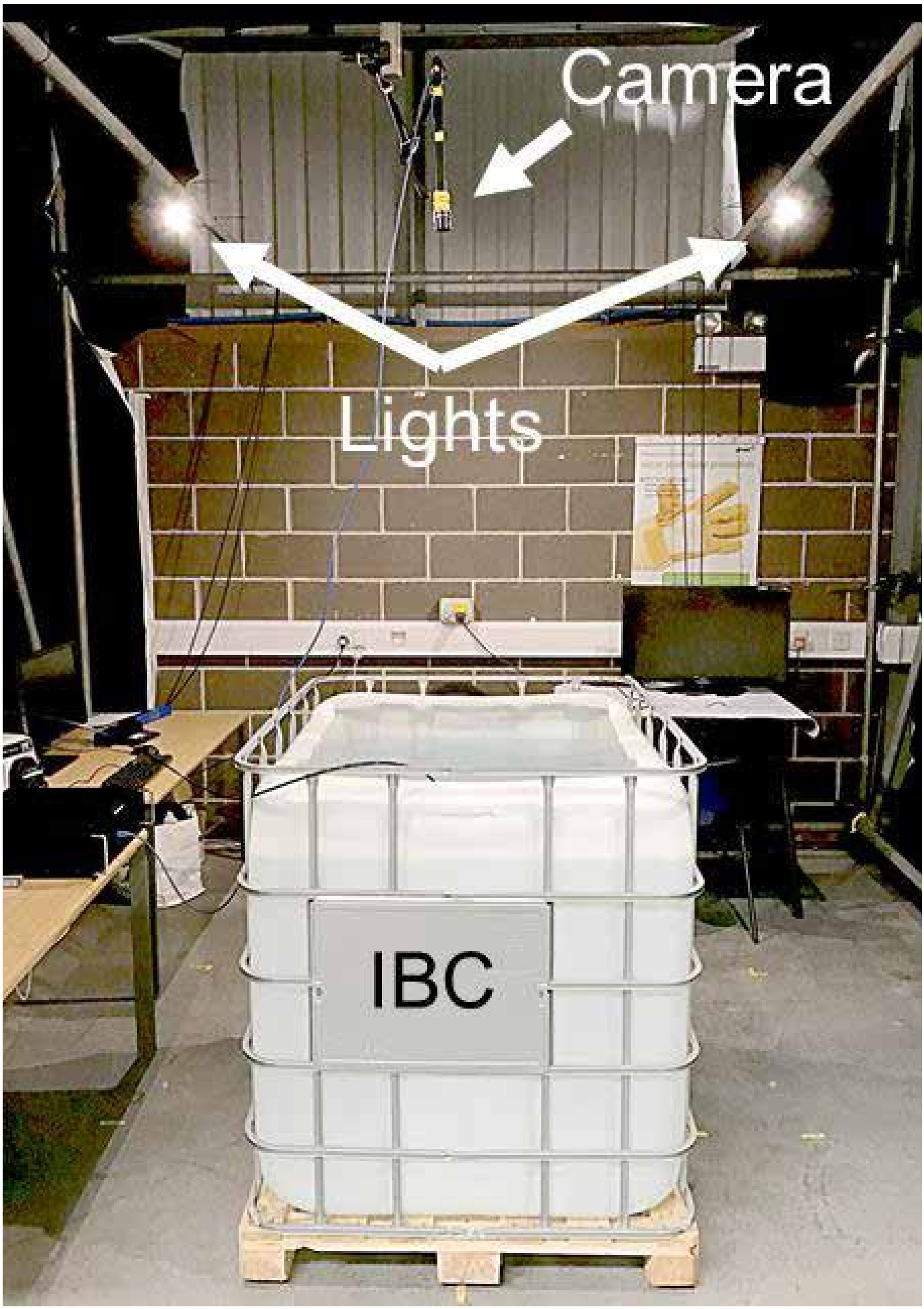
Compared to more conventional methods of measuring hydrogen gas emission rates this system has a number of advantages, the most significant of which is ease of deployment (the main requirement is an installed camera). This would therefore provide a low maintenance, simple system to provide information 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).

Delivery partners
Amec Foster Wheeler, Mirion Technologies

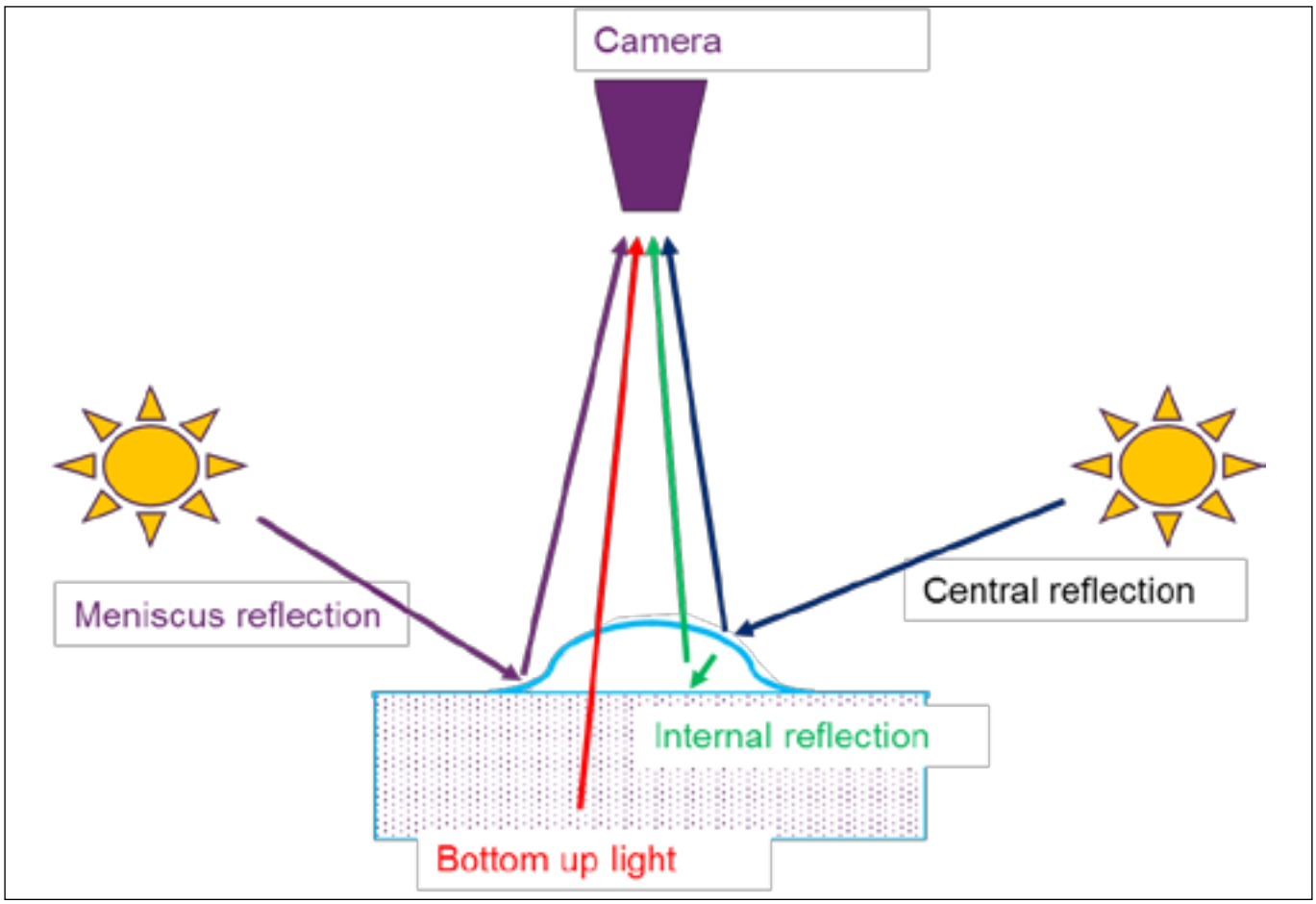
Contact
Alex Allen (MSSS Strategy & Technical)
alexander.allen@sellafieldsites.com



Bubble imaging for overhead and peripheral LED ring lighting and the effect of liquor turbidity



Intermediate bulk container experimental rig (2 of the 4 lights are visible)



Schematic showing the different light paths which affect bubble imaging

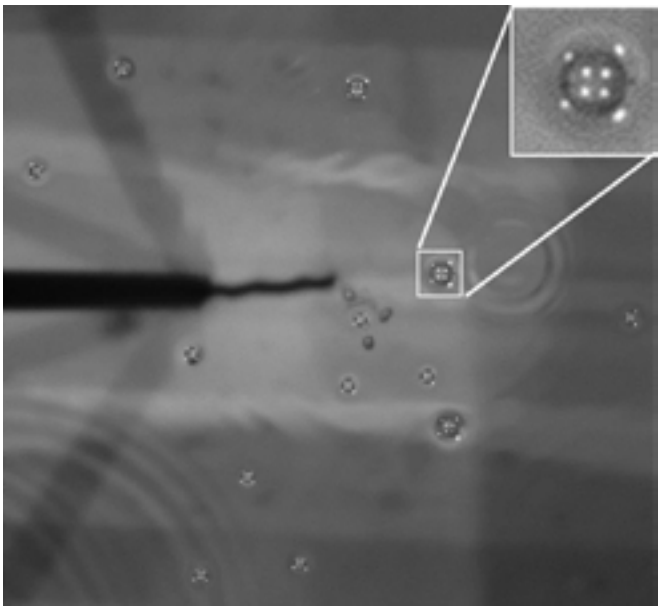


Image showing the bubble image pattern obtained using four discrete lights arranged in a square. Clear water with small bubbles

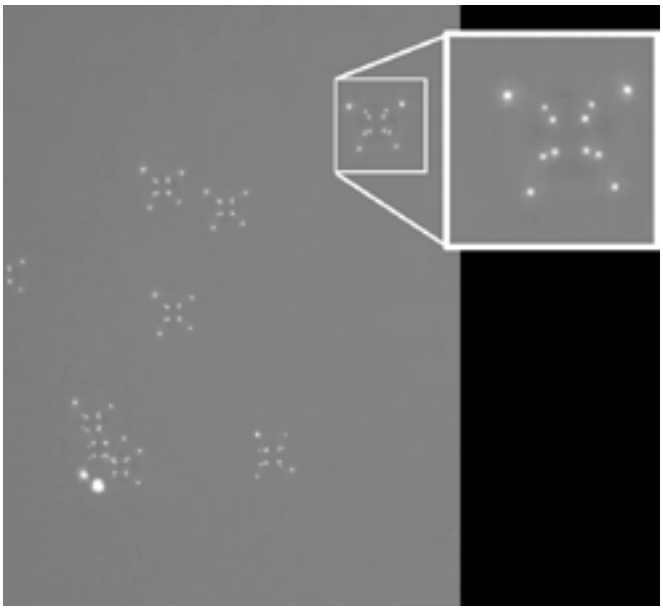
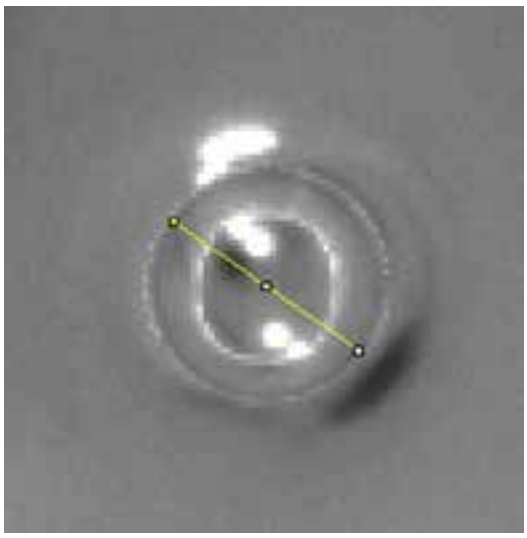
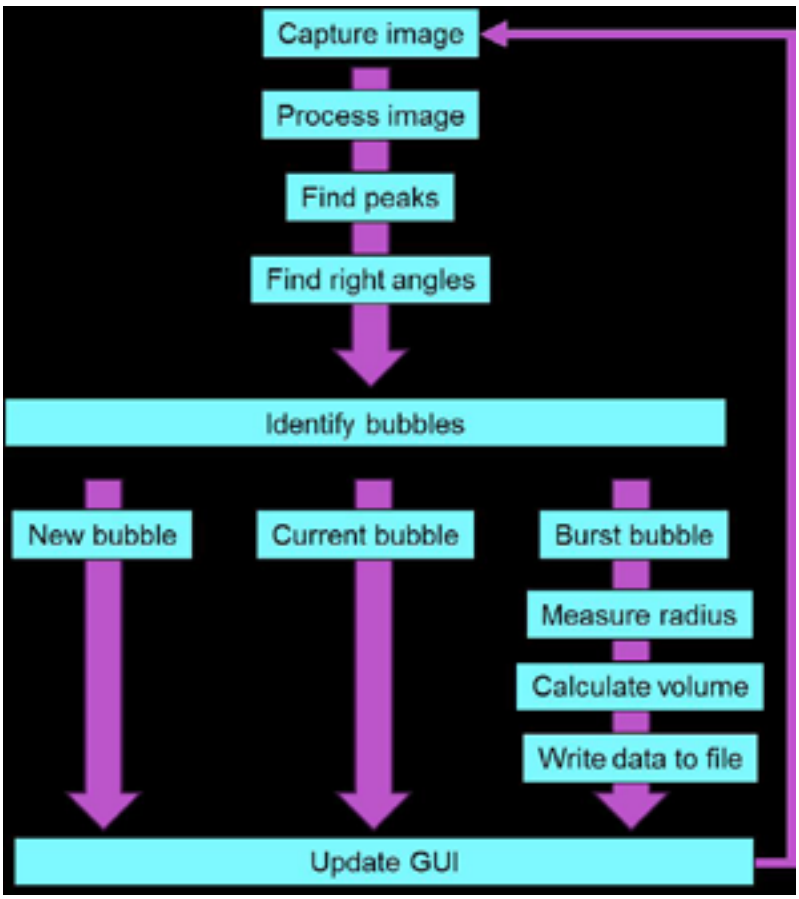


Image showing the bubble image pattern obtained using four discrete lights arranged in a square. Turbid water with large bubbles



Bubble showing a typical diameter measurement



Outline bubble analysis software flow chart

Example of the general user interface from the bubble analysis program

Magnox Swarf Storage Silos liquor and effluent management

MSSS effluents risk strategy

The accelerated MSSS retrievals programme means that shortened timescales are available for mitigation plans that need to be put in place to mitigate any potential effluent risks; however a review undertaken in November 2016 agreed that the proposed effluent strategy for MSSS is technically robust. It was also recognised that an enterprise level decision making process is required to implement any contingencies against identified effluent risks and uncertainties.

Contingency planning against effluent risks is ongoing with MSSS, FGMSP and the SIXEP programmes collaborating to produce a pragmatic tactical plan that will:

- Deploy simple engineering capabilities.
- Be based on a "lead and learn" approach (containing actual plant data and R&D).

Additional contingencies were also explored and collated as "Should We?" decisions.

Following cross programme endorsement, expected in April 2017, the next phase of the project is for the MSSS technical team to lead a planning phase to support the subsequent "How do we?" decisions which will involve:

- Study brief to identify stakeholders and resource planning.
- Update to SIXEP stream decision calendar.
- MSSS requirements for each contingency.
- Impact assessment from relevant projects for each contingency.
- MSSS Strategy & Technical optioneering study.
- "How do we?" decision making.

This work has identified governance routes for a cross programme enterprise level decision making process for the mitigation of effluent risks as well as acceptance of uncertainties which have been difficult to quantify.

Delivery partners
DBD Ltd.

Contact
Wallis O'Brien (MSSS Strategy & Technical)
wallis.j.obrien@sellafieldsites.com

MSSS effluents gPROMS model

The MSSS effluent management strategy is supported by modelling of the MSSS effluent stream. During 2016/17 the project focussed on improving the chemical modelling arrangements with the aim of developing a dynamic flowsheet for MSSS effluents.

During 2016/17, the project effluents team delivered:

- The MSSS effluent gPROMS model in three tranches:
  1. Steady state model with fixed effluent composition.
  2. Linear process - simple linear relationship for leach rates and release fractions from solid waste into the liquor over time.
  3. Coupled non-linear process – e.g. thermodynamic modelling of effluent chemistry using PHREEQC.
- Revised technical baseline input data (including learning from sample analysis).
- Integration plan for the existing and new MSSS models.

The MSSS gPROMS model allows more detailed modelling than Excel models (the current platform for MSSS effluent suite of flowsheets) and is compatible with kinetic and thermodynamic software to enable chemical modelling of the effluent stream. This capability will capture the understanding gained from relevant R&D programmes in order to bound the assumptions relating to the liquid effluent compositions. In addition, integrating the new and existing models will enable assessment of the effect of the chemistry on scheduling of events and vice versa.

The validation of the baseline effluent discharge profile with downstream capability has been completed and further work includes:

- Feedback from stakeholder/users to update model and user interfaces.
- Provide detailed training to stakeholders.
- Ongoing development of the chemical model using MSSS "lead and learn" strategy.
- Development of a silo liquor database and integration with MSSS gRPOMS effluent model.

Delivery partners
National Nuclear Laboratory, DBD Ltd.

Contact
Wallis O'Brien (MSSS Strategy & Technical)
wallis.j.obrien@sellafieldsites.com

MSSS inter-compartment liquor transfer

MSSS required a means of reducing the overall liquor level from the third extension compartments to accelerate high hazard reduction. The project commissioned the Innovation Centre to design and build a prototype capable of transferring liquor from MSSS compartments to a designated discharge stream without interacting with the solid waste. The prototype must be tested in a realistic inactive scenario to provide confidence that the system can be installed correctly and perform adequately during operations.

The development of the MSSS liquor transfer system was carried out as part of the 6 week Innovation Centre project between January and March 2017. Following briefing of the challenge, the project team worked to develop a prototype for transferring liquor between MSSS third extension compartments via existing overflow routes. Using this system liquor can be transferred over to the only compartment with a discharge route to site effluent treatment. Development involved generation of concept ideas, selection of a final concept through optioneering, detailed design, manufacture and proving through inactive testing.

The final design consists of a borehole pump suspended through a compartment 150mm (internal diameter) inspection penetration. The pump is connected to a length of flexible stainless steel hose which is installed to the compartment overflow channel by an ROV using a carabineer-clip style mechanism. This phase of the project concluded with a presentation of the prototype to MSSS stakeholders and demonstration of its function upon a rig within the Underwater Testing Facility at Sellafield.

Future work will be undertaken by MSSS in 2017/18 to further develop the prototype design into a system that can be deployed on plant. Development of the MSSS liquor transfer system has provided a safe, fit-for-purpose, cost effective solution to removing liquor from the third extension with a short installation time. Additionally, the risk of releasing liquor onto the operations floor is eliminated by installing all equipment inside the compartments.

Delivery partners
WF Senate, ERIKS UK

Contact
Matthew O'Sullivan (Innovation Centre/Operations Support)
matthew.osullivan@sellafieldsites.com

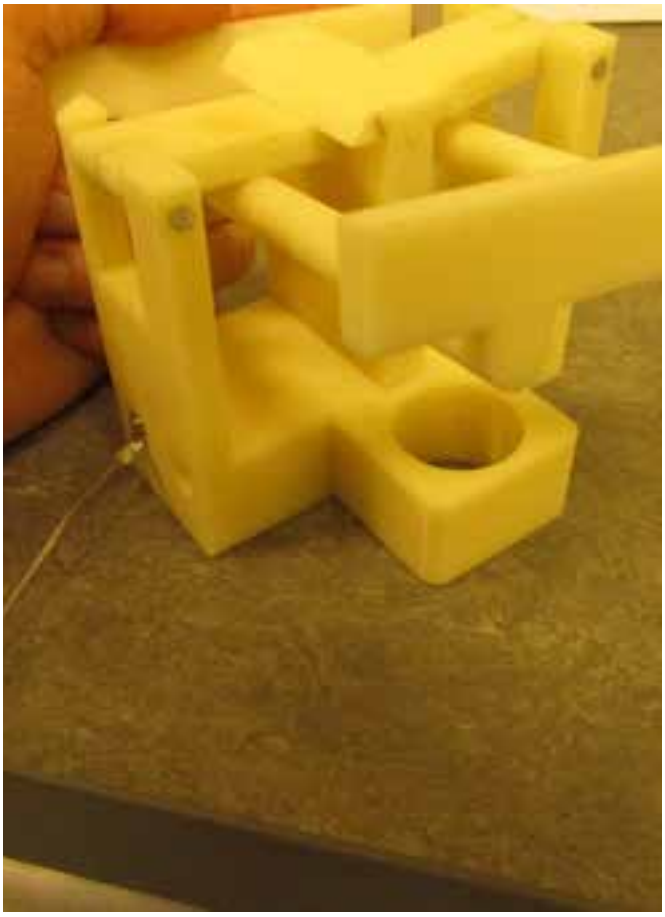
Prototype outlet spout front view with aluminium latching mechanism and cylindrical floats to improve buoyancy for ROV installation

Prototype outlet spout rear view with ROV grip on cylindrical float

View of entire outlet spout taken during high level flow testing

View of stainless steel hose and float system taken during high level flow testing

Pump control panel



3D printed concept latching mechanism

Close up of hose with buoyancy aid

Pump connected to hose, taken during testing of system deployment

Entire system deployed into test pond

System pumping water in test pond

Liquor balance model development

MSSS is a plant built in four parts; original building, first, second and third extension. The older extensions were built in the 1960s and 70s prior to modern standards and it is therefore necessary to demonstrate appropriate control of containment of liquors throughout retrieval operations. This is provided by means of a liquor balance model (LBM) which calculates the mass balance of the silos.

The operational LBM, as of 2016, had been approved in 2006 as a supplementary trending tool. Recent work on the MSSS leak mitigation strategy and the Ground Environment Management Scheme (GEMS) project highlighted the importance of the model and a programme of work was therefore needed to develop the Quiesant LBM in a phased manner as new retrievals factors are introduced. Throughout 2016/17 the LBM went through the first of many development phases which improved alignment to recent trial data, ullage pressure correction and cooler operation correction. It was then taken through a rigorous validation and specialist peer checking process. The fully validated iteration of the model, the first in more than 10 years, was brought into operation in January 2017. Work is now being progressed to scope the next phase of development and install new instrumentation.

The LBM is now aligned to the site standard for a number of operational plants. There is also a baseline from which to develop the model further to ensure that the model, as part of the MSSS leak detection capability, is robust and demonstrates the application of best available techniques (BAT). In addition a robust plan is in place to continually improve the LBM throughout the facility lifetime. This will allow informed decisions to be made regarding the retrievals strategy as MSSS enters its new operational phase.

Contact
Matthew Baird (MSSS Operations Support)
matthew.b.baird@sellafieldsites.com

In-ground mitigation technologies

In-ground mitigation technologies have been assessed and developed through the GEMS study in support of MSSS retrievals. Specifically, the aim of the work is to ensure that Sellafield Ltd understands the capability available to respond to, and limit the impact of, contamination in the event of a new leak to ground, resulting from waste retrieval activities associated with hazard reduction of legacy facilities. A range of technologies are available that could provide a benefit in terms of minimising the migration of the potential contaminants of concern, and the associated risks to off-site receptors. The purpose of this work is to assess these technologies in the context of deployment at Sellafield, to develop those offering the greatest potential and assess their likely effectiveness against the specific contaminants of concern associated with Sellafield Ltd legacy facilities.

To ensure the consideration of BAT, an international collaborative consortium headed by CH2M and including the National Nuclear Laboratory, Quintessa and Eden Nuclear and Environment was chosen to undertake the work, which commenced in 2013/14. This included an initial review and selection of those technologies that are considered potentially suitable, followed by further development of the chosen schemes to increase the TRL and provide evidence to underpin the technology roadmap through to potential deployment. The latter phase included laboratory batch and column testing of reagents, supported by modelling of groundwater, geochemistry and operational risk evaluation.

The project identified two potentially viable intervention techniques to control the spread of groundwater contamination (specifically strontium 90 (Sr-90), technetium 99 (Tc-99) and, to a lesser extent, carbon 14 (C-14)), these were: ‘Pump and Treat’ and ‘In-Situ Redox Manipulation (including injection of reactive materials)’. Suitable reagents and reactive materials were identified from an extensive list of options through the laboratory testing work, and schemes to implement these technologies and materials were developed to demonstrate the options were viable if their use was required in the future.

As a result of this work, Sellafield Ltd has acquired sufficient understanding of the context-specific performance and practical deployment issues associated with these technologies to underpin any future decisions related to their potential implementation. The project developed the chosen technologies to a suitable state of readiness to enable their timely deployment if required. The target TRLs have been achieved and a clear plan developed to support their potential future deployment if required.

Delivery partners
CH2M, National Nuclear Laboratory, Quintessa Ltd., Eden Nuclear and Environment Ltd.

Publications/press releases/web links
Day, J.; Summary of the Sellafield Project for Development of In-ground Options to Mitigate Potential Leaks from an Aging Waste Storage Facility – Development of Candidate Technologies. Unconventional Contaminants, NICOLE Network Spring Meeting & Workshop, Manchester, UK 24-26 June 2015.

Contact
Nick Atherton (Land Quality, Site Remediation)
nick.atherton@sellafieldsites.com

Column testing of reagents in NNL facilities, to assess performance with Sellafield soils and potential groundwater contaminants

Drilling rig, typical of what would be required to establish a borehole array for the potentially viable intervention technologies

Pile Fuel Storage Pond dewatering trial: Temporary lowering of the pond level by 23cm for concrete characterisation and decontamination trials

The Pile Fuel Storage Pond (PFSP) programme is in the process of decommissioning and working towards dewatering the pond (starting 2019). This will involve remediating the pond concrete walls and floors (the target is R2C2 radiological conditions) and removal of sludge and solids over a 10 year period at which point the interim state will have been achieved and a period of care & maintenance commenced prior to final demolition.

In preparation for dewatering further information/ characterisation of the concrete walls was sought and a dewatering trial was undertaken in Feb/ March 2017 to:

- Simulate the conditions for permanent dewatering which is expected to start in 2019.
- Test a number of decontamination techniques, which enabled data to be collected on wall conditions and penetration by contaminants to gain a better understanding of concrete characteristics.
- Provide information that can be used to underpin the plans for dewatering and decommissioning.

The trial involved:

- Temporary lowering of the pond by 23cm for approximately two weeks.
- Modification of the Liquid Effluent Treatment Plant (LETP) to enable its continued operation at lower water levels.
- Dose/gamma monitoring of concrete surfaces using collimated dose rate and gamma spectroscopy monitoring both pre and post lowering of the water level.
- High pressure washing to clean pond walls before and after lowering the water level.
- Shaving to remove concrete samples at between 3-9mm depth (after first lowering the water level).
- Use of epoxy sealants in a number of sample locations to act as a sealant in a number of wall locations.

During the dewatering trial two independent contractors were chosen to undertake Cs137 depth penetration profiling measurements:

- A technique called D:EEP (created by Createc and Costain) was deployed to estimate the penetration of Cs137 through concrete walls without the need to core the wall or otherwise cause damage.
- Cavendish Nuclear also deployed a proprietary non-destructive depth profiling technique of their own to determine Cs137 penetration based on a different algorithm and different field instruments.

The combination of modelling (at shaved and non-shaved areas) and separate dose rate/gamma spec measurements taken at four shaved concrete areas of the pond centre wall gave the programme further confidence regarding the extent of activity penetration more generally through the pond wall. The continued maturation of the depth penetration algorithms is part of the key programme driver of 'lead and learn' for both FGMSP and the wider Sellafield site.

Learning outcomes from the trial

The information below outlines the impact on dose rates from the decontamination techniques used:

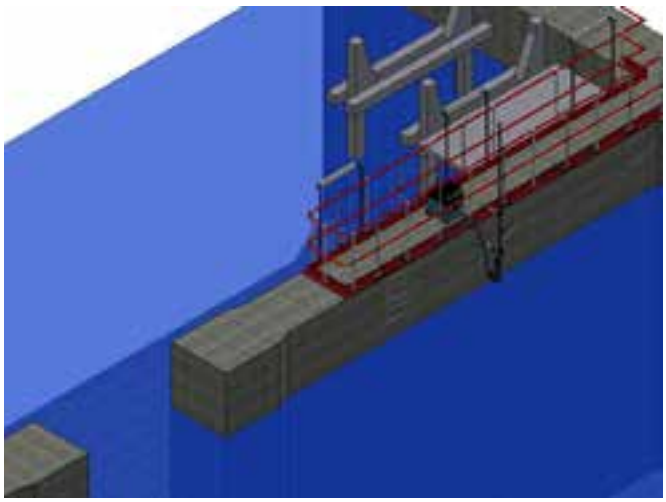
- Both underwater and out of water washing removed algae that could become friable (and therefore potentially an airborne hazard).
- Underwater and out of water washing had no significant impact on reducing dose rates.
- Shaving to 3mm reduced surface activities by >90% with no significant reduction with further shaving to 6 and 9mm.
- There was no obvious increase in airborne activity within the bays building.
- Fixed radiometrics showed a small increase in ambient gamma dose rates.

The trial output, particularly the depth of penetration (<5mm) at the pond walls, has contributed to a reassessment of the baseline interim state. An alternative interim state which involves near surface removal by concrete shaving in preference to liner removal is currently being proposed.

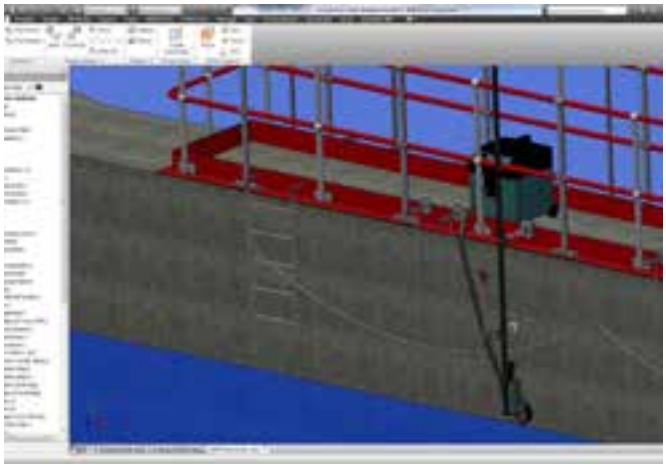
Such was the success of the dewatering trial that approval to commence permanent dewatering of a pair of connected bays in 2018 (develop cleaning/sealing/shaving and shielding capabilities) has now been granted.

Delivery Partners
Cavendish Nuclear, REACT Engineering Ltd., Createc, Costain

Contact
Chris Watson (Project Manager)
chris.w.watson@sellafieldsites.com



The animated screen shot shows the shaved locations, north centre pond wall



Shaver/planer deployment (shaving head located in dewatered zone, extraction unit show on the walkway)

Epoxy sealant applied to PFSP pond wall (wall shaved at 3mm, 6mm and 9mm). White undercoat followed by a blue top coat.

Deployment of radiometric equipment at a washed area of previously submerged concrete wall. Concrete planer also pictured.

Research & development to underpin the impact of legacy waste retrievals on the First Generation Magnox Storage Pond effluent stream

Sellafield Ltd has recently initiated a significant programme of legacy waste retrievals from FGMSP and in the future similar activities will also take place in MSSS. These operations are expected to generate effluents that pose a higher challenge to SIXEP, mainly due to increased radionuclide concentrations and changes in the solution chemistry. This results from both the disturbance of the waste inventory in FGMSP and MSSS and in the movement of legacy fuel from the pond into containerised storage in FHP. FHP also discharges effluent to SIXEP during fuel management activities. At present, the main concerns are that waste retrievals and legacy fuel storage activities in these upstream facilities could cause elevated marine discharges from SIXEP, and this could impact on the rate that retrieval operations can proceed and unduly delay the high hazard and risk reduction programmes, which are critical to the delivery of the site lifetime plan.

To understand the risks to SIXEP posed by effluents generated during legacy waste retrievals, Sellafield Ltd funded an R&D programme carried out by the National Nuclear Laboratory which covered three effluent streams, to investigate:

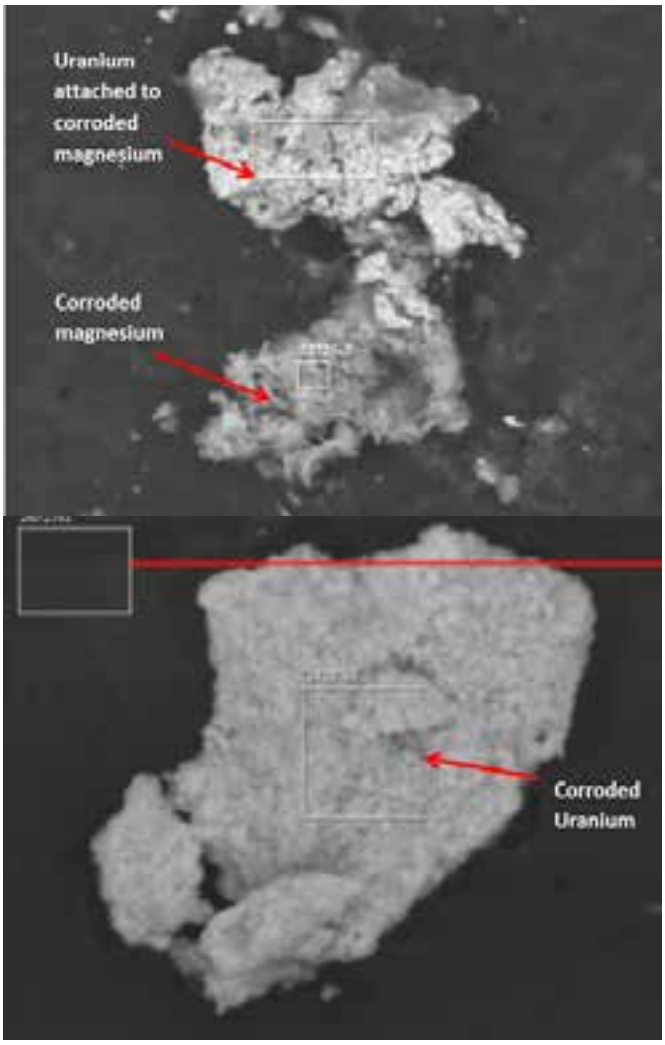
1. The alpha activity in the Sludge Packaging Plant 1 (SPP1) supernate, to assess whether SIXEP can effectively reduce the particulate and colloidal phase activity in the effluent arising from sludge retrievals in FGMSP.
2. Risks associated with beta-star colloids during MSSS retrievals, in order to establish whether stable suspensions of magnesium-hydroxide solids could form in the silo liquor following waste disturbance, which could then be discharged to SIXEP, via the Effluent Distribution Tank (EDT) – facility managed by the FGMSP programme.
3. The chemical behaviour of aluminium in the SIXEP effluent stream, to understand the risk associated with soluble aluminium in the alkaline liquors generated during the export of legacy fuel from FGMSP, and interim containerised storage in FHP.

Stream 1 (SPP1-FGMSP)

In 2016/17 a number of liquor samples were obtained from the SPP1 Effluent Collection Vessel (ECV) and sent to the National Nuclear Laboratory for detailed characterisation. This confirmed the nature of the alpha activity challenge and whether this was associated with particulate, colloidal or soluble material. The analysis successfully identified that the alpha activity in the effluent was associated with mixed-phase agglomerates of corroded magnesium and uranium material from the pond sludge and fuel, which was persistent throughout the SPP1 settling process. The presence of alpha activity associated with colloidal uranium material was also confirmed. After this, the ECV liquor was fed through a mini-SIXEP rig to assess the abatement of alpha activity at different stages of the treatment process.

The results from the experiments will be used to inform the strategic and operational decisions during the FGMSP sludge and fuel retrievals programme throughout 2017/18, including commissioning of the direct effluent return line from the SPP1 ECV to SIXEP which bypasses the current route through the FGMSP.

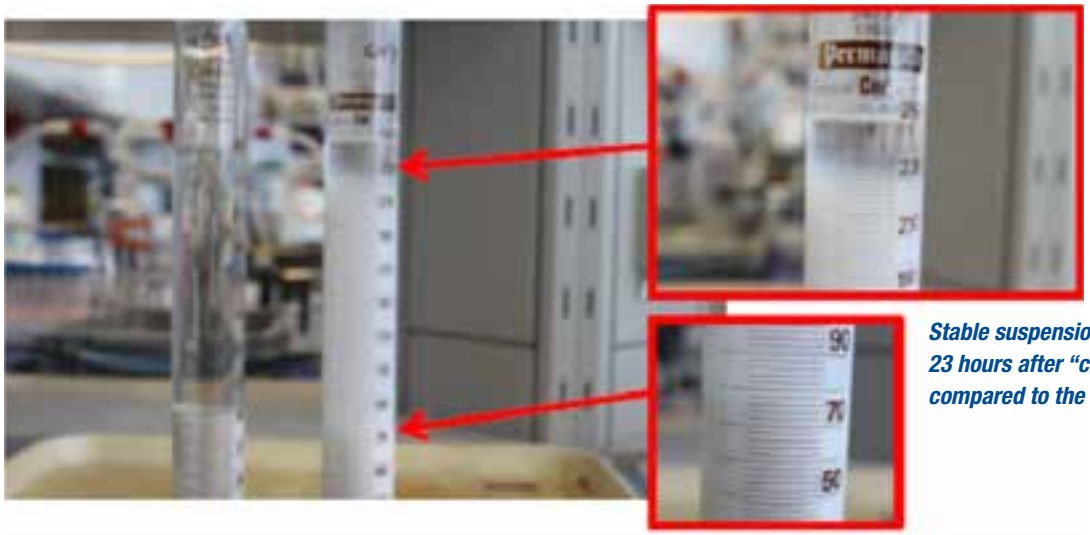
More work is planned during 2017/18, to further understand the behaviour of alpha activity in the stream, including the characterisation of plant samples from the SPP1 ECV, EDT East Chamber and SIXEP sand bed filter, to assess the form of the alpha activity that is persistent throughout the process. In addition, further laboratory work is planned to understand the mechanisms which explain the association of alpha activity with corroded uranium in the system, and how this will behave when subjected to changes in the process chemistry through SIXEP.



Active solids in ECV liquor sample

Stream 2 (MSSS-EDT)

This task built upon some previous work to understand the mechanisms which could lead to the formation of beta-star material during MSSS retrievals. It was successfully confirmed that beta-star would not form under the majority of process operations that would be expected during retrievals and/or, following the change in the chemical conditions encountered in EDT where the pH of the liquor is raised by caustic dosing. Despite this, the work identified if a scenario occurred where un-corroded Magnox swarf could be exposed to high concentrations of chloride, or if the settled sludge in the silo was to be "chemically shocked" by demineralised water during SEP machine wash-down operations, then beta-star material could form and this may present a risk to SIXEP when MSSS retrievals operations commence. This is because any suspended material would be subsequently transferred to EDT then SIXEP during liquor level management transfers. The work in 2016/17 investigated this further and this is now complete. The key conclusions were used to inform strategic decisions within the SIXEP effluent stream and identify whether mitigation solutions may be required.



Stable suspension of beta-star material, 23 hours after "chemical shock" (right) compared to the control sample (left)

Stream 3 (FGMSP-FHP)

It has previously been identified that soluble aluminium could be released from legacy aluminium-clad fuel stored in FGMSP, if disturbed, and this could have detrimental impacts on the operation of SIXEP due to fouling of the ion exchange beds. Experimental work undertaken by the National Nuclear Laboratory in 2015/16 confirmed that the solubility of aluminium in the pond was in fact controlled by hydrotalcite, a magnesium-hydroxide phase with aluminium inclusions. Hence, it was concluded that the movement of aluminium-clad fuel within FGMSP would pose no risk to SIXEP, as any aluminium released into solution would precipitate as hydrotalcite in the presence of the magnesium-based pond sludge. The conclusion informed by the initial set of experiments was then used to explore whether the export and storage of aluminium-clad fuel in FHP would present a further risk to SIXEP. Further experimental work was undertaken during 2016/17 to assess whether the aluminium in the liquors generated during fuel export and containerised storage would be controlled by similar interactions with Magnox sludge in the SIXEP Bulk Storage Tanks (BST). The experiments determined that the SIXEP BSTs have sufficient sludge capacity to remove an excess of soluble aluminium from solution, should the aluminium cladding corrode during export from FGMSP and storage in FHP and the soluble aluminium be purged to the SIXEP BSTs during FHP liquor management operations. However, some residual risks were identified, which aligned with areas of the effluent stream where contact with Magnox sludge could not be guaranteed. The information obtained from the experimental work has been used to inform the SIXEP position with respect to the residual risks posed by aluminium. This information will be used to support technical and strategic decisions aligned with the retrieval of legacy aluminium-clad fuel from FGMSP.

The three streams of effluent-related R&D funded by Sellafield Ltd outline an enterprise level approach to understanding the risks to SIXEP, posed by effluents that are generated during legacy waste retrievals. By understanding these risks, the business is in a position where strategic and operational decisions can be made to address them. Alternatively, based on the work undertaken to date, decide whether investment in further programmes of work to develop mitigation solutions is required. These options would be in order to effectively deliver the high hazard and risk reduction programmes in both FGMSP and MSSS. Furthermore, the R&D work has been used to understand and interpret the plant effluent chemistry data from FGMSP and SPP1 during routine sampling and monitoring of the effluent stream and provide regulatory bodies with assurance that the challenge is well-understood during sludge and fuel retrievals operations in the pond. This information has also been used by other areas of the business including those which will embark on similar retrievals processes such as the SIXEP Waste Management project or process solids arising from retrievals such as BEP both of which will produce effluent that is also discharged to SIXEP.

Delivery partners

National Nuclear Laboratory

Contact

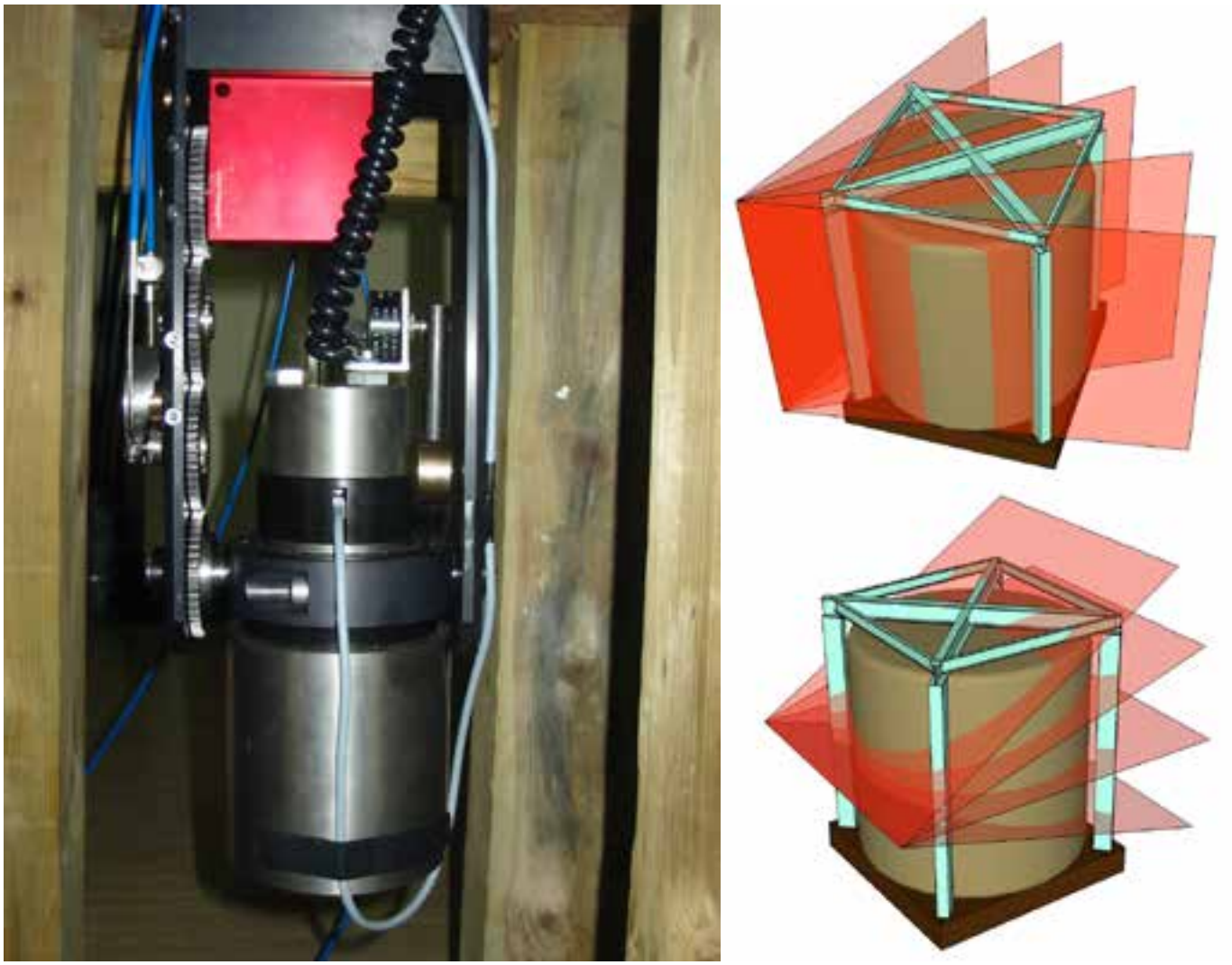
Bruce Rigby (Legacy Ponds Strategy & Technical)
bruce.j.rigby@sellafieldsites.com

Peter Jenkinson (Legacy Ponds Strategy & Technical)
peter.jenkinson@sellafieldsites.com

Highly Active Liquor Evaporation and Storage radiometric characterisation

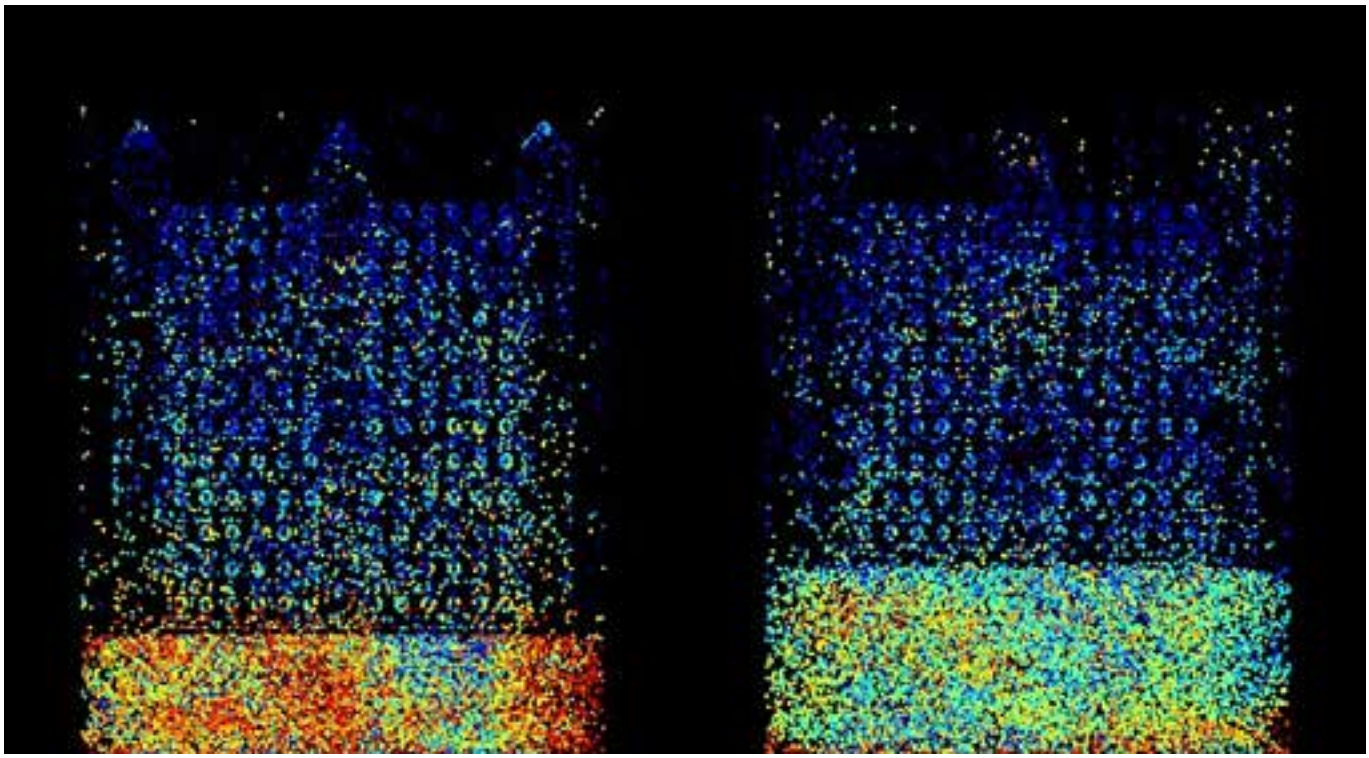
As part of the preparations for POCO there is a requirement to develop tools to determine information about the highly active (HA) inventory within cells and vessels. Within the Highly Active Liquor Evaporation and Storage (HALES) facility, the high dose rates associated with the inventory prevent the deployment of off-the-shelf systems such as gamma cameras. This project is a collaboration between Sellafield Ltd and Cavendish Nuclear which has developed a technique to map the distribution of activity within the HALES HA cells. The data from this project will inform strategic decision making in preparation for the start of POCO, and provide a means to monitor the effectiveness of POCO operations.

A collimated Geiger-Muller tube is used to measure the dose rates along linear planes within a cell. Multiple measurements from different deployment locations and at different angles and heights are then combined and using an iterative modelling technique, the probable distribution of activity within the cell can be determined.



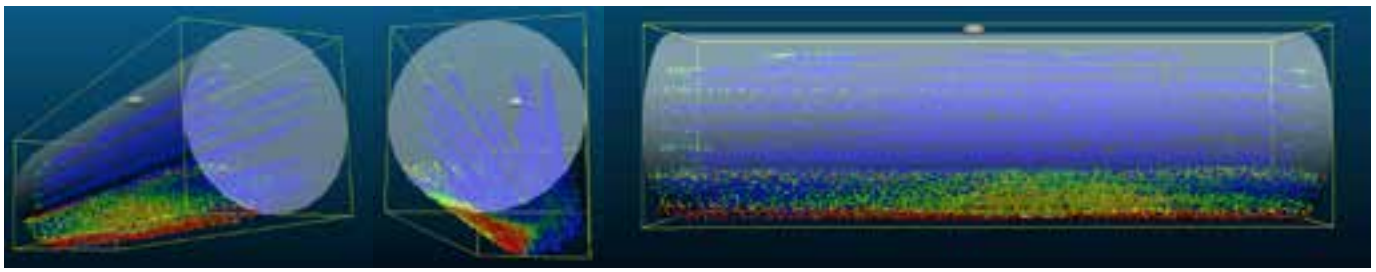
The tungsten collimated detector used in this work (left) alongside two examples of the methodology used to scan a vessel

The measurement device was developed by Sellafield Ltd, Cavendish Nuclear and Rovtech Solutions Ltd in 2015/16. During 2016/17 a number of successful deployments were made within the HALES facility. Analysis of the raw radiometric measurements was carried out using a model and this allowed 3D visualisations of the activity distribution within three separate storage tanks. A scan of one of the tanks was also successfully carried out to image the change in activity resulting from the transfer of liquor from it.



Distribution of activity in a newside storage tank before the removal of concentrated highly active liquor (left) and after replacement with weak evaporator washings (right)

The visualisation of the activity distribution in the oldside Highly Active Storage Tanks (HASTs) has provided valuable information to inform development of the POCO strategy for these legacy assets. There was considerable uncertainty about the distribution of the inventory and therefore the amount of engineering intervention and volumes of wash liquors that would be required to complete POCO. The data gained from the radiometric characterisation have reduced this uncertainty and allowed a more detailed POCO strategy to be developed. Additional characterisation of a newside HAST has allowed operators to see the impact of emptying operations on the inventory of a tank – clearly demonstrating the effectiveness of ongoing hazard reduction within the facility.



Distribution of activity in an oldside storage tank clearly showing the level of activity which is deposited on the coils in comparison with the concentration in the liquor itself

Additional planned work includes the development of a more automated collimated device to provide repeatability for the measurements and development of the computer model to account for scattered radiation incident on the detector.

Delivery partners

Cavendish Nuclear, Rovtech Solutions Ltd.

Contact details

Tom Page (Operations Division - Technical and Strategy)
tom.page@sellafieldsites.com

Gamma imaging for dose mapping

Understanding radiation environments is important in order to best determine if any protective measures are needed such as decontamination or shielding to ensure safe working. Current methods to do this involve simple, manually deployed probes which provide limited information about the location and type of any sources. Advancements in detector technology indicate that new systems may be able to measure not only the dose rate, but also the location and quantity of radioactive sources contributing to the overall dose environment.

Over the past 2-3 years Sellafield Ltd has facilitated the demonstration of nine different gamma imaging systems. These technologies varied from small developmental handheld systems, to large remotely operable collimated devices. The purpose of these demonstrations was to understand the performance of each system and which were the most appropriate for the challenges on the Sellafield site. During the financial year 2016/17 the GeGI (germanium gamma ray) imager developed by PHDS Co. was trialled. This technology provides fast results with excellent energy resolution and isotopic identification. The demonstrations helped identify the strengths of the different systems and as a result, an N-Visage gamma imager and a GeGI gamma imager system were purchased.

These devices have been added to the Sellafield Ltd radiometric measurement capability with multiple deployments planned across the Sellafield site.
A potential saving of £50k per task is also expected, with the new technologies.

Delivery partners
REACT Engineering Ltd., PHDS Co.

Contact
James Moore (Decommissioning Capability Development - Remediation) james.d.moore@sellafieldsites.com

N-Visage (REACT Engineering Ltd.)

Deployment of GeGI on plant

Unmanned aerial vehicles

Accessing areas of interest, both indoors and outside, on the Sellafield site can be challenging particularly in contaminated environments or inaccessible areas. For example, constructing scaffolding to perform simple monitoring tasks is a lengthy and costly process and sometimes the balance of cost or practicality compared with the benefit gained means that assumptions are made instead of impractical inspections. With the emergence of small unmanned aerial vehicles (UAVs) for low-cost visual and radiometric monitoring, assumptions can be challenged with minimally intrusive activities.

Over the past 4 years, there have been a number of successful flights on the Sellafield site including, inside a cell on the solvent recovery plant and into the contaminated base of the Windscale Pile 1 chimney. As a result of these activities the supply chain has built up a UAV capability to meet the needs of Sellafield Ltd. In financial year 2016/17 the project focussed on standardising the use of UAVs on the site so that it can deliver a capability that provides routine use of the equipment in inspection activities. Technical support was provided for several flights in Sellafield Ltd airspace including; monitoring the local beaches, and civil inspections of the First Generation Reprocessing Plant (FGRP) chimney and the turbine roof at Calder Hall.

The use of UAVs is now standard practice on the Sellafield site with the benefit of reducing dose, time and cost for inspections and future development work may include more novel UAV platforms to increase the possible applications for these systems.

Delivery partners

James Fisher Nuclear Ltd., WYG

Publications/press releases/web links

http://www.sellafieldsites.com/wp-content/uploads/2017/02/EnergiseApr2017.pdf

Contact

James Moore (Decommissioning Capability Development - Remediation) james.d.moore@sellafieldsites.com

UAV in flight over the separation area

Alpha camera

The non-intrusive characterisation of nuclear environments, such as gloveboxes where actinides are present, presents a particular challenge because these are mainly alpha emitting isotopes which are a particularly challenging set of species to map due to their very short range. The purpose of this project was to demonstrate systems, in active environments, that are able to measure the presence of alpha contamination from a specific distance. The system is based on detection of ultraviolet (UV) fluorescence which is emitted by nitrogen when irradiated by alpha particles.

Following on from the demonstration completed, in the financial year 2015/16, on a device from Bubble Technology Industries, Sellafield Ltd trialled a CEA (Commissariat à l'énergie atomique et aux énergies alternatives) alpha camera which also uses UV fluorescence to detect alpha contamination. The French camera was tested, in 2016/17, in the same environment as the previous trial to allow for an effective benchmarking.

The successful trial of the CEA camera demonstrated the ability to detect alpha species within a challenging environment and the project is now complete. As new cameras are developed for the mapping of alpha particles Sellafield Ltd will aim to benchmark them to further expand understanding of the technologies available.

Delivery partners
CEA

Contact
Alex Jenkins (Operations Technical)
alex.jenkins@sellafieldsites.com

Xavier Poteau (Strategy & Technical)
xavier.poteau@sellafieldsites.com

Alpha camera in front of a glovebox

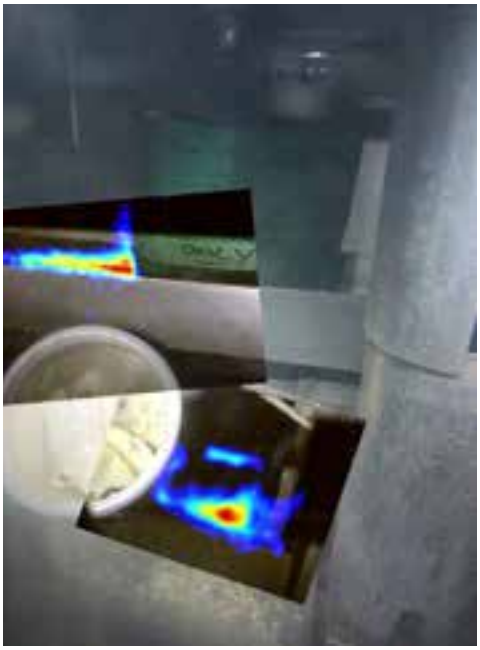


Image rendering

Activity depth profiling in concrete

At Sellafield, there are a number of areas where concrete surfaces have become contaminated and due to the porous nature of concrete this contamination can permeate beneath the surface. As a consequence, the depth of the contamination needs to be determined to ensure correct classification of the material. The current procedure for measuring the activity profile in a structure involves extracting core samples and off-site laboratory analysis. This destructive analysis process has several limitations:

- Coring is time consuming and involves operators working in potentially high dose environments.
- Laboratory analysis can take weeks to months before receiving results.

To address this challenge, faster and less dose intensive techniques are required and over recent years Sellafield Ltd has tested several potential non-destructive solutions for measuring activity depth profiles. This work has involved supply chain technologies tested in two active environments on site, with core samples taken to provide a known result for comparison. In 2016/17, the results from both active demonstrations were analysed, with recommendations for future development and use identified for each system. Additionally, the first non-demonstration use of systems developed by Cavendish Nuclear and Createc/Costain took place in the PFSP to further underpin the capability of the technology.

Non destructive techniques have the potential to provide accurate depth profiles of activity with fast results with robust sentencing of intermediate and low level waste. This is a key benefit because ILW disposal costs are significantly higher than low level waste (LLW) disposal. Future activities include the identification of further deployment opportunities so that the technology may be further underpinned with a view to providing a routine capability at Sellafield.

Delivery partners

Createc, Costain, Cavendish Nuclear, Canberra UK

Contact

Bill Johnson (Decommissioning Capability Development - Remediation) future.decommissioning@sellafieldsites.com

Depth profiling equipment

ViridiScope

Surface sampling is a common activity on the Sellafield site with swabs and scrapings from concrete walls, ceilings, and floors taken in order to determine any contamination that may be present. This information forms part of the process for characterising and disposing of bulk concrete wastes. Sellafield Ltd has been looking for ways to improve efficiency in the collection and analysis of concrete samples in a safe manner. ViridiScan is a collaborative R&D project, funded by the Innovate UK process, which uses a laser to remove a small sample of material for in-situ analysis. The sampling head can be small and either handheld, or deployed from a remotely operated vehicle (ROV). Additionally, the samples required by ViridiScan are significantly smaller than those needed for laboratory analysis. Larger sample collection can be very time consuming, dusty and can generate airborne contamination.

Throughout this project, Sellafield Ltd has been offering end-user support. In April 2016 the sampling end of the ViridiScan, the ViridiScope, was demonstrated in a non-active area at Sellafield. The ViridiScope extracts the sample and collects it on a filter paper for analysis. Following this demonstration, an active trial of ViridiScope was carried out in November 2016 so that the ViridiScope sampling process could be compared with current baseline techniques. The generated samples were sent for analysis and the results will provide valuable learning for the ViridiScan development. The output from this active demonstration will help quantify the benefits the ViridiScope/ViridiScan tool can bring to the challenges at Sellafield.

Delivery partners

Viridian Consultants Ltd., Amec Foster Wheeler

Contact

Bill Johnson (Decommissioning Capability Development - Remediation) future.decommissioning@sellafieldsites.com

Sample removal using the ViridiScope

Waste estimation

Understanding the volume and expected classification of waste that may arise from decommissioning operations at Sellafield is a key requirement during the planning stage. The treatment and disposal costs of ILW and LLW can vary significantly and therefore robust estimates are required. Additionally, since ILW is placed in interim storage on the site, estimates of ILW volumes are used to determine the number and size of storage facilities required. Estimates are often conservative, based on operational experience with samples taken for analysis. Sellafield Ltd has undertaken a series of trials using gamma imaging systems in order to determine in-situ quantities of ILW and LLW in a non-destructive manner.

In 2016/17, five technologies (from four organisations) were tested in an active cell in the FGRP. The task involved quantifying the activity within six vessels that were known to be of differing activities and waste classifications.

The four organisations involved were:

- Canberra
- Createc
- REACT Engineering Ltd.
- Nuvia

Sellafield Ltd carried out tests using these systems and the results will be analysed with the Sellafield Intelligent Customer for radiometric systems, to better understand the future capabilities of each deployed technology.

Delivery partners

Nuvia, Canberra UK, Createc, REACT Engineering Ltd.

Contact

Bill Johnson (Decommissioning Capability Development - Remediation) future.decommissioning@sellafieldsites.com

Hotspot located using a gamma imaging device

AVEXIS: a remotely operated mini-submarine for the exploration of facilities with restricted access

A number of underwater legacy facilities exist on the Sellafield site where the use of already existing access points is limited to 6" wide or where access is challenging because debris might block an entrance point or do not allow the use of even the smallest underwater commercial-off-the shelf (COTS) submarine. To address this challenge a small submarine has been developed by Sellafield Ltd and The University of Manchester that can go through small access points and to survey areas with limited access.

Over the past few years Sellafield Ltd and The University of Manchester worked together to develop an underwater exploration solution which could be used to survey challenging areas in underwater storage facilities. As part of an approach to design sacrificial robotic tools (i.e. tools that would likely be less expensive to replace than to maintain in a nuclear environment) the development led to the successful design of a mini underwater vehicle that can fit within a 6" opening. Following a series of tests in a non-active environment the prototype system was commercialised by Forth Engineering Ltd. as AVEXIS FORTH during 2016/17. The first AVEXIS FORTH was purchased by Sellafield Ltd for use on MSSS to perform survey and debris removal using a long metallic finger that was been added to the front of the submarine to dislodge debris from places that are difficult to reach. This is expected to take place in 2017/18.

Although the concept of a small remotely operated vehicle started 5 years ago as an academic exercise, the AVEXIS (Aqua Vehicle Explorer for In-situ Sensing) concept truly took shape when Sellafield Ltd became involved around mid-2014 while looking for low cost technology with the potential to access tanks, silos or caves through existing ports. The project included a 2 year programme of R&D to evolve the unit into a working device and a further year for Forth Engineering Ltd. to commercialise it. The AVEXIS FORTH has been a successful R&D project from end-user led design to a full commercial unit that will be used at Sellafield. Design of the submarine is expected to evolve over time and to provide bespoke solutions.

Delivery partners
The University of Manchester, Forth Engineering Ltd.

Publications/press releases/web links
www.uomrobotics.com/research/avexis150

Contact
Xavier Poteau (Strategy & Technical)
xavier.poteau@sellafieldsites.com

The AVEXIS FORTH and control unit

DEMplus® modelling demonstration

Virtual reality and simulation technologies have been used outside the nuclear industry and they can provide an alternative or complimentary solution to the conventional planning tools adopted for decommissioning projects. It has been recognised that more efficient planning, optioneering and scheme development could save millions of pounds for POCO and decommissioning operations.

DEMplus® is a software tool which is intended to aid the planning of decommissioning projects to develop optimised programmes. The technique combines operational data such as working times and waste routes with a geometric and radiological 3D model. Alternative approaches can be visualised and quantitatively compared. The benefits from improved scenario planning include:

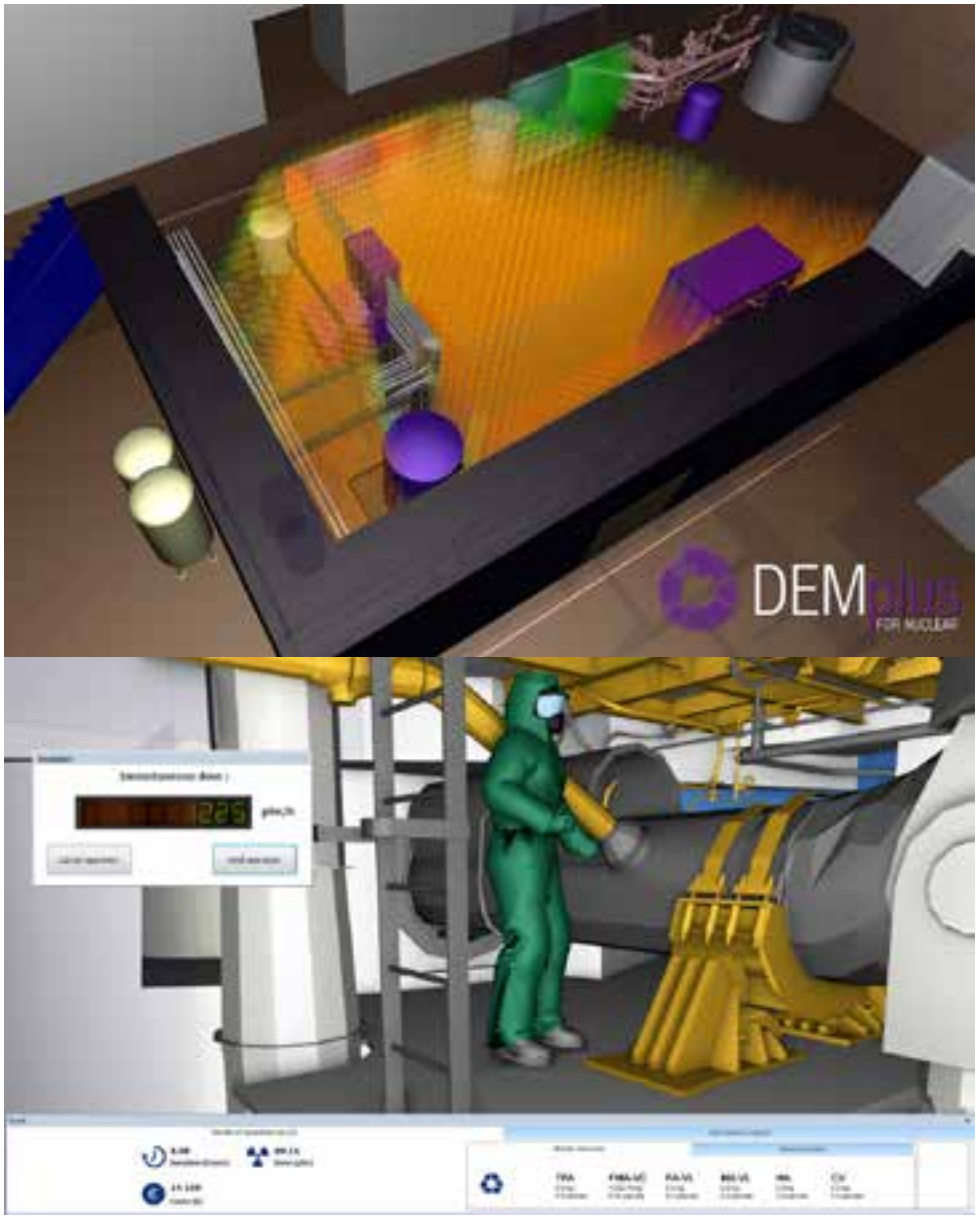
- Improved decommissioning and dismantling strategies.
- Ability to see the effects of in-situ decontamination.
- Optimised working and dose reduction.
- Waste forecasting (future store needs).
- Reduction in cost through more efficient planning.

In 2015/16 this software was first demonstrated at Sellafield, taking real data from three cells on site to determine the impact of different decommissioning strategies. These models have been completed and a number of other tasks have begun utilising this software. These other tasks include the first use of DEMplus® at Sellafield in a study phase of a decommissioning project.

In addition, Sellafield Ltd has taken the decision to purchase DEMplus® and embed it within the business.

Delivery partners
ATKINS, REACT Engineering Ltd., OREKA SOLUTIONS

Contact
Graeme Askew
(Decommissioning Capability Development - Remediation)



DEMplus® simulated model

Strippable coatings and fixatives waste disposability and performance assessment

In support of current operations and decommissioning of the Sellafield site fully understanding decontamination methods and products is essential. Historic plants were not built with decommissioning in mind and the risk of making loose contamination airborne could delay the POCO process. Fixatives and strippable coatings are chemicals in the form of liquids or gels that can be, painted, rolled or sprayed onto a substrate (such as concrete, brickwork and metals) and left to cure over a period of time (nominally 24hours). Whilst the fixatives remain in place on the substrate in contrast, the strippable coatings can be peeled off once cured and disposed of as a solid wasteform.

Sellafield Ltd is carrying out work to baseline fixatives and strippable coatings. The applicability of coatings and fixings is plant specific because some chemical coatings may react differently in varying environments and it is therefore necessary to develop a number of approved products suitable to a particular environment. This will allow for smart deployment of coatings which will lead to increased efficiency and a thorough understanding of which product is acceptable for every scenario.

With the purpose of building up a prescribed list of approved products that have been formally assessed for their use across the Sellafield site and the NDA estate, work during financial year 2016/17 focussed on engagement with various stakeholders from several waste management streams.

From these discussions a selection of products were chosen for testing to build up a baseline of acceptable chemicals. Following this, products were irradiated in their cured state and tested at The University of Manchester's Dalton Cumbrian Facility to determine the products tolerability to high radiation fields and how they potentially degrade.

Active trials also took place in the FGMSP area to investigate ease of application, coverage, adhesion, ease to peel, and resistance to tearing, together with the ability to pick up contamination, and the retention of the loose contamination within the products.

The experimental trials are now complete with a review of findings underway. The next phase of the work will review any potential gaps to ensure that all scenarios are covered and an approved list of products will be produced for operators to use.

Delivery partners

Low Level Waste Repository Ltd., Radioactive Waste Management, The University of Manchester, Shepley Engineers Ltd.

Contact

Alex Jenkins (Decontamination CoE Lead)
alex.jenkins@sellafieldsites.com

Liz Ostle (Decontamination Support)
liz.ostle@sellafieldsites.com

Active trials in FGMSP, operator applying coatings

Active Trials in FGMSP, coatings on the left are on painted brickwork on the vertical plain, coatings on the right on stainless steel on the horizontal plain

MIRRAX: a mini robotic platform for the deployment of characterisation tools in facilities with restricted access

The Mini Robots for Restricted Access Exploration (MIRRAX) is a low cost platform for characterisation of nuclear environments developed by Sellafield Ltd and The University of Manchester as part of an approach to design inexpensive sacrificial robotic tools to address surveying challenges that can be found across the site. For example some areas can only be accessed through small openings.

In 2016/17 Sellafield Ltd and The University of Manchester worked together to develop a ground-based robotic solution which could be used to survey challenging areas across the site. The development is part of a set of sacrificial survey tools (which also includes AVEXIS) that has led to the successful design of a platform offering:

- Access through a 6” port.
- Omni-directional ability.
- 3D mapping capabilities.
- A mechanical design incorporating COTS technology to minimise cost.
- High definition camera.
- I, L or U (shaped) reconfigurable deployment options

The robustness of the design has been tested in a non-active environment and this demonstrated the unique mobility function of the prototype. Future work in 2017/18 includes the development of a radiological mapping capability and, once equipped with this, an active demonstration is planned to underpin the system. This is expected in early 2018. The MIRRAX aims to provide fast-track surveys using existing access ports to facilitate more efficient decommissioning planning.

Delivery partners
The University of Manchester

Publications/press releases/web links
http://uomrobotics.com/research/mirrax150.html

Contact
Xavier Poteau (Strategy & Technical)
xavier.poteau@sellafieldsites.com

MIRRAX in various modes

LaserSnake2

Decommissioning the Sellafield site will involve a large number of operations in hazardous and restricted environments. A significant number of these operations will be cutting or size reduction tasks - either to free an object for handling and removal, or to fit into a waste container. Previous decommissioning work has relied on human intervention to perform the majority of activities. Human access is sometimes prohibited because of high levels of contamination or physical access may be difficult and therefore remote approaches are often the best option. Historic experience using robotics for decommissioning has shown large uncertainties in costs and productivity. Increasing productivity in remote decommissioning is estimated to save up to millions of pounds over the lifetime of the site and there are potentially further savings from using remote solutions to carry out activities previously thought of as manual operations.

Lasersnake2 is a collaborative R&D project which combines two relatively mature technologies:

- high energy laser cutting,
- a multi-jointed “snake arm” manipulator.

The resultant system is a remotely operated device capable of reaching awkward locations and performing size-reduction activities. Since the majority of the electronics and high value equipment are situated outside of the work area, it is particularly suitable for use in areas with high levels of contamination. The project led by OC Robotics and includes The Welding Institute (TWI), Laser Optical Engineering, ULO Optics, and the National Nuclear Laboratory and is funded by the Innovate UK process. Sellafield Ltd provided end user support and facilitated an active demonstration in 2016.

The environment chosen for the active demonstration was a redundant dissolver in the First Generation Reprocessing Plant with multiple challenges, these were:

- Double skinned.
- Stainless steel thicknesses from 9mm to 50mm.
- Access possible through only one port into cell.
- The location was on the 9th floor and therefore equipment was installed using a crane.

Preparations for this demonstration, required input from a large number of Sellafield Ltd stakeholders and preparations included:

- Creating a light-safe cell – with access hole for the snake arm.
- Infrastructure installation (ventilation, compressed, electrical supply, CCTV and lighting).
- Plant modification proposals, risk assessments and operator instructions.
- Training and site access for suppliers.

The demonstration began in June 2016, and was so successful that it was extended to over 10 weeks, cutting over 200m of material and completely size reducing the dissolver vessel for future disposal. Further work is planned including a remote deployment of the snake arm with depth profiling technology in an active redundant water duct.

The success of the trial was recognised across the industry and the team received awards including, the NDA Supply Chain Award (Technology/Innovation Implementation) and the Sellafield Ltd Business Excellence Award (People’s Choice). This work has also opened opportunities for the technologies involved as well, with future deployments planned for both laser cutting and snake arm-deployed tooling.

Challenge: Dismantling / size reduction of pipes, vessels, and steelwork with limited access in a hazardous environment

Solution: A robotic ‘snake arm’ manipulator with a high powered laser for remote / semi-remote cutting

Benefits: Flexible remote approach, reducing risk and increased cutting rates for higher productivity

Status: LaserSnake system actively demonstrated on the Sellafield site with new opportunities for future decommissioning and demonstration identified

Future Activities: Laser cutting in alpha decommissioning and vitrification cell, depth profiling tools deployed from a snake arm

Milestones achieved: April 2016 – Underwater demonstration of snake arm

September 2016 – Active demonstration complete

Delivery partners: OCRobotics, The Welding Institute, National Nuclear Laboratory, Laser Optical Engineering Ltd., ULO Optics

Awards: NDA Estate Supply Chain Awards - Technology/ Innovation Implementation award

Sellafield Business Excellence awards 2016 – People’s Choice award for LaserSnake2 active demonstration

Contact:
Alan Cardwell (Decommissioning Capability Development - Remediation) alan.cardwell@sellafieldsites.com

LaserSnake within its housing

Initial underwater trials

Control desk with OCR operators carrying out commissioning tests with the snakearm

"Robotics is becoming an important part of our daily activities. The ability to support our clean-up mission by accessing areas that are too radioactive for human entry makes new robots, like the LaserSnake, an essential part of the team."

Rebecca Weston, Technical Director

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 current 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 effluents, the treatment of highly active wastes stored in tanks and improvements made to package inspections:

- Thermal Treatment Integrated Project Team
- Encapsulation Integrated Innovation Team
- Production of an Enhanced Actinide Removal Plant test rig
- Accepting decontamination liquors in the Enhanced Actinide Removal Plant
- Electrochemical Enhancement of Nuclear Decontamination Solutions (ELENDES)
- Application of graphene oxide materials in the nuclear industry
- Test rig work to support Evaporator D commissioning
- Robotic arm mounted condition monitoring and inspection instrumentation for waste package inspection
- Vitrified Product Store – Debris Removal Hatch inspection
- SonicH_2: a micro-sensor for hydrogen sensing

Thermal Treatment Integrated Project Team

Thermal treatment processes are increasingly being developed worldwide to treat a range of wastes ranging from municipal wastes to legacy nuclear wastes. The term 'thermal treatment' covers a wide range of high temperature processes from simple incineration to the higher integrity products produced by technologies such as plasma melting, in-container vitrification, joule heating, steam reforming and induction melting. Thermal processes have been less developed in the UK, particularly with regard to their potential application in the nuclear industry. Sellafield Ltd is leading a collaborative technical project to establish the viability of thermal treatment technologies to treat higher activity wastes (HAW) at the Sellafield site and across the UK nuclear estate.

The primary objective of the Thermal Treatment IPT (Integrated Project Team) is to develop thermal treatment technologies to the degree that they can be considered a technically credible option for future waste treatment challenges at Sellafield, the wider NDA Estate and the UK Nuclear Industry. This will be achieved by the active validation and demonstration of thermal technologies on the Sellafield site, using active wastes. The process will be waste-led but the programme for individual studies is aligned to key future waste treatment decisions to ensure that the technical underpinning is available in a timely manner to support these decisions and to ensure that thermal technologies can be considered a technically credible option.

Significant funding through the NDA's Direct Research Portfolio (DRP) has enabled a series of generic demonstrations at the National Nuclear Laboratory's Central Laboratory. To date trials have been conducted on magnesium hydroxide sludge, clinoptilolite, decommissioning wastes and soils. Further trials are planned for 2017/18 with key radionuclides present to obtain representative mass balance information. This series of trials will then be repeated using active materials to demonstrate product homogeneity, distribution of key radionuclides, passivity of product and mass balance information. Additional demonstrator capacity will also be installed within the Central Laboratory to continue active demonstration work on future ILW treatment options.

Thermal treatment processes have the potential to deliver significant benefits for waste treatment such as volume reduction, product passivity and organics destruction. To date efforts in the UK to develop these technologies have been disparate with each waste owner delivering their own development programme in isolation. By bringing all interested parties together Sellafield Ltd can enable a collaborative effort to be directed, working from a single delivery programme, to maximise efficiencies and eliminate duplicated effort.

Delivery partners

Nuclear Decommissioning Authority, National Nuclear Laboratory, Atomic Weapons Establishment, Radioactive Waste Management

Contact

Mark Dowson (Strategy and Technical)

mark.dowson@sellafieldsites.com

Magnesium hydroxide sludge demonstration (before, during, after)

Clinoptilolite demonstration (before and after)

Decommissioning waste demonstration (before and after)

Encapsulation Integrated Innovation Team

The Encapsulation Integrated Innovation Team (EIIT) is aiming to assist future HAW decommissioning projects through identification and development of alternative encapsulation options that may provide significant benefits over the current Portland cement baseline process. It is intended that development studies will involve a combination of industrial and academic based research.

During 2016/17 a high level technical road map was produced for the forward programme with a more detailed programme to be produced in 2017/18. Currently three packages of work are planned or being undertaken which include:

- A joint National Nuclear Laboratory/Sellafield Ltd funded critical review of national/international experience of alternative encapsulants in order to robustly define suitable matrices for the study.
- Initial geopolymer formulation development and product quality studies (previous experience has identified this system as a potential suitable encapsulant) involving industrial manufacturers (Banah UK Ltd.) and the University of Sheffield. Fluid systems have been produced on a small scale by the National Nuclear Laboratory at Workington which meet current set and bleed criteria.
- A 'proof of principle' study is planned by the National Nuclear Laboratory for FGMSP in which sludge incorporation rates in suitable geopolymer formulations defined from the above study are to be assessed against a baseline cement option.

The work is expected to provide sufficient data on identified encapsulants to progress their technology readiness levels (TRL) such that adequate comparisons can be made with the current baseline option. This will enable projects to concentrate on options deemed most viable on appropriate timescales. The potential benefits of alternative encapsulants include enhanced waste loadings (reduced package numbers), improved long term product properties (less condition monitoring and inspection or rework, provide alternate disposal options such as shallow disposal) and mitigating future encapsulant supply risks. During the next phase of the work, small scale trials will be scaled up to support near term treatment decisions relating to SIXEP wastes and FGMSP sludge.

Delivery partners

National Nuclear Laboratory, Banah UK Ltd., Lucideon Ltd., University of Sheffield

Contact

Mark Dowson (Strategy and Technical)

mark.dowson@sellafieldsites.com

The images are from small scale geopolymer trials completed in March 2017. 2017/18 will see the scaling up of this work to produce products for longer term product quality testing such as strength and dimensional stability.

Production of an Enhanced Actinide Removal Plant test rig

EARP is a medium active effluent treatment facility based around chemical precipitation and ultrafiltration. EARP operations are well understood and the flowsheet has remained relatively consistent over the last 20+ years, with over 90% of the feed volume received from Magnox reprocessing operations. In 2020, Magnox reprocessing is due to finish and this will lead to a major change in the flowsheet. Rig work will be required to build understanding of the EARP chemistry and process to underpin operations in a new regime.

In April 2016, the first module of the EARP rig was available at the National Nuclear Laboratory Workington facility. This was the ultrafiltration module and it was delivered first due to the phased approach to funding. In 2016/17, the chemical precipitation module of the rig was designed and built as a result of a collaboration between the National Nuclear Laboratory and Axium Process Ltd. with input from Sellafield Ltd as required. The two modules were integrated and the commissioning process was initiated using water. Sellafield Ltd and National Nuclear Laboratory personnel were trained on the operation of the rig and intend to work closely together to deliver the developmental programme.

EARP rig

Floc simulant

This work provides a test rig for the ongoing EARP development programme with the first rig runs planned for summer 2017. An EARP operating plan, underpinned by the R&D work carried out on the rig, is being developed to manage the work streams required to deliver the support needed by the site. This rig will help ensure BAT is demonstrably applied to discharges from Sellafield until 2043.

Delivery partners

National Nuclear Laboratory, Axium Process Ltd.

Publications/press releases/web links

Part of Business Excellence Award submission on collaborative working between Sellafield Ltd and the National Nuclear Laboratory

Contact details

Dick Blackham (Effluents Technical)
richard.a.blackham@sellafieldsites.com

Accepting decontamination liquors in the Enhanced Actinide Removal Plant

As operations at Sellafield become focussed on remediation, the effluents arising around the site will change. Accelerating hazard and risk reduction or reducing the overall costs of operations is enabled by the use of decontamination. This project aims to expand the capability of EARP to accept more decontamination liquor and secure these benefits. The first stage of the project focussed on ethylenediaminetetraacetic acid (EDTA) and citric acid as the first reagents.

During 2016/17, active experimental work was carried out in collaboration with the National Nuclear Laboratory as part of a framework agreement. The work focused on the effect of EDTA and citrate on the uptake of actinides to the flocculant or "floc" (the iron hydroxide precipitate formed during the treatment process). Both simulant and plant samples were used for the experiments and a potential acceptance envelope was identified. The results were endorsed within Sellafield Ltd and documentation will be updated to implement the broader operating envelope.

This work will allow Sellafield Ltd to expand the envelope of EARP to accept citric acid and EDTA and it therefore provides new options for decontamination operations to reduce activity in cells around the Sellafield site. The main benefits of this are:

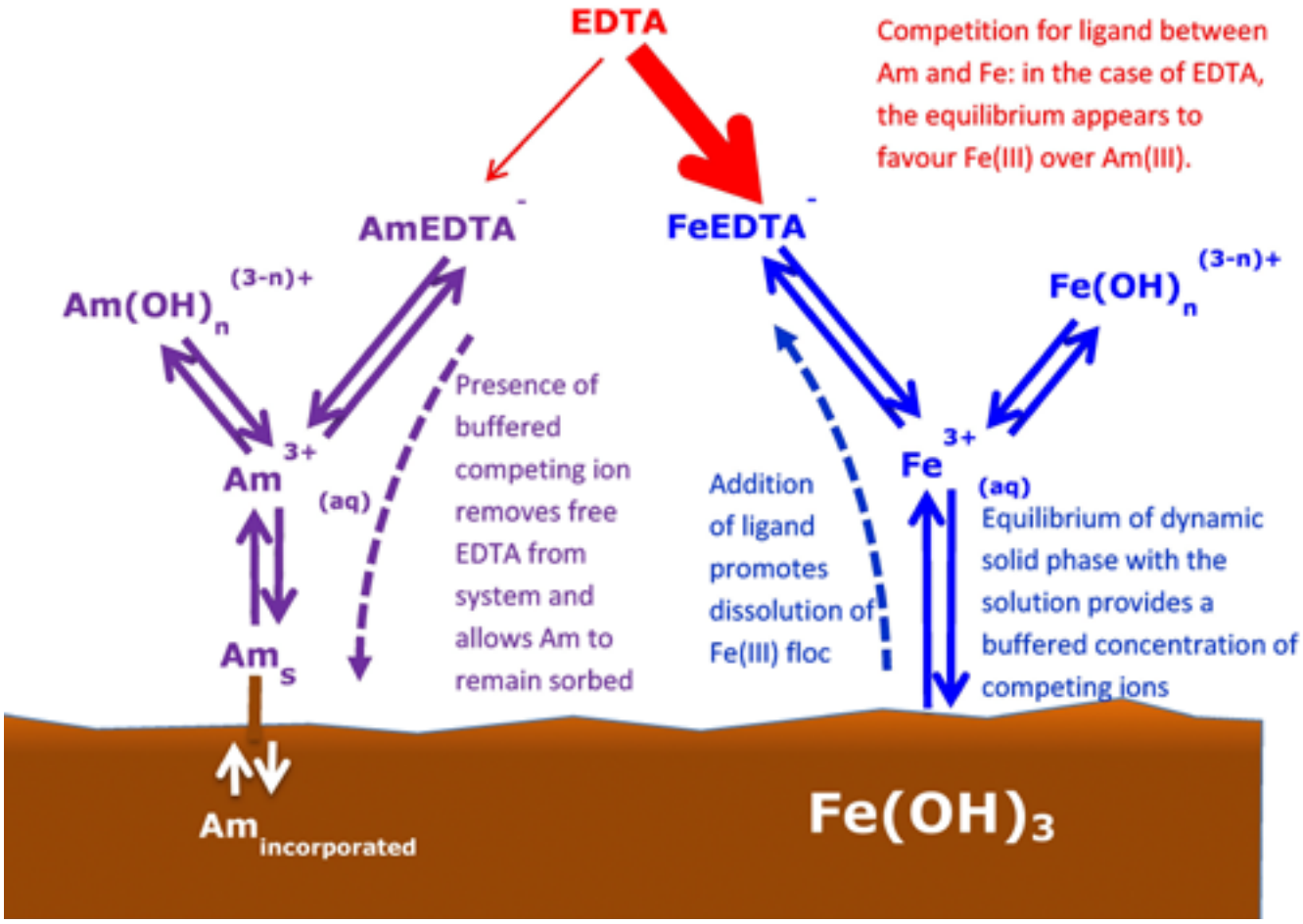
- Reducing care and maintenance costs.
- Allowing reclassification of ILW to LLW in line with the waste management hierarchy.
- Enabling man entry to cells for more effective operations.

Underpinning lab work has been completed for EDTA and citric acid with potential for future work to investigate other decontamination agents. Rig work is planned with experiments on EDTA to determine any impact on operations.

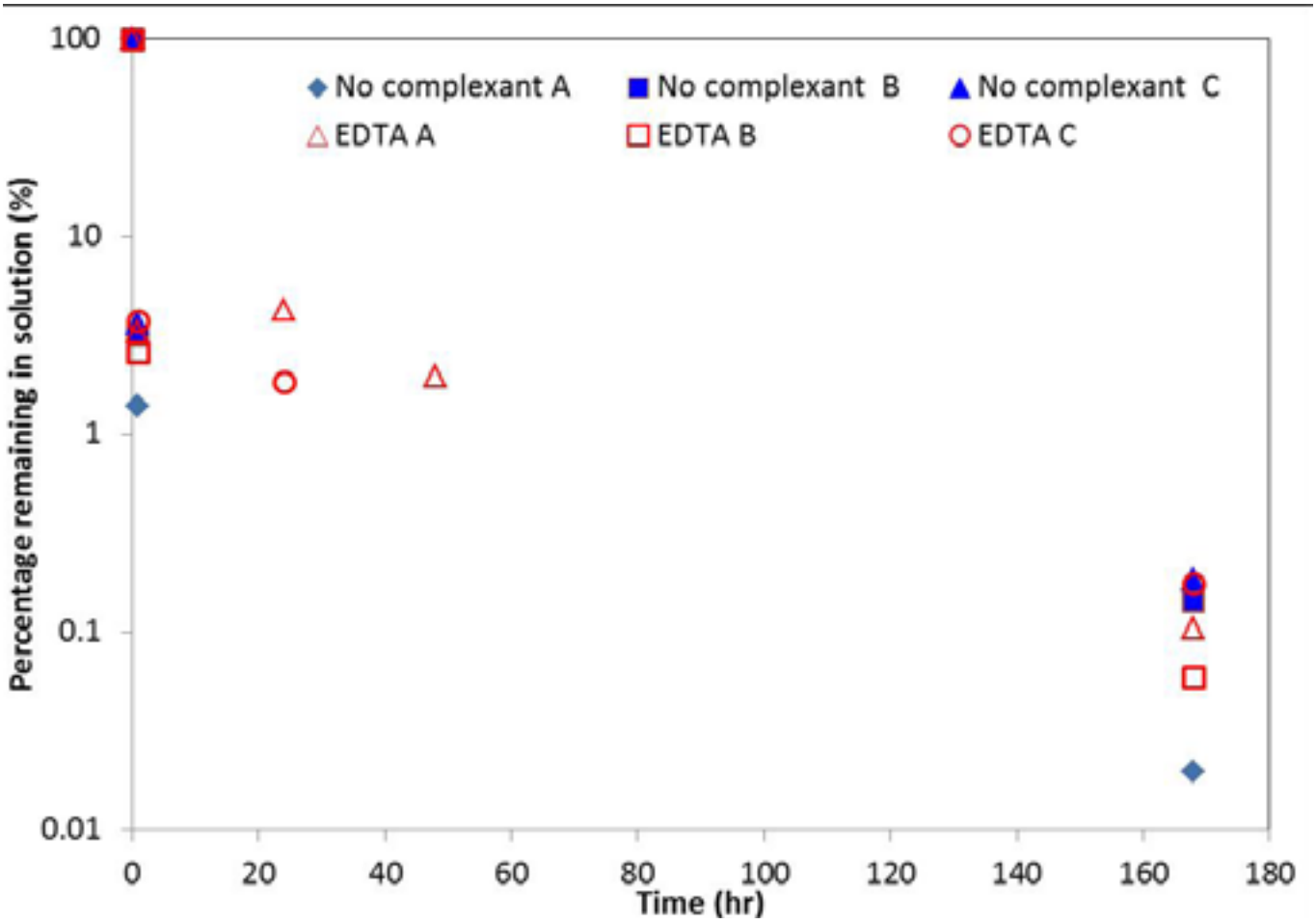
Delivery partners
National Nuclear Laboratory

Publications/press releases/web links
Part of Business Excellence Award submission on collaborative working between Sellafield Ltd and the National Nuclear Laboratory

Contact
Dick Blackham (Effluents Technical)
richard.a.blackham@sellafieldsites.com



EDTA competition


100
10
1
0.1
0.01
Percentage remaining in solution (%)
No complexant A
No complexant B
No complexant C
EDTA A
EDTA B
EDTA C
0
20
40
60
80
100
120
140
160
180
Time (hr)

EDTA graph

Electrochemical Enhancement of Nuclear Decontamination Solutions (ELENDES)

There are large quantities of contaminated stainless steel at Sellafield, with a significant amount being classified as ILW. There is an opportunity to decontaminate the material so as to reduce hazard during decommissioning and to reduce the amount of ILW waste that must be stored and disposed.

There are currently significant limitations in the decontamination reagents that can be used due to the requirement to ensure compatibility with downstream processes (such as effluent treatment and disposal routes). ELENDES allows more aggressive reagents (such as hydrochloric acid (HCl) and complexants) to be employed by providing the capability to electrochemically remove the problematic components from decontamination solutions before discharge and disposal. ELENDES can also be used to process problematic organic wastes which currently do not have a disposal route (such as short and long-chain fatty acids (carboxylics), formate, acetate, propionate, butyrate, etc., detergents, aromatics, and polymer wastes).

ELENDES has been developed collaboratively by C-Tech Innovation and the National Nuclear Laboratory with funding support from the Innovate UK process and Sellafield Ltd.

The process has been demonstrated actively on Sellafield site at laboratory scale and scale up has been successfully demonstrated at pilot scale, in both cases exceeding performance targets.

Work has been conducted with active samples (both simulants and real wastes) at laboratory scale and inactive testing at pilot scale along with a range of inactive test materials that represent waste streams of interest (for example ethylene glycol and formic acid). Further work is planned to treat decontamination solutions and also active organic wastes that do not currently have a disposal route.

Delivery partners

C-Tech Innovation Ltd., National Nuclear Laboratory

Publications/press release/web links

http://ctechinnovation.com/press-releases/CT22-31million-investment-to-stimulate-innovation.pdf

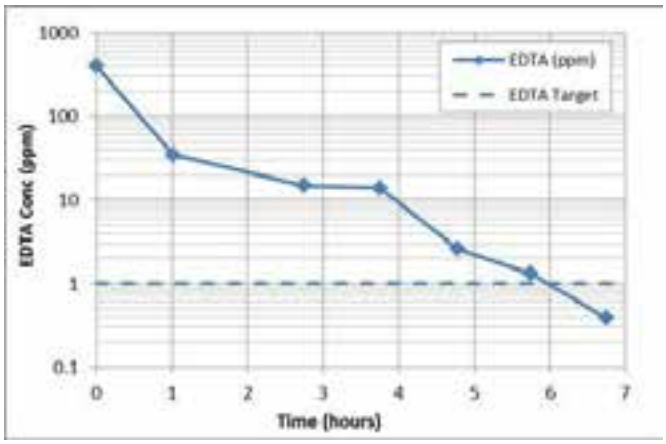
Contact

Luke O'Brien (National Nuclear Laboratory)

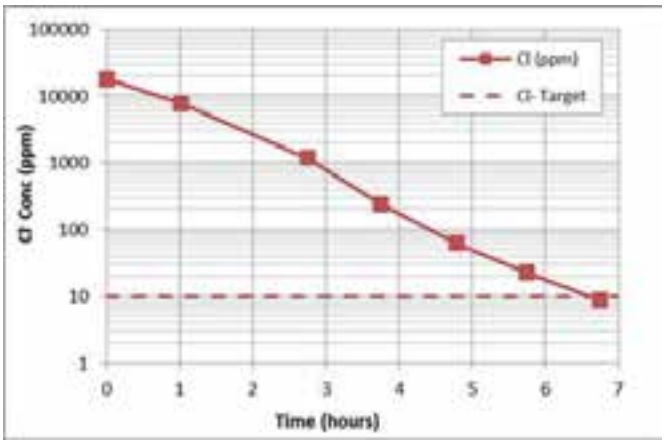
luke.o'brien@nnl.co.uk

Treatment of active waste at laboratory scale

Laboratory scale treatment unit for process optimisation

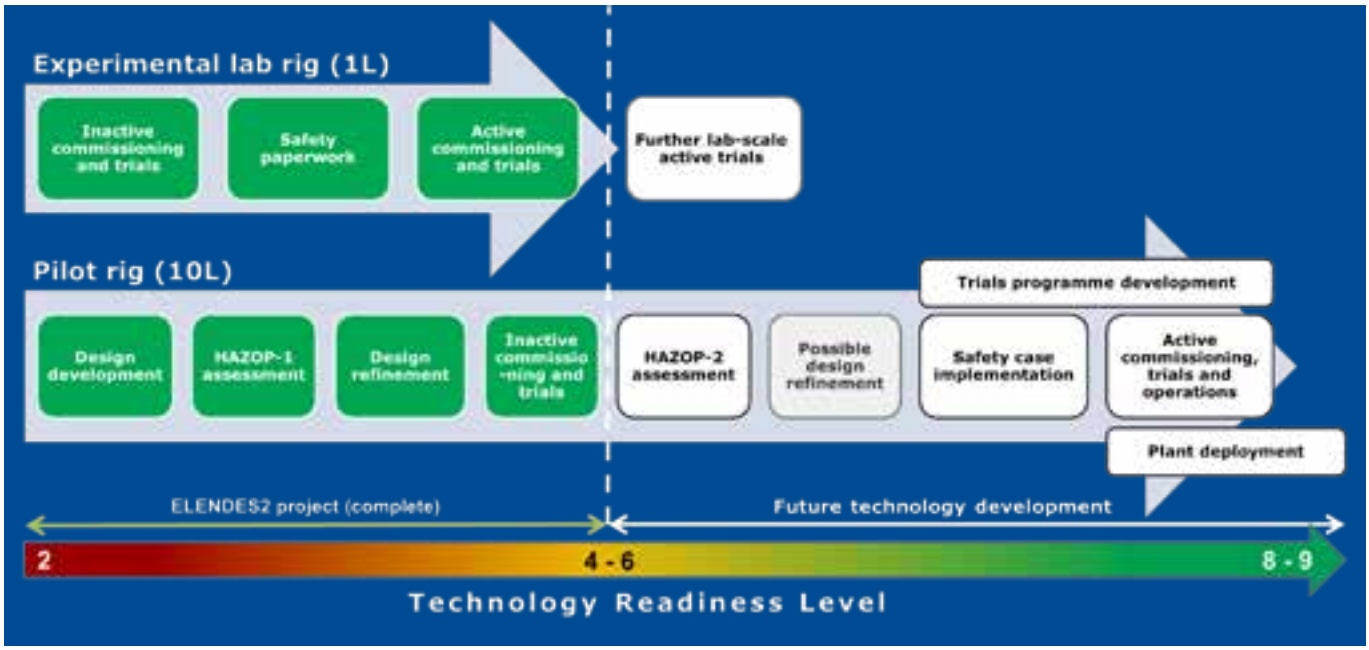


Treatment of organic complexant



Removal of chloride from waste decontamination solution

Pilot scale rig during inactive commissioning



TRL status

Application of graphene oxide materials in the nuclear industry

Applications for graphene materials are currently being explored in a range of different sectors due to their promising reported properties. Proposed applications for these materials include their use in chemical sensors, protective coatings and even wearable electronics. In the nuclear industry, one area where these materials could be applied is through their utilisation as sorption materials to remove radionuclides from waste effluent streams.

Decommissioning operations at Sellafield could result in challenging feeds for the effluent treatment plants. To address this, alternative ion exchange materials have been investigated for the removal of radionuclides from waste effluents, by sorption. During 2016/17 active laboratory experimentation was carried out at National Nuclear Laboratory's Central Laboratory with the aim of examining the sorption capability of different graphene oxide materials when they are exposed to simulated effluents generated at Sellafield. Graphene oxide synthesised for these trials was supplied in part by the University of Cambridge. In addition, computational modelling was performed in parallel by The University of Manchester to complement this work.

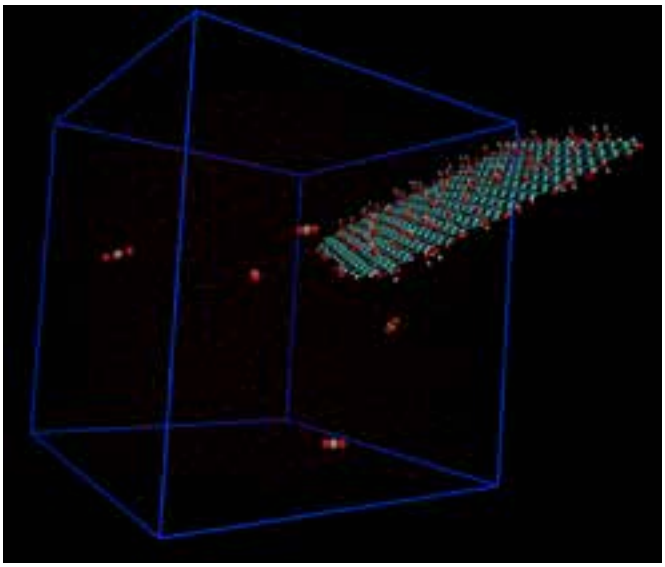


Image illustrating the modelling work to probe the sorption properties of graphene oxide materials

Image of the academia and industry engagement workshop entitled 'Graphene Materials and the Nuclear Industry'

An engagement workshop was held in September 2016 as part of this programme of work. At this event members of the academic and industrial communities were invited to share their expertise in graphene materials and discuss how they could be applied to tackle the challenges that exist in the nuclear industry. A number of collaborative opportunities were highlighted from the workshop and are now being pursued as future projects. Funding for this work was provided by Sellafield Ltd and the National Nuclear Laboratory through its internal research programme. The benefit of this work has been to establish a new research community for the use of graphene materials in the nuclear industry and to identify new materials that could be applied to address decommissioning challenges.

Delivery partners

National Nuclear Laboratory, University of Cambridge, The University of Manchester

Contact

Sean Morgan (Strategy and Technical)

sean.p.morgan@sellafieldsites.com

Test rig work to support Evaporator D commissioning

As part of the commissioning of a new evaporator, Evaporator D, in the HALES facility at Sellafield, there was a challenge to design a feed lute which would transfer highly active raffinate from a storage tank to the evaporator, without getting blocked by solids. However, there was uncertainty regarding the time required for solids to settle to a point in which they could no longer be re-suspended and the sizing of an orifice plate. A test rig was rapidly converted from an existing Sellafield Ltd rig based at the National Nuclear Laboratory Workington facility to support non-active commissioning tests on the plant. Tests were required to enable risks identified during the commissioning process to be minimised prior to active commissioning.

Sellafield Ltd initiated a project for the National Nuclear Laboratory to develop a Lute Test Rig (LTR) to carry out non-active trials using simple non-active test materials, to investigate how solids may behave in the evaporator lute feed. A rig was developed by converting an existing HALES technical rig located at the Workington facility (Slurry Transport Rig (STR)) in October 2016 for the experimental trials. These involved allowing the solids to settle over certain periods of time, in order to determine if they could be successfully re-suspended when the reverse flow diverter (RFD) was switched back on. The test rig also enabled the trials of different sized orifice plates to be used, to allow the effect of flow-rate on the suspension of the solids to be investigated. Testing under short, fixed deadlines was required to minimise delays during the Evaporator D commissioning process.

Several successful trials were carried out in a timely and efficient programme managed by combined Sellafield Ltd/ National Nuclear Laboratory team. The data collected have provided important information during the commissioning of Evaporator D. The trials and calculations have validated the chosen orifice size on plant and also significantly reduced the uncertainty around the time it would take for the solids to permanently settle. They have also provided confidence in the ability to handle settling solids within the plant and the proposed wash procedures. One of the key benefits of the trials is that they proved that solids could be kept in suspension with the current design of the lute, preventing additional engineering modifications and interventions. This has meant the commissioning for Evaporator D has stayed on schedule, and active tie-ins are due to commence in autumn 2017.

The image shows the solid simulants in the lute feed of the Lute Test Rig

Delivery partners
National Nuclear Laboratory

Contact
George McArthur (HLWP Technical)
george.ah.mcarthur@sellafieldsites.com

Robotic arm mounted condition monitoring and inspection instrumentation for waste package inspection

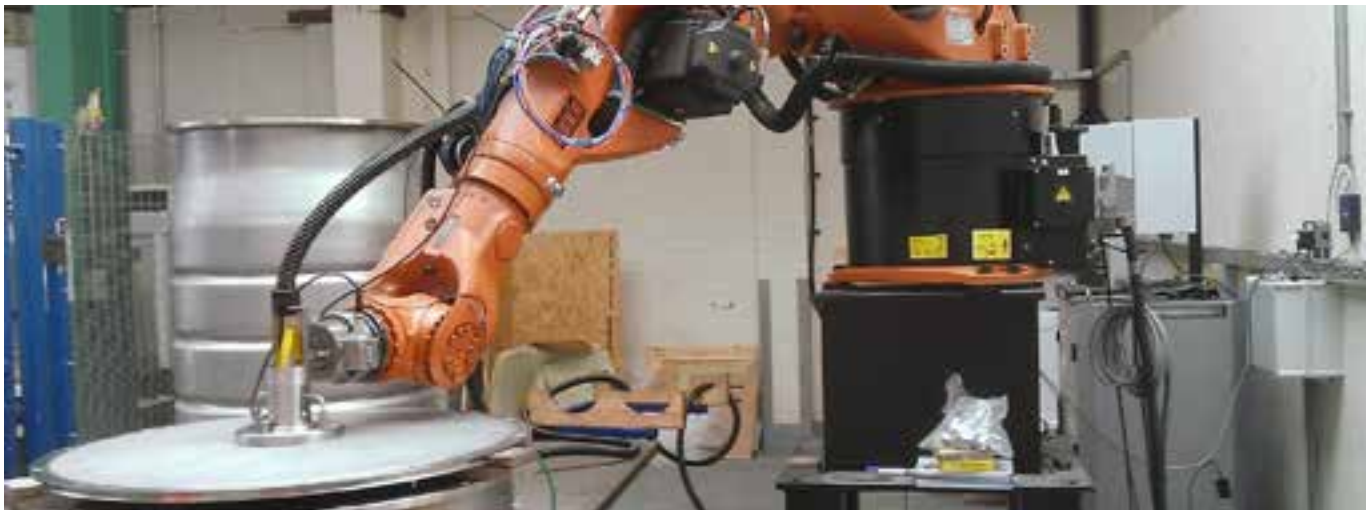
ILW waste package inspection needs to be carried out to ensure that package integrity is maintained during long term storage. However, very limited inspection technology is available that can be readily deployed to characterise ILW waste packages.

In the past, temporary installation of different instruments has been used to supplement visual information during retrieved 500L drum inspections. These instruments were static and it was realised that an articulated deployment platform would be highly desirable. An industry standard KUKA 6 axis robotic arm, with a turntable as an external axis, has been used to show that any measurement device could operate when moved or in motion and that power, control and signalling could be maintained with connection cable lengths of 25 m between sensor and user interface. A project was established to create a tool box of measurement probes that could provide materials-based characterisation of the condition of a waste package and a comprehensive survey of waste package integrity.

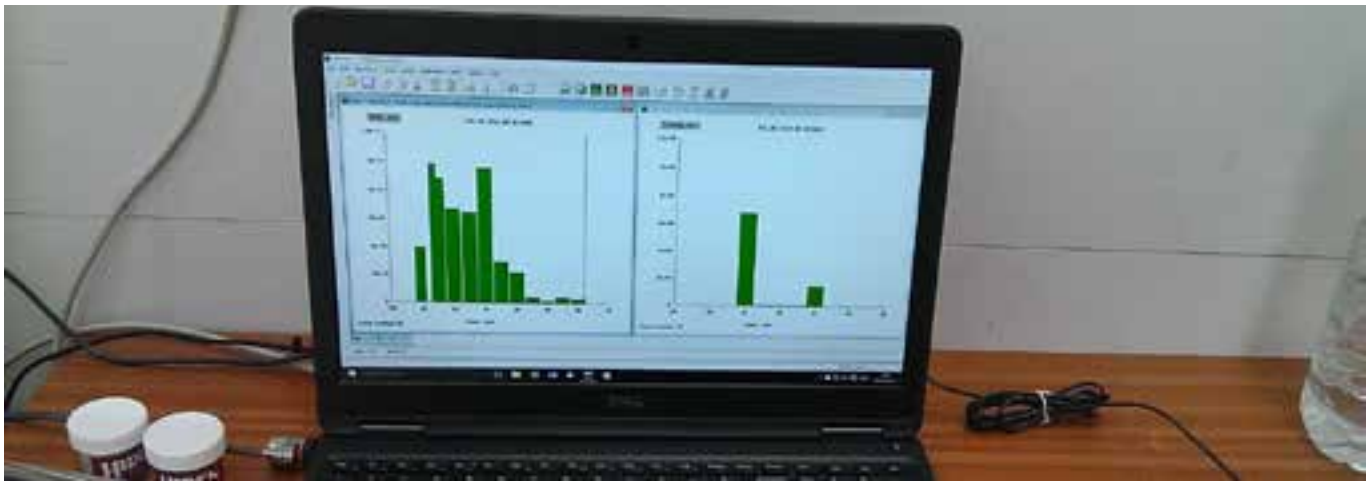
Following on from the 2015/16 trials of an ultrasonic thickness probe, an infra-red camera and a magnetic permeability probe, in 2016/17, 3 further robot arm mounted devices were successfully tested at Graham Engineering Ltd., these were: a mass spectrometer, alpha detector and an optical inspection system. The integration work for the various instruments was carried out by TTP (The Technology Partnership), design input from Hiden Analytical, device calibration and error testing by the University of Bristol, device supply and verification from the University of York and Kromek Group plc and finally, calibration support was provided by the National Physical Laboratory.

Mass spectrometer

The mass spectrometer was successfully trialled by sampling through the vent of a 500L drum. The purpose of this test was to enable the analysis of ILW container vent gases to determine corrosion or other processes potentially taking place within the container. The sample head is a generic design that can be used, with slight modifications, on other waste containers such as 3m^3 boxes, self-shielded boxes and other transport flasks.



Mass spectrometer trial - sampling through vent on 500L drum



Mass spectrometer results display

Alpha detector

The alpha detector was manufactured by Kromek Group plc based on the research and development work by the University of York with design input from Sellafield Ltd. The shape that was used for the 500L drum can be modified for use with other container shapes to indicate levels of alpha contamination. The detector was primarily developed for internal pipe inspections and an opportunity to apply the technology to external surfaces was recognised.

Alpha detector head

Alpha detector head and with test drum

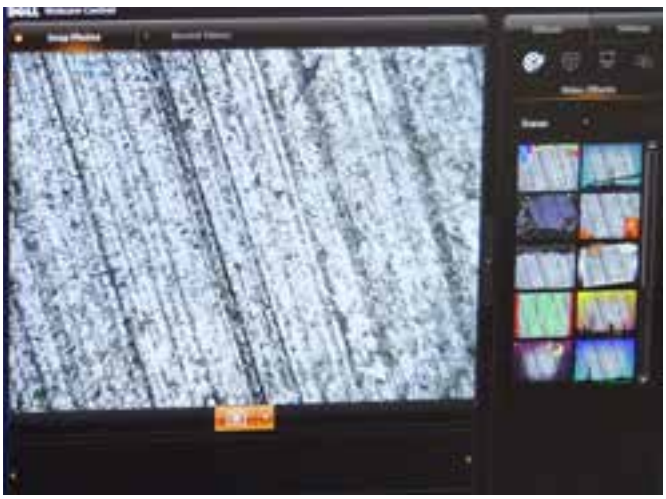
Optical inspection system

The optical camera system built by TTP and designed in collaboration with Sellafield Ltd has a number of features including the detection of surface variations and close examination of welds. It has oblique lighting to enhance and show small features and uses laser cross hairs to show surface variations. This device may be used in conjunction with an infra-red imager for surface inspection.

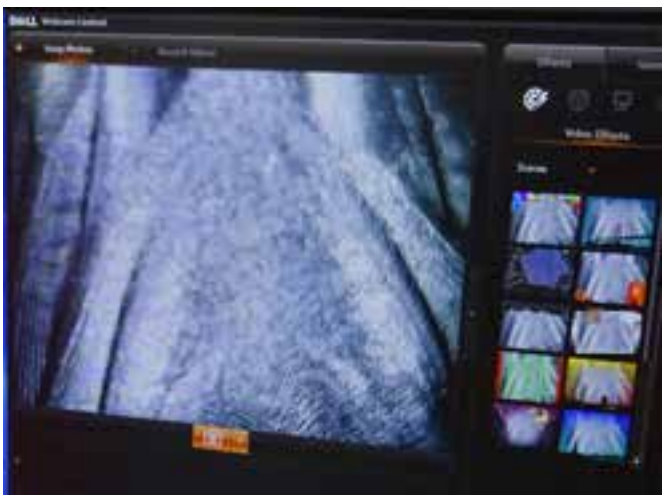
Optical camera system - original development configuration

Optical camera system - components in enclosure

Laser cross hairs highlighting surface defects



Drum surface finish zoom



Drum weld zoom

Drum test panel

Drum test feature close up

Drum feature zoom

These trials were completed in 2016/17 with further instrument trials planned.

Delivery partners

Graham Engineering Ltd., The Technology Partnership, Bristol University, York University, National Physical Laboratory, Hiden Analytical, Kromek Group plc

Contact

John Jowsey (Operations Technical, Technical & Strategy)
john.jowsey@sellafieldsites.com

Vitrified Product Store – Debris Removal Hatch inspection

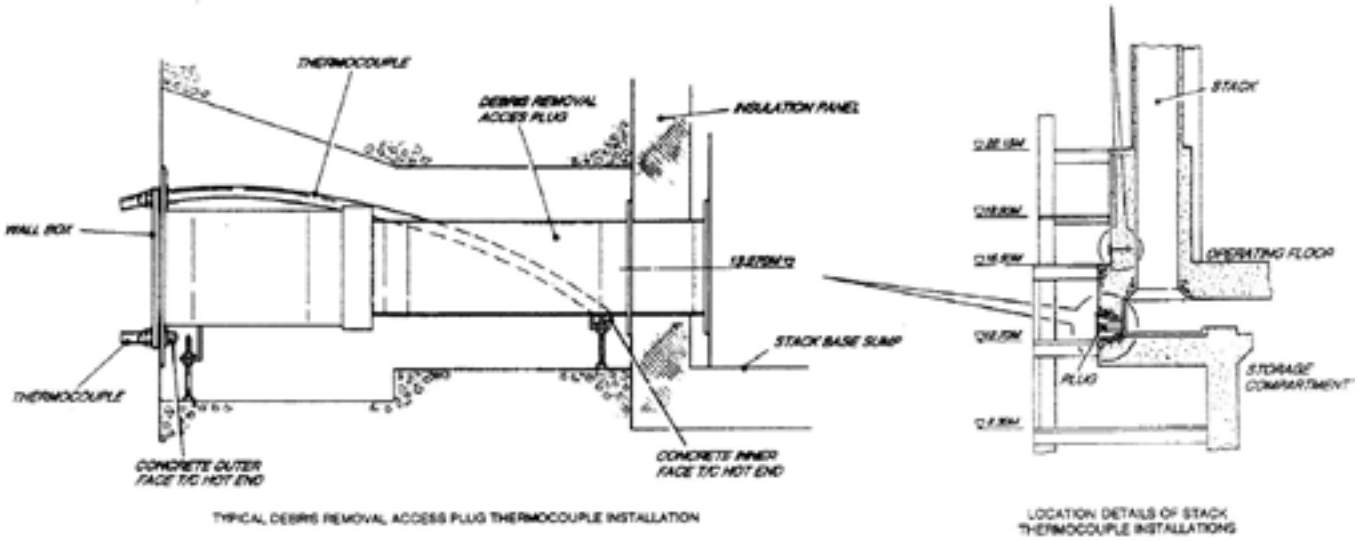
The Vitrified Product Store (VPS) is a repository for vitrified highly active (HA) waste. The new Debris Removal Hatch (DRH) inspection is the first inspection route delivered as part of a series of inspections formulated to underpin the life of the VPS. This reduces the risk of needing multi-million pound expenditure to replace it. The entry, achieved by a joint specialist team from Sellafield Ltd's Operations Technical team and the National Nuclear Laboratory, also represents the first view into the interior of the VPS's vaults since active commissioning in 1990.

The joint specialist team work together to deliver inspections in HA areas principally focussed on the HALES area. The team uses experience and skill to develop specialist deployment techniques, shielding methods and equipment in order to reach problematic locations. This new inspection represents the transfer of over a decade of learning to the new VPS condition monitoring programme.

The DRH inspections are a first step in respect of the assurance of the store's condition in line with the VPS condition monitoring strategy. The DRH's, were originally designed to allow removal of debris from the outlet stack base, and had not been removed or needed since the VPS was built but afforded a view of the upper vaults. There can be no man access to the vault interiors and many electronic devices would be damaged by what are very challenging radiological conditions. In such areas periodic remote colour closed circuit television (CCTV) inspections can be used to baseline and then check for any degradation in a nuclear assets condition without putting personnel at risk.

Working in awkward surroundings, scaffolding and the removed port plug, the team introduced the camera and radiation detector into a horizontal port from a narrow corridor.

Debris Removal Hatch – access corridor



Schematic of the Debris Removal Hatch

Despite some minor issues with heat haze, the inspection clearly showed the permanent structures in the upper section of the vault, such as the stainless steel cladding and camera rails, to be in excellent condition.

Merged picture of the upper plenum of a storage vault

The team were also able to confirm an earlier business decision to inspect individually the replaceable steel vault access plugs, as these could be seen to be tarnished. Having successfully proven the inspection concept and benefits, this new inspection route will now become a standard business operation. 1 of the 4 vaults were completed with 3 further vaults due in early 2017/18.

Delivery partners

National Nuclear Laboratory

Contact

Jo Proud (Operations Technical) jo.proud@sellafieldsites.com

Jack Denwood (Operations Technical) jack.denwood@sellafieldsites.com

Tracey Binks (Materials & Plant Inspection, NNL) tracey.j.binks@nnl.co.uk

SonicH_2: a micro-sensor for hydrogen sensing

Sellafield Ltd and TTP have initiated the development of a miniature sensor for the detection of gaseous hydrogen. Based upon the ability to accurately interpret gas composition from speed of sound through it, the micro hydrogen sensor SonicH_2 has been tested successfully as a laboratory prototype. With its unique properties of size (only a few cm^3) and limited potential for interference from other parameters, the interest to wirelessly measure the generation of hydrogen in waste storage head-space has a broad interest for Sellafield Ltd. Furthermore, with low power consumption, the envisaged system could run for up to 10 years on a single D-cell.

During 2016/17 a feasibility study was followed by the production of a prototype and this was successful in establishing the potential of SonicH_2 as a solution for hydrogen sensing in a variety of environments with restricted space. The first phase of development of this sacrificial micro-sensor reached TRL 4 and a follow-up phase of development is in progress for 2017/18 to ascertain the capability of the sensor to achieve the required range and sensitivity across a range of working conditions.

Delivery partners
The Technology Partnership

Contact
Xavier Poteau (Strategy & Technical)
xavier.poteau@sellafieldsites.com

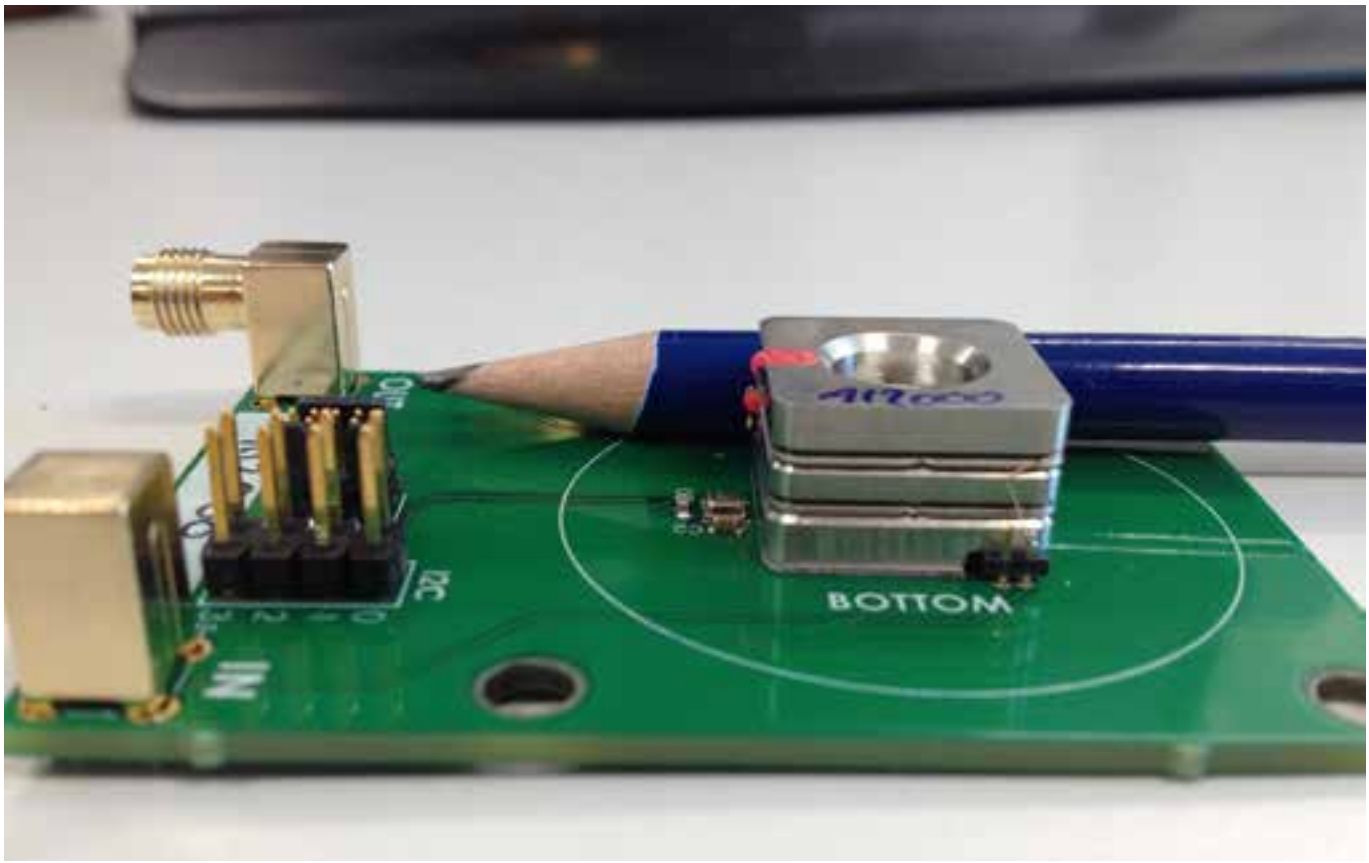


Image of the SonicH_2

Enabling technologies

Most of our R&D solutions are produced to address a specific need but sometimes they have possibilities as “enabling technologies” for wider application:

- 3D printing capability for the Sellafield site
- Wireless instruments

3D printing capability for the Sellafield site

3D printing is a growing technology both at Sellafield and within the supply chain and as a result of this a 3D committee was set up in 2016/17 to provide a single source of management of, and advice about, 3D printing.

This approach will ensure that there is a coordinated approach to 3D printing with consistent, verified parts available for use by plants. The committee collaborates with the Atomic Weapons Establishment (AWE), since they already have a 3D print facility, to benefit from their experience. In addition to this a 3D print room is being planned which would provide both the physical managed capability and the experience and learning to provide the intelligent customer role.

Delivery partners

Atomic Weapons Establishment, partnership with external 3D print bureau's and lease companies to be established.

Contact

Penny Rathbone (Technical and Strategy)
penny.j.raththbone@sellafieldsites.com

Stuart Quinn (LAEMG Engineering
stuart.g.quinn@sellafieldsites.com

3D printed connector (white part) developed during design trials

Connector split open

Machined connector based on the final design from the 3D printing trials

Images of a powder laser printed vacuum head

Wireless instruments

Control and instrument (C&I) systems are an important part of running a nuclear power plant, however there is a large decommissioning cost associated with the cables and infrastructure for these systems. If future cable installation is reduced or avoided, this will drastically reduce costs.

Historically, C&I systems include an infrastructure of cables, cable glands, trays, trunkings, conduit, junction boxes, marshalling panels and power supplies. These require design, purchase, installation and maintenance and final decommissioning. Where C&I systems are in remote locations (for example plants in POCO, decommissioning, bunds and pits, steam and water services and trenches) or where cable access is difficult (for example stacks, chimneys, furnaces and areas of high background radiation), cable costs dominate C&I budgets. As a result a project was established to investigate the use of ISA100Wireless® protocol instruments to improve the cost, time, quality, safety and flexibility at Sellafield.

Many wireless instruments are available commercially off the shelf from the supply chain, some are not. Progress during 2016/17 year covered two areas –

- Use of COTS wireless instruments on the Sellafield site.
- Adaptation of non-wireless instruments to ISA**100**Wireless®.

Use of COTS wireless instruments

Sellafield steam mains monitoring

Historically steam for plants on the Sellafield site was provided by reactors at Calder Hall and more recently a Combined Heat and Power (CHP) plant local to the site. In order to improve the information gathered on the pressure, temperature and direction of flow of steam, 21 wireless instruments were installed together with 10 steam trap monitors. This had considerable advantages over a cabled instrument system in terms of cost and it was installed on a shorter timescale.

Fan bearing monitoring

After a recurring issue with the electric motor bearings of extract fans following maintenance it was recognised that the problem might be solved by the installation of a vibration monitor on the fan. These monitors are able to send data to a logger for analysis enabling the move from reactive maintenance to proactive maintenance i.e. allowing the bearing to be fixed before the fan fails. Using ISA**100**Wireless® drastically reduced installation time and costs.

Air compressors

Existing air compressors at Sellafield have historically provided good service but there have been some recent problems with no easily detectable causes and it was thought that additional measurements and data-logging would help explain these problems and reveal the causes. Wireless pressure, flow and temperature monitors, were installed, in the air compressors to reveal presently unmeasured faults. The faults were revealed and fixed and then the instruments were removed and used elsewhere.

Tank farm refurbishment

The aim of this project was to install 80 wireless instruments on a tank farm. This needs to operate on a continuous basis and has difficult physical access. The challenge was two physically degraded instrument panels, containing DCS I/O (distributed control system input/output) outstations with potted cable entries (sealed for life), and extensive cable runs, on old, corroded and damaged tray-works.

Adaptation of non-wireless instruments to ISA100Wireless®

A number of popular wired instruments were also adapted to ISA100Wireless® by Sellafield Ltd, these were:

- CANBERRA® iCAM and G64 radiation monitors
- Micatrone® MF-PFA low-range dP instrument
- KURZ® 454FTB thermal mass flowmeter
- VAISALA® HMT330 moisture in air instrument
- FLEXIM® ADM7407 ultrasonic flowmeter
- Pyropress® Titan pressure switch
- VEGA® RADAR level instrument
- Pneumatrol® E4318CP00B solenoid valve
- Dräger® Polytron 7000 gas monitor

These wire instruments were adapted using the YOKOGAWA® ISA**100**Wireless® FN Adaptor and connected to YOKOGAWA SmartDaq+ paperless chart recorder. In future it may prove that the SmartDaq+ may fulfil many of the programmable logic controller (PLC) and DCS requirements for POCO, decommissioning and waste management.

A number of benefits of using wireless systems were demonstrated on these five projects including:

- Significant time and cost savings. Indeed, some jobs would never have been started without it.
- Similar quality measurements to wired systems in terms of accuracy, etc.
- Reliable performance and good availability.
- Flexible and the possible only option for some projects.

These projects are now complete with wireless systems becoming very popular at Sellafield. Further work is planned with several other projects identified as potential candidates for adopting ISA**100**Wireless® instruments.

Delivery partners

Yokogawa® UK Ltd. www.Yokogawa.com/eu

Publications/press releases/web links

The work has been featured in The Journal of the Institute of Measurement & Control and was the winner of the Honeywell Prize for best paper in that journal, May 2016.

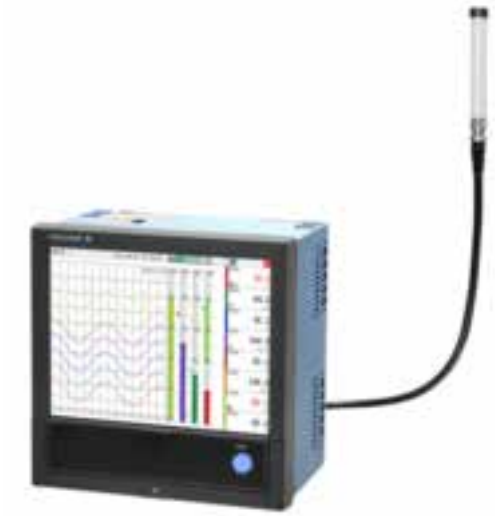
Contact

Tom S Nobes (Project Delivery Directorate)

tom.s.nobes@sellafieldsites.com

Some of the wired instruments adapted to ISA100Wireless®

Wireless gas detector



Wireless control system

Abbreviations and acronyms

AFM	atomic force microscopy
AGR	Advanced Gas-Cooled Reactor
AILWA	Alternative intermediate level waste approach
ANSTO	Australian Nuclear Science and Technology Organisation
ARPANSA	Australian Radiation Protection and Nuclear Safety Agency
AVEXIS	Aqua Vehicle Explorer for In-situ Sensing
AWE	Atomic Weapons Establishment
BAT	Best available techniques
BEP	Box Encapsulation Plant
BST	Bulk Storage Tanks
CAD	Computer Aided Design
CCTV	Closed Circuit Television
CEA	Commissariat à l'énergie atomique et aux énergies alternatives
CFD	Computational Fluid Dynamics
CHP	Combined Heat and Power
CINDe	Centre of Innovation in Nuclear Decommissioning
COTS	Commercial-off-the-shelf
C&I	Control and instrument
CE&I	Control, Electrical and Instrument
CoE	Centre of Expertise
DCS	Distributed Control System
DIAMOND	Decommissioning, Immobilisation And Management Of Nuclear wastes for Disposal DISTINCTIVE Decommissioning, Immobilisation and Storage soluTIons for NuClear wasTe InVEntories
DRH	Debris Removal Hatch
DRP	Direct Research Portfolio
EARP	Enhanced Actinide Removal Plant
ECV	Effluent Collection Vessel
EDT	Effluent Distribution Tank
EDTA	Ethylenediaminetetraacetic
EIIT	Encapsulation Integrated Innovation Team
EPSRC	Engineering and Physical Sciences Research Council
EPS WTR	Encapsulated Product Store Waste Transfer Route
FGCoE	Flammable Gases Centre of Expertise
FGMSP	First Generation Magnox Storage Pond
FGRP	First Generation Reprocessing Plant
FHP	Fuel Handling Plant
GEMS	Ground Environment Management Scheme
GDF	Geological Disposal Facility
HA	Highly Active
HALES	Highly Active Liquor Evaporation and Storage
HAST	Highly Active Storage Tanks
HAW	Higher Activity Waste
HIP	Hot Isostatic Pressing
HWP	Hydrogen Working Party
ILW	Intermediate Level Waste
IPT	Integrated Project Team
LBM	Liquor Balance Model
LETP	Liquid Effluent Treatment Plant
LIBS	Laser-Induced Breakdown Spectroscopy
LLW	Low Level Waste
LO-RISE	Long-lived radionuclides in the surface environment
LSBU	London South Bank University
LTR	Lute Test Rig
LWR	Light Water Reactor
MIRRAX	Mini Robots for Restricted Access Exploration
MSSS	Magnox Swarf Storage Silo
NERC	Natural Environment Research Council
NDA	Nuclear Decommissioning Authority
NDE	Non Destructive Evaluation
NGN	Next Generation Nuclear
NNUF	National Nuclear User Facility
NWDRF	Nuclear Waste and Decommissioning Research Forum
PCM	Plutonium Contaminated Material
PDRA	Post-doctoral Research Associate
PFSP	Pile Fuel Storage Pond
PLC	Programmable Logic Controller
POCO	Post Operational Clean Out
PXRD	Powder X-ray Diffraction
RCNDE	Research Centre for Non-Destructive Evaluation
R&D	Research and Development
RFD	Reverse Flow Diverter
ROV	Remotely Operated Vehicle
RST	Residual Settling Tank
SCP	SIXEP Contingency Plant
SEM	Scanning Electron Microscope
SIXEP	Sellafield Ion EXchange Effluent Plant

SME	Small and Medium sized Enterprise
SPP1	Sludge Packaging Plant 1
SSA	Specific Surface Area
STFC	Science and Technology Facilities Council
STR	Slurry Transport Rig
S&T	Strategy and Technical
TDA	Technology Development Alliance
TGA	Thermo-gravimetric Analysis
THORP	Thermal Oxide Reprocessing Plant
TRL	Technology Readiness Levels
TR&S	Thorp Receipt and Storage
TTP	The Technology Partnership
TWI	The Welding Institute
UIWG	University Interactions Working Group
UAV	Unmanned Aerial Vehicle
UV	Ultraviolet
VPS	Vitrified Product Store

Sellafield Ltd

Sellafield, Seascale, Cumbria CA20 1PG UK

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