Decommissioning Waste Handling and Storage Challenges

Part of the “Sellafield Ltd Game Changers” Series

How to use this document

This document introduces the challenges associated with the dismantling, size reduction and decommissioning of the legacy nuclear plants on the Sellafield site.

Sellafield Ltd seeks a toolkit of options to minimise radioactive and chemotoxic waste, providing cost effective waste management solutions to ensure waste can be sorted, segregated and packaged. Solutions are sought for waste and effluent treatment, ideally a flexible, repeatable modular capability.

The document has been formatted to provide information on:

- Current baseline technologies which are available for use today
- Limitations of current baseline technologies, that could potentially be addressed with innovation
- Perceived gaps with the existing approaches and suggestions on areas where there is an opportunity for innovative solutions

Innovation might be technologies or approaches successfully deployed in other industrial sectors, or completely novel ideas and concepts.
Introduction to Decommissioning
Decommissioning ageing nuclear engineering facilities is one of the major challenges of the 21st century. The international market in nuclear decommissioning and waste management relating to power generation and reprocessing plants is estimated to be in the region of £250 billion, with the operations requiring in excess of 100 years to complete\(^1\). The UK component of this is estimated to be approximately £70 billion\(^2\), with completion on similar timescales.

The UK has been at the forefront of the development of nuclear technology since the early 1940s in the design, build and operation of power reactors and their associated reprocessing and waste treatment facilities. This has resulted in significant technical waste management and decommissioning challenges and opportunities for the UK to develop and deploy technological solutions on UK sites, including Sellafield, and for the international nuclear market.

Sellafied Site Overview
Sellafield is the most complex industrial site requiring remediation in Western Europe, comprising approximately 283 hectares in the west of Cumbria. Nuclear operations on the site commenced in the 1940s, reflecting the full range of activities undertaken by the UK civil nuclear industry. The site consists of more than 2200 buildings including 170 major nuclear facilities. As reprocessing operations cease around 2020, the major focus will shift to Post Operational Clean Out, waste management and decommissioning activities. Due to the variety of operations performed at Sellafield, a wide range of challenges will need to be addressed including characterisation of:

- Enclosed cells containing redundant chemical operations
- Gloveboxes used for research, development and fuel fabrication operations
- Facilities used for the storage of spent fuel
- Waste storage and handling facilities
- Spent nuclear fuel reprocessing facilities
- Pipe and ductwork within a range of plants
- Sewers, pipe bridges and trenches
- Redundant facilities, such as turbine facilities, that have been left to decay

The Sellafield decommissioning mission will require the handling, treatment and storage of wastes generated from the closure and decommissioning of the facilities on the site. Sellafied Ltd currently performs a lot of waste handling and storage, but new approaches will be needed to meet the challenges posed by the waste generated during plant closure and decommissioning. This will require significant input from the supply chain. The need for this will increase significantly as the site prepares for increased intensity of decommissioning activity in the next 5 to 10 years. Provision of timely and fit for purpose techniques to handle and store hazardous radioactive waste in more efficient ways will be a key enabler to optimise decommissioning and waste management. There is potential to significantly reduce the decommissioning cost and timescale.

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\(^2\) Nuclear provision – Explaining the cost of the cleaning up Britain’s nuclear legacy, Nuclear Decommissioning Authority, February 2015
Business Benefit
Sellafield Ltd needs to integrate a diverse range of information to plan and execute decommissioning and waste management activities. The aim is to provide information to enable better decision making at the design and planning phase; provide virtual environments to test options and tools; link to additive manufacture and support safety assessment; train operators; provide human performance and other information to operators via for example augmented reality.

Sellafield Ltd needs to reduce the cost of decommissioning and has identified ‘improved waste handling and storage’ as a key area of focus.

Decommissioning Waste arising over the next 50 years
Waste Handling and Storage Challenge Overview

Radioactive waste handling and storage poses challenges due to the inherent chemical and physical hazards of the waste. The wastes from decommissioning range from wet, mobile slurries and sludges to large heavy pieces of plant and building structures. Individually these wastes may be problematic due to radiological and chemotoxic hazards that may preclude direct man access to facilities in order to deploy equipment. The facilities containing waste do not have man-access. Further waste arising from decommissioning may be mixed and potentially need further segregation, for example pieces of plant such as tanks and vessels may still contain residual liquors, slurries or deposits. Innovative tools and techniques for the remote handling of waste are required to work alongside or replace baseline technologies so that waste handling is more efficient.

Options that allow us to optimise our waste management hierarchy performance are important to Sellafield, to prioritise waste prevention, as the preferred option, followed by reuse, recycling, recovery including energy recovery (not an easy option with radioactive materials) and as a last option, safe disposal.

Once retrieved wastes need to be stored in a safe and secure manner, often for several decades before a national disposal facility becomes available. Innovative ways to efficiently package waste whilst still maintaining safety requirements that minimise the storage capacity required will be essential to reducing the cost of decommissioning the Sellafield Site.
A number of factors challenge the effective handling of wastes across the Sellafield site:

- Access may be restricted, so that often waste items and packages are limited to those handleable by a person.
- The process of filling waste packages in restricted environments often leads to packages becoming contaminated and needing cleaning.
- The weight of shielding often leads to the waste being loaded in a liner first which adds to the cost and waste volume.
- Space limitations mean that there is often little opportunity for decontamination, sorting and segregation of waste where it is generated.
- A range of different pH environments (pH<0 to greater than 11) in different plants.
- Heterogeneity of materials.
- Lack of ‘direct line of sight’, deployment inside shielded cells means that operators cannot see directly how equipment is engaging with the waste items nor can operators enter to make connections to waste items.
- Assessment of contents of redundant items and waste packages are assumed; assumptions have to be made about the contents, geometry, and mass etc. of the waste. Better measurement and assessment techniques could lead to a significant reduction in ‘phantom’ waste; this is waste that is consequently disposed via a different route which is less expensive.
- Waste sentencing – waste needs to be measured to confirm that it can be disposed of via a certain waste route. Techniques for waste measurement and decision making software’s are required.

Waste Handling and Storage Vision

Imagine if we could with dismantle plant no human intervention into hazardous environments and pack those waste items into secure containers with optimum efficiency with the result that the minimum number and volume of waste packages is required for long-term on site storage and disposal.

Imagine that we had the ability to take all decommissioning materials and render them inert, or at least decontaminate, sort and segregate the waste to maximise our waste management hierarchy performance.

Imagine that we could package or render all types of waste passively safe until the radioactivity decays to a background level.
Game Changers
A Sellafield initiative, delivered and managed by Innovus

Waste Packages / Containers

Sellafield's vision is to reduce the lifetime cost of Higher Activity Waste (HAW) containers by 50% by implementing an improved range of cost-effective waste container options for decommissioning and final disposal. The objective is to contain waste for transport and storage, whilst enabling easy handling, inventory analysis and inspection, as well as ensuring compliance with relevant storage and disposal requirements.

The use of stainless steel for ILW containers is disproportionately expensive. The cost estimates of waste boxes (3m³ and 4m³ boxes) range from £50,000 to £120,000 per box. Current projections suggest that Sellafield will spend approximately £2bn on waste containers. The high cost of waste containers is largely driven by real and perceived requirements from Radioactive Waste Management (RWM) so that waste is acceptable for long term geological disposal.

The high cost of the current waste storage solutions provides suppliers with a unique opportunity to demonstrate engineering excellence. Last year, UK supplier Stainless Metalcraft were awarded a £47 million contract to provide waste containers for the Sellafield nuclear site, with a second contract of the same value secured by Darchem Engineering Ltd. Going forward, innovation in container design and containment strategy will be key to delivering a cost-effective solution.

Baseline Methodology

- Plutonium Contaminated Waste (PCM) is stored in 200 & 500 litre stainless steel drums in purpose-built stores.
- Lower Level Waste (LLW) is disposed of in a LLW repository in ISO containers (mostly half-height).
- Intermediate Level Waste (ILW) from decommissioning is stored grouted in 3m³ stainless steel boxes in purpose built stores.

500 litre Drum
Stillage + 4 x 500 litre Drums

Waste Packages / Containers
Limitations

- Where appropriate waste should be compatible with the proposed Geological Disposal Facility.
- The provision for storage of LLW (at LLWR) is limited.
- Compatibility of containers with treatment and storage plants.
- Weight limits, the waste is, or will be, transported by road and rail to disposal sites.
- Total activity / dose rate limits.
- Fissile content limits.
- Management of heat generation and gaseous evolution (e.g.: hydrogen) for some wastes.
- Long term integrity (package integrity shall remain stable, intact and be maintained for 150 years and should be maintained for 500 years).
- Lifting & Movement of packages.
- Safe transportation – transport regulations on public roads and railways.

Perceived Technology Gap / Opportunity

Expense of some of the packages.

Fundamental challenge to site infrastructure/stores, to RWM requirements and to LLWR requirements (these challenges may allow changes to current relations and allow containers of different construction and much larger size/capacity).

Something strong, scalable and flexible e.g. vacuum packing / cling film. These packages need to be road transportable adhering to ISO freight and weight limits for public roads.

Stillages to provide more ordered waste packing to increase packing efficiency of waste.

Fissile inventory assessment is known to be pessimistic due to, amongst other things, measurement and assessment techniques used.
**Waste Treatment**

The objective is to provide a capability for dealing with the wide range of decommissioning wastes likely to be generated in accordance with the principles of good Waste Management practice (i.e. reduce, reuse or recycle waste whenever possible). The purpose is to provide optimum waste treatment (safety, environmental, cost and schedule).

A secondary objective is to have local fit for purpose waste treatment rather than rely on site-wide infrastructure. The purpose is to reduce waste volumes generated and avoid the need for the construction of significant waste treatment facilities. Sellafield would like to focus on modular container systems which are reconfigurable and transportable between facilities.

**Baseline Methodology**

Currently, waste arising during decommissioning is either packaged at or near the place it arises or sent to existing waste treatment infrastructure which was mostly provided for reprocessing wastes.

- Lower active and out of scope waste tends to be segregated and packaged at the place it arises, typically placed in bags or drums that can later be monitored for disposal to either specified landfill or consolidated into half-height iso-freights for disposal at the Low Level Repository.
- Intermediate Level Waste (ILW) tends to be processed in one of our existing treatment plants which were originally designed to support reprocessing; these grout the waste into stainless steel drums and boxes.

- Plutonium contaminated waste is directly packaged into 200 litre stainless drums which are then taken for compaction and grouted into 500 litre stainless steel drums.
Limitations

- Space and other compromises for local waste treatment facilities including dealing with background radiation.
- Small number of routes – more options required. ILW routes based on those that support reprocessing of spent fuel.
- Limited decontamination, sort, segregation and consolidation facilities on site and locally available.
- Recycling and reuse of contaminated materials not routine.
- Ability to store materials pending reuse.
- Avoid producing waste streams that are not compatible with current waste routes.

Perceived Technology Gaps / Opportunities

New techniques / technologies – alternatives to baseline technologies
Small, cost effective, universal facilities to deal with the waste from specific facilities
Reliable, robust and easily maintained: crushers, compactors and shredders
Modular facilities and containers that are reconfigurable and transportable between facilities
Long Term Monitoring of Waste Containers

The objective is to detect long term (decades) changes in waste container integrity. The purpose is to reduce the potential for container failure and associated contamination of a facility. The ability to observe small changes over long periods of time is required. Improved cameras are not required.

Baseline Methodology

- Sample waste packages are taken out of stores for non-destructive assessment.

Limitations

- Often visual/camera inspection of the material
- The ability to observe and highlight small changes over long periods of time (decades).
- Changes in shape and size of containers – primary effect not known
- Done on sampling approach
- Cannot easily detect minor changes such as swelling of packages

Perceived Technology Gaps / Opportunities

Sensors in waste packages to indicate evolution of waste and integrity of package. More detailed inspection and monitoring is required to track and indicate earlier when things change and to provide information earlier to reduce over design

- Sensors on waste packages to indicate package performance
- SMART coatings to indicate package performance
- RFID or similar on or in the waste package to identify and track the waste and possibly hold data about package and contents.
- In-situ inspection using mini-robots
- Some early disposal (10-20 years) was in vaults and trenches and we now need to confirm they are safe and confirm how long they can be stored there safely.
- Long term monitoring may allow us to re-categorise some packages
- Use of autonomy/machine vision to identify changes
- Early warning of defective packages
- Technology that can image the interior of packages and wasteforms.
**Waste Assessment**

The objective is to **assay bulk plant items and equipment (with radioactive content including that with curved surfaces, shielding and difficult to access locations (internal contamination))** in order to enable a **sentencing decision** (which way the waste will be routed) made by suitably qualified and experienced people at Sellafield. For example, this internal contamination happens inside computers and kit with ventilation grills. The purpose is to **deal with waste sentencing of alpha contaminated items in the most efficient way in order to enable segregation of waste categories**. Sentence other waste in-situ is often problematic as high back-ground radiation or unknown geometry, weight and materials can lead to over pessimistic assumptions.

**Baseline Methodology**
- In Plutonium facilities, the default is to classify waste as Plutonium Contained Material (PCM)
- Swabs are taken and an alpha radiation detector (DP6) is used if access to the sample is available
- Activity assessment methodologies use provenance and assumptions
- Detectors and monitors are used to assess bulk packaged waste

**Limitations**
- Shielding of alpha particles to prevent them becoming mobile and airborne
- Internal components difficult to access
- High background radiation meaning a higher waste classification
- Challenging disposal criteria
- Varying fingerprints and age of material
- Assessment of waste methods often done using overly conservative codes derived for nuclear fuel irradiation assessment (FISPIN).

**Perceived Technology Gaps / Opportunities**

Ability to measure internally contaminated alpha bearing items with minimal intervention at the required confidence level and then declassify. So, such as, a computer with a fan which has been in an ‘Alpha’ environment will be disposed of as PCM waste because we are not able to measure the internals as clean.

Better waste classification of components to enable low level radioactive content to be processed in a more efficient way.
Encapsulation

The objective is to have efficient encapsulation of wastes, maintaining a Radioactive Waste Management (RWM) compliant waste form and minimizing voids. The purpose being to produce RWM compliant waste form that can be disposed of in waste packages. The encapsulation process takes place inside heavily shielded concrete cells which ensure maximum operator protection.

Baseline Methodology

- Plants are designed to process solid, intermediate level radioactive waste, packaging it into a convenient form which provides for efficient and simple handling, transport and storage.
- Waste Encapsulation Plant (WEP)
- Magnox Encapsulation Plant (MEP)

Limitations

- Management and disposal of radioactive waste acceptance (*see link below)
- Minimising voidage (conditions for acceptance)
- Weight limits for transport and movement. For example the weight limit is 64 tonnes for rail transportation
- Reaction with waste contents and reactive with cements
- Sourcing, availability and supply of suitable container materials
- Reliance on energy intensive cement and supply of blast furnace slag and pulverised fuel ash.

Perceived Technology Gaps / Opportunities

- Use of super-plasticisers to enhance void filling (high fluidity, non-reactive encapsulants)
- Injection for void filling
- Neutron absorbing materials (neutron poisons)
- Requirement to encapsulate at all?
- Alternative encapsulants
- Use of geopolymers
- Increase packing fraction