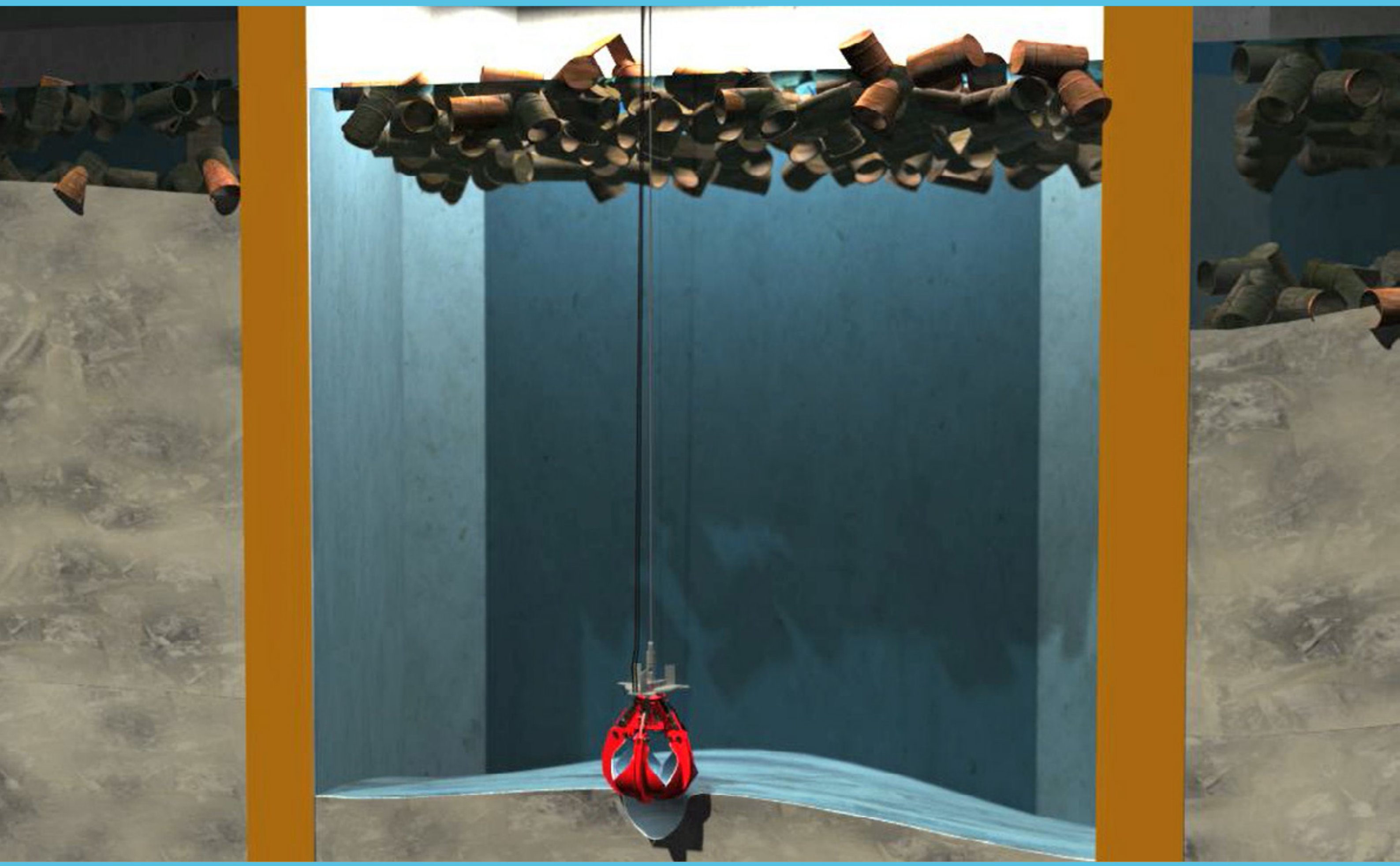

CHALLENGE:

Remote analytical techniques for characterisation of fuel derived materials

Sellafield Ltd is seeking remote analytical techniques to characterise nuclear fuel derived waste materials. This will enable better sentencing of that waste for future processing operations and disposal, reducing associated risks and improving the efficiency of retrieval of legacy waste from existing storage facilities.

Introduction

Nuclear fuel reprocessing ceased on the Sellafield site in 2022 and the site is now in its decommissioning phase. In over 70 years of operations the plant received and reprocessed nearly 55,000 tonnes of spent nuclear fuel. This resulted in a legacy of nuclear fuel derived waste and debris consisting of the following materials:

- **Magnox:** a magnesium-aluminium alloy used to clad uranium fuel.
- **Magnesium hydroxide:** a corrosion product of Magnox in water.
- **Uranium:** a nuclear fuel.
- **Uranium corrosion products:** mainly uranium oxide.
- **Swarf:** the Magnox cladding removed from uranium fuel bars, which includes some residual uranium. There are two variants of Magnox swarf, images of which can be seen in **Figure 1.**
    - Active: derived from reactors, with a passive oxide film which includes soot incorporated from the carbon dioxide coolant gas.
    - Inactive: swarf that has not been subject to reactor conditions and does not have the passive oxide film or soot incorporation as seen in active swarf.
- **Sludge:** swarf that has undergone some extent of corrosion and mainly consists of magnesium hydroxide and uranium oxide.
- **Miscellaneous Beta Gamma Waste (MBGW):** solid items of waste such as drums and metal sheeting.
- **Debris:** a heterogenous mixture of fuel derived materials, MBGW and fuel rod components such as steel and ceramic.

Figure 1: Active swarf on the left and inactive swarf on the right.

As part of its decommissioning operations, Sellafield Ltd is carrying out a retrievals programme to remove the fuel derived waste materials from the storage facilities described below. Waste is removed from these facilities and transferred to engineered waste containers known as skips for onward processing and eventual geological disposal.

Magnox Swarf Storage Silo (MSSS)

The Magnox Swarf Storage Silo (MSSS) is a radioactive waste storage facility comprising of multiple storage compartments. These storage compartments are 16m tall, with one third built underground, and are typically 6.4m x 6.4m. The nuclear waste in MSSS is stored under water.

This waste predominantly consists of a mixture of swarf and sludge with proportions varying between the storage compartments.

Waste is retrieved from the compartments by a Silo Emptying Plant (SEP) machine. This removes waste via a hydraulic grab and tooling system through an import/export tunnel sited on the top of the storage compartments. Retrieved waste is typically damp, as the water is drained out of the waste during the retrieval process, though the extent of water carryover is not yet known.

The SEP machine is located on the operations floor, a typically congested area situated above the MSSS compartments. Access to the compartments is via 150mm roof penetrations, or through the main compartment ports which are constrained to 1.2m square.

Pile Fuel Cladding Silo (PFCS)

The PFCS is a dry storage silo built to store Magnox, aluminium and graphite.

Based on the design of a grain silo, the concrete structure is 29m long, 10m wide and 18m high and is divided into six tall compartments.

The PFCS is an argon inerted environment that can be accessed via 200mm roof penetrations.

First Generation Magnox Storage Pond (FGMSP)

The FGMSP is a complex of buildings and associated ponds. The are three connected ponds which are approximately 130m in length in total, 17m wide and have a water depth of approximately 5m. Visibility within the pond is intermittently poor as a result of sludge disturbance or algal blooms. The pond temperature varies seasonally from 5-20°C and the pH is approximately 11.6.

The ponds contain:

- Spent nuclear fuel, and sludge (which has been generated from corroded fuel, corroded cladding materials and contains dead algae).
- Debris consisting of MBGW and components of fuel rods such as Magnox, steel and ceramic.

Pile Fuel Storage Pond (PFSP)

The Pile Fuel Storage Pond is one of the oldest buildings on the Sellafield site and was constructed in the 1940s to support the operation of the Windscale Piles; the first nuclear reactors to be built at Sellafield.

The outdoor pond was used for the cooling, storage of spent fuel from the reactors as part of the UK's post-war atomic weapons programme.

The PFSP is a complex of decanning bays and a pond containing an inventory of historic fuel, sludge and solid MBGW. The main pond is approximately 100m long by 25m wide and approximately 5.5m deep. The pond temperature varies seasonally from 5-20°C and is approximately pH 9.6.

The Need for Characterisation

The sludge and swarf stored within MSSS have the potential to generate hydrogen, which poses an explosive and expansion risk. This is the limiting factor for the amount of waste that can be stored in the retrievals skips. As these are currently filled on a worst-case assumption, a solution which can characterise these materials would allow the payload to be optimised. This would potentially reduce the number of skips required to complete the retrievals programme, providing significant cost savings.

For other legacy facilities (FGMSP, PFSP, PFCS), solving this challenge brings the potential to provide better material accountancy. This is defined as the quantification of nuclear material by measurement or technically justified estimate, in order to account for material during movements between areas. The ability to improve material accountancy supports compliance with Nuclear Safeguard Regulations 2019.

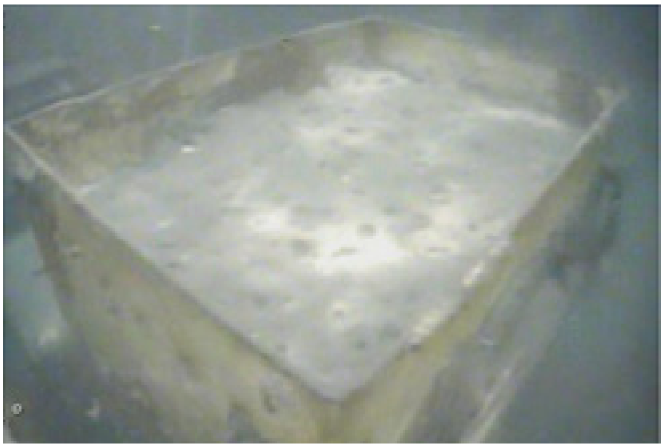

Figure 2: Skip containing debris within FGMSP.

Figure 3: Unwashed (top) and washed debris (bottom) within FGMSP.

Current Practice

MSSS

Modelling is used to infer where sludge and swarf are situated within each MSSS storage compartment. The modelling details the transition zones between different materials and works on a worst-case assumption. Confidence in visually determining material composition within transitions zones is low. It is, therefore, likely that skip payloads are poorly optimised, resulting in excessive skips being used.

The use of AI to interpret images and identify Magnox in sludge is currently being explored, although this work is still in the early stages of development.

Legacy Ponds & the Pile Fuel Cladding Silo (PFCS)

Whilst retrieving waste from legacy pond facilities and PFCS, visual inspections are carried out. These visual inspections are conducted by trained operators who look at camera footage to identify and pick out materials to determine the appropriate waste routes. Although this is currently the best option available to Sellafield Ltd, it does not provide accurate analytical data and can be subject to operator bias.

The development of AI computer vision for item identification is being explored but is currently at a very early stage.

Challenge Aims

Sellafield Ltd is seeking solutions that can effectively identify and quantify fuel derived materials including:

- **Magnox**
- **Magnesium hydroxide**
- **Uranium**
- **Uranium corrosion products, which are predominantly uranium oxide**

These materials may be stored under dry, damp or underwater conditions, depending on the facility. It is understood that a single solution may not be viable to conduct characterisations under all of these conditions. **Partial solutions that can characterise materials in any of the storage scenarios described are welcomed.**

To enable characterisation within the FGMSP, a solution must be capable of being mounted on a Remotely Operated Vehicle (ROV) or manipulator arm, to reach fuel derived waste that is stored under water.

Wider benefits could be realised if a proposed solution can:

- Distinguish other materials such as steel and aluminium.
- Perform characterisation at various processing stages to ensure materials are managed appropriately and allow for informed decision-making based on accurate data.
- Characterise the compositions of materials in the MSSS compartments in-situ, prior to retrieval. This would allow for more streamlined retrieval operations and provide feedback to the current material transition models.
- Identify small pieces of waste, typically between 8mm and 100mm in size, which would improve waste management and processing outcomes.

As Sellafield Ltd's legacy waste retrievals programme is currently ongoing, solutions that can be implemented within a 1-2 year timeframe would be advantageous.

Whilst deployability of characterisation methods is a critical consideration, finding a solution capable of conducting the required characterisation of these fuel derived materials is the initial challenge. Design of deployment methodology will be addressed at a later stage.

Benefits to Sellafield

The ability to characterise fuel derived waste materials will have broad benefits across the whole NDA estate and support compliance with Nuclear Safeguards Regulations 2019. Enhanced material accountancy and characterisation would contribute to better defined end states for fuel derived waste materials and refinement of future processing and disposal strategies.

Optimising MSSS skip fill payload would bring enormous benefits to the overall decommissioning programme, significantly cutting the cost of the waste retrievals. The cost of excess skip manufacture, storage, disposal and associated operational costs are in the order of £100M+. A small step-change in efficiency could result in multi-million-pound savings. Additionally, skips are ultimately destined for the Geological Disposal Facility (GDF), reducing the number of skips could bring an additional £100-200M of cost savings.

MSSS characterisation could give real data feedback which would be beneficial for validating baseline modelling assumptions. By leveraging data collected from processing, the modelling can continuously improve its predictive capabilities, enhancing accuracy over time.

Within FGMSP, the capability to identify small pieces of fuel, metals and other fuel derived materials, typically between 8mm and 100mm in size, would improve waste management and processing outcomes.

Solving this challenge would mitigate against overspend and delays in the waste retrievals programme. Better materials accountancy would enable specific parameters for future processing, such as quantities of grout for encapsulation, or the requirement for ventilation due to hydrogen generation to be optimised efficiently.

Constraints

Any proposed solutions to this challenge must operate within the following constraints:

- Radiation levels up to 12Gy/hr in the storage facilities.
- Materials are stored under a variety of conditions, including dry, damp or underwater.
- There must be minimal disruption to waste retrievals operations.
- No additives should be introduced to any waste.
- Once installed, access to equipment is likely to be difficult.
- Should any equipment require disposal, it must be compatible with designated waste routes.

Storage facility specific constraints:

MSSS

- SEP machine operations must not be disrupted, although it may be possible to integrate a solution within the SEP machine, e.g. on the hydraulic grabber via 150mm ports.
- Access to silos is available through 150mm through-roof penetrations.
- The operations floor is a very congested area, therefore space is limited.
- If a skip is used to deploy equipment, the equipment must be less than 1.2m x 1.2m x 1.1m in size.
- Power and data cabling is limited; however, options for adding additional cabling are being explored.
- High humidity.
- Nitrogen inerted environment.

PFCS

- Argon inerted environment.
- Access to silo is via 200mm roof penetrations.
- Operations area is congested.
- High levels of loose contamination.

Legacy Ponds

- Weight limit is typically 10kg for any equipment to be deployed on an underwater ROV or Brokk manipulator arm, although this can vary.

- If deployed under water, the operating depths will be up to 5m, with visibility intermittently poor as a result of sludge disturbance or algal blooms. Pond temperature varies seasonally from 5-20°C. FGMSP is approximately pH 11.6, and PFSP is approximately pH 9.6.
- If deployed within a skip, size constraints of 1.4m x 1.4m x 1.1m need to be considered.

Functional Requirements

Any proposed solutions should have the features below.

Essential

- Ability to identify and quantify Magnox, magnesium hydroxide, uranium and associated corrosion products.
- Provide consistent and repeatable results.
- A variety of conditions (dry/damp/underwater) apply to this challenge; solutions that can work in all environments are preferable; however, solutions that work in any one of these scenarios are of definite interest.
- Ability to characterise a heterogenous mixture of fine and coarse material.
- Provision of a real-time analysis is vastly preferred over a post-processing option.
- Stand-off techniques are preferred; however, contact with the waste could be considered if appropriate.
- The solution must be radiation tolerant.
- For underwater legacy ponds, the solution must be capable of being mounted on a ROV or manipulator arm.

Desirable

- A single solution capable of characterisation in all environmental conditions would be advantageous.
- Remotely deployable; a solution which requires no manual operator interference would be highly advantageous.
- Ability to distinguish steel and aluminium; there will be no requirement to quantify these materials.
- Ability to self-calibrate.

Find Out More

Game Changers are hosting a workshop for this challenge where delegates will have the opportunity to meet challenge owners. Details are available on the Game Changers website www.gamechangers.technology.

If you have new ideas or innovations which can be applied to address this challenge, we invite you to join us. If you'd like more information about the funding available through the Game Changers programme, please visit Our Funding Process (gamechangers.technology).

The deadline for applications for this challenge is 3pm on Monday 14th April 2025.

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