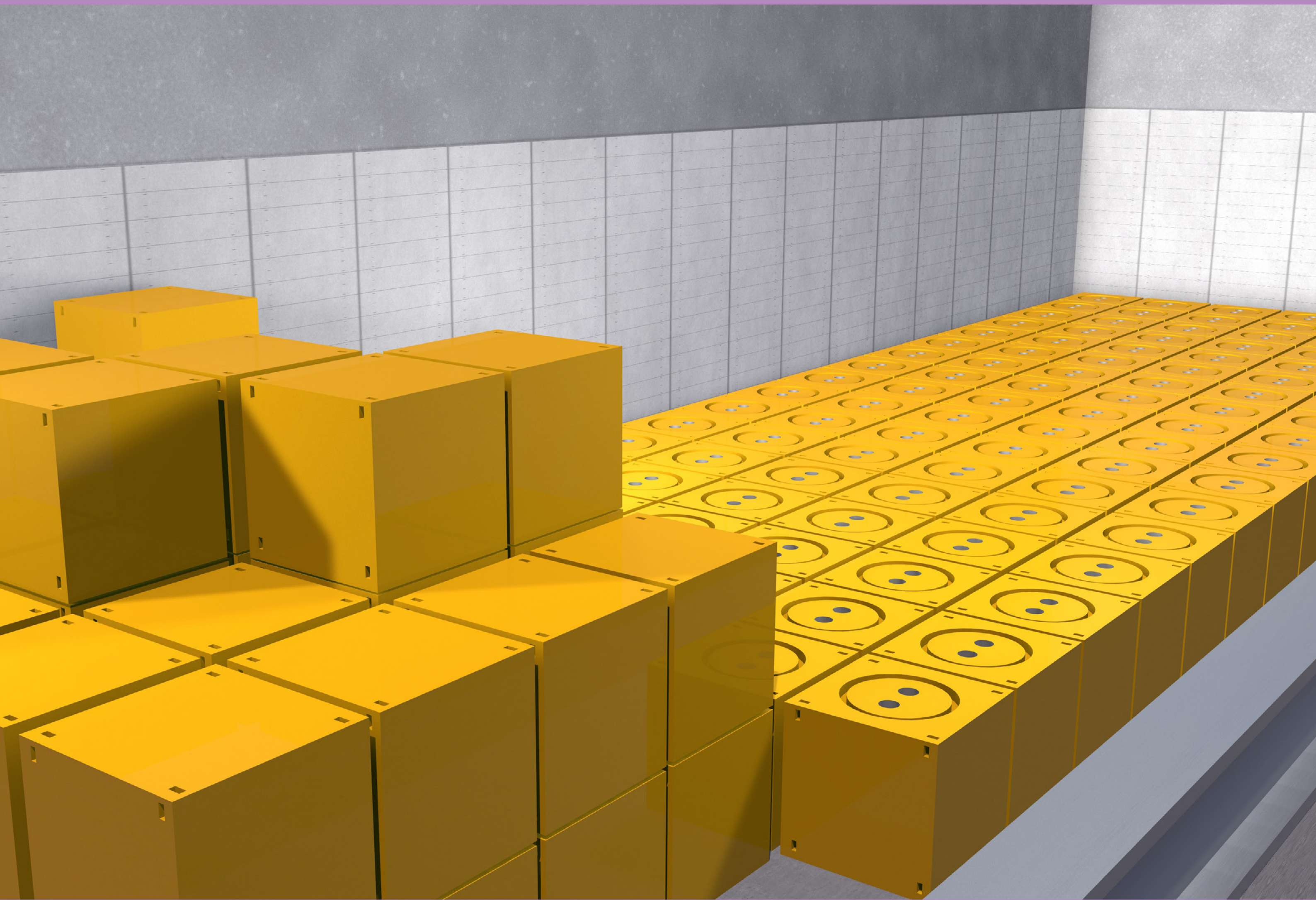

CHALLENGE:
Monitoring of Waste Packages

Nuclear decommissioning uses the interim storage of radioactive waste in a variety of specialized containers, known as waste packages. The ability to monitor the condition of these packages and their contents will inform their ultimate disposal strategy. This challenge seeks to explore a range of condition monitoring parameters and whether they can be applied to a variety of waste packages being employed by Magnox and Sellafield.

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FIS 360 INNOVATION | TECHNOLOGY | BUSINESS

NATIONAL NUCLEAR LABORATORY

Introduction

Magnox and Sellafield are both responsible for decommissioning nuclear sites which requires the disposal of radioactive wastes. These wastes will ultimately be disposed of in a Geological Disposal Facility, which is yet to be built. In the meantime, the waste is stored safely in what is commonly referred to as **interim storage**. This involves taking the wastes and storing or immobilizing them in containers. The waste and its container are referred to as a waste package. These **waste packages** may require interim storage for up to 100 years.

The buildings where the waste packages are stored are known as **Interim Storage Facilities (ISF)**. These are purpose built enclosures with a range of designs and layouts. Waste packages are stacked and accessed via an overhead crane with varying levels of access around each stack. Figures 1 and 2 show examples of ISFs.

Sellafield has an ISF with a capacity to store ~500 waste packages and there are plans to build a second and even a third. Figure 1 is generally representative of arrangements within ISFs, although some stores have a vaulted roof that further limits access, as shown in Figure 2. In some ISFs access is only possible upon final retrieval of the waste packages.

A variety of container types are employed in waste packaging and each has its particular constraints. It is, therefore necessary to monitor the physical condition of the waste packages and the waste throughout the duration of their interim storage. This provides information regarding the integrity of the waste packages prior to their removal from the ISF. Both Magnox and Sellafield's current monitoring arrangements are deemed suitable under current best practice and according to guidance available at:

https://www.gov.uk/government/publications/interim-storage-of-higher-activity-waste-packages

Magnox and Sellafield are keen to explore novel technologies and innovations that will:

- Indicate the condition of the waste package in the latter stages of its period of interim storage
- Indicate the condition of the waste within the waste package
- Reduce operator dose through remote means of monitoring
- Enable the monitoring of aspects of waste package ageing that have been forecast for which economic and practicable means for doing so have yet to be identified

Accurately predicting the behaviour of waste and a waste package over a 100 year timeframe is obviously challenging. Some deterioration is to be expected. However, techniques which offer some early indications of degradation or change would greatly increase regulator confidence. Such techniques may in future become routine depending on the ease of use, suitability of information provided and package ageing.

Figure 1: Sellafield Interim Storage Facilities

Figure 2: Hunterston A Intermediate Level Waste storage facility

Waste package details

Magnox have several waste package container types under consideration. These vary in design and construction material (see details in Table 1 and illustrations in figures 3A to 3F).

At Sellafield, Self-Shielded Boxes known as SSBs (Figure 4) are used for various streams of waste from Sellafield's Legacy Ponds. These wastes are typically contained within skips and depending upon what the waste stream is there may be additional furniture inside the skip. The skips are placed inside the SSBs and transported to the Interim Storage Facility (ISF). To permit the storage of wet wastes, the SSB design includes passive ventilation in the form of sintered metal filters to manage gas generation from the contents of the box. This allows for the exchange of gases between the SSB and the ISF atmosphere.

Container specifications	Magnox SS Drum	Magnox SS Box	DCIC Drum used by Magnox	DCIC Box used by Magnox	Magnox CB	Sellafield DCIC SSB
Construction material	Stainless steel	Stainless steel	Ductile cast iron	Ductile cast iron	Concrete reinforced with steel re-bar	Ductile cast iron
Shape	Cylinder	Cuboid	Cylinder	Cuboid	Cuboid	Cuboid
Approximate volume	500 L / 2.75m^3	2.75m^3	500 L	2.5m^3	6m^3	2.2m^3
External dimensions mm	800 / 1720 diameter 1230 / 1245 height	1720 long 1720 wide 1245 height	1070 diameter 1520 height	1610 wide 2010 long 1740 height	2210 wide 2438 long 2210 height	1750 wide 2000 long 1700 height
Internal dimensions mm	As above	1706 wide 1706 long 1050 height	740 diameter 1140 height	1290 wide 1690 long 1420 height	1714 wide 1917 long 1705 height	1247 wide 1447 long 1190 height
Wall thickness mm	3 /3	6	150-180	160	240-273	245
Aperture size mm	730 / 765 diameter	1214 x 1214	730 diameter	730 x 730	1942 x 1714	TBC
Internal container	N/A	N/A	N/A	N/A	Some concrete boxes contain galvanized and/or painted mild steel bins	Long or short skips
Internal space mm	N/A	N/A	N/A	N/A	TBC	40 above the skip and 55 to 133 at the sides
Ports	None	None	1 or 2	1 or 2	Up to 4	2 within the lid
Venting	Passive through sintered metal filters	Passive through sintered metal filters	Passive through sintered metal filters	Passive through sintered metal filters	Walls gas permeable, some boxes have filters	Passive through sintered metal filters

Table 1 – Summary of specifications by container type

Figure 3A - Magnox SS Drum 500L

Figure 3B - Magnox SS Drum 2.75M^3

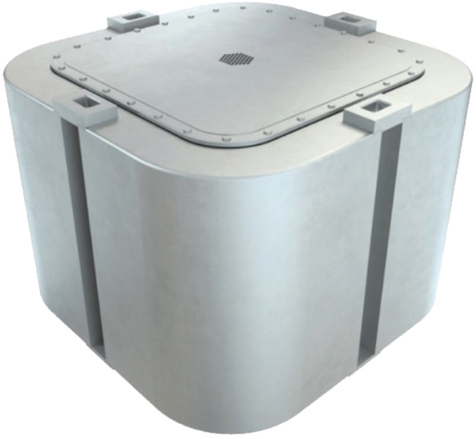

Figure 3C - Magnox SS Box

Figure 3D – DCIC Drum used by Magnox

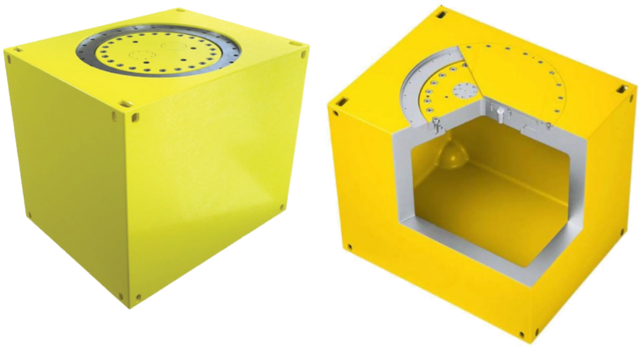

Figure 3E – DCIC Box used by Magnox

Figure 3F – Magnox Concrete Box

The images in Figures 3A to 3F above were obtained from: Waste Package Specification and Guidance Documentation, Specification for Waste Packages Containing Low Heat Generating Waste, Part D – Container Specific Requirements (published by Radioactive Waste Management June 2020)

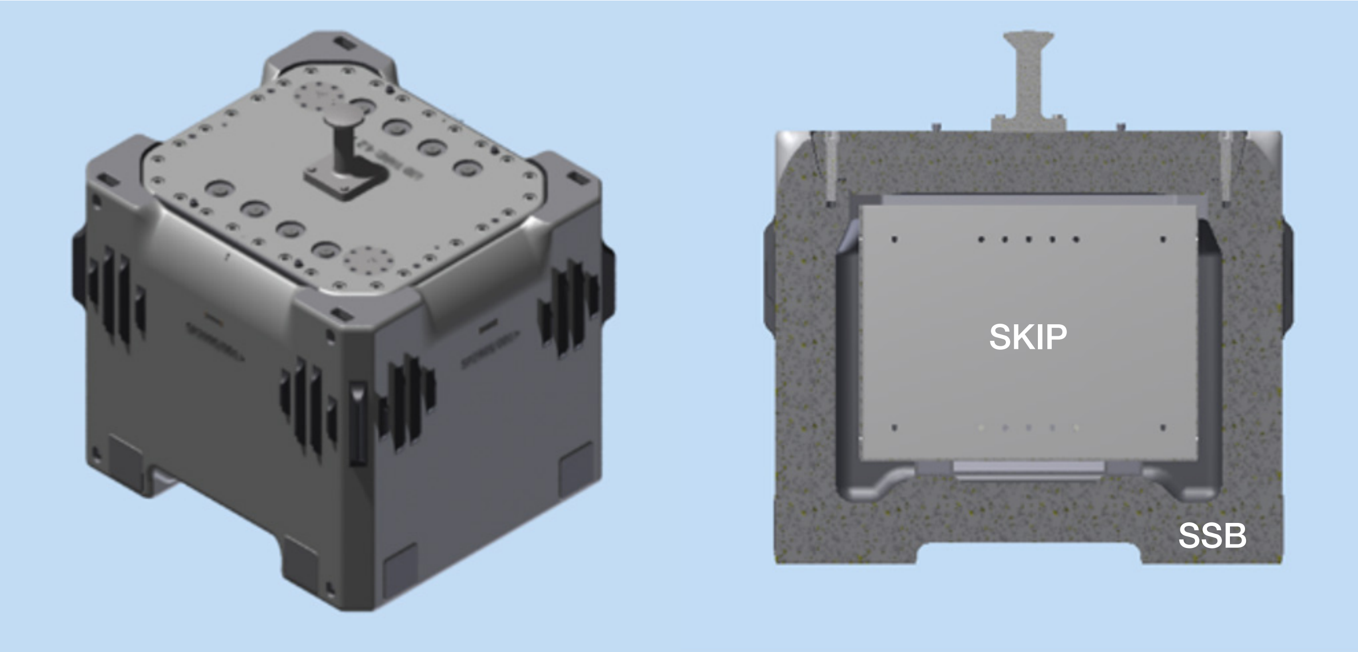

Figure 4 - Image of a Sellafield SSB (LHS); Cross sectional image of a skip within the SSB (RHS)

Current Practice

Magnox and Sellafield in-situ inspection

As human access inside an ISF is prohibited, one of the following methods of inspection are deployed:

- Static remote camera systems
- Cameras and lights on a mobile crane mounted frame (Figure 5), but viewing is restricted to the top and sides of a stack of containers and the current systems are cumbersome and time-consuming

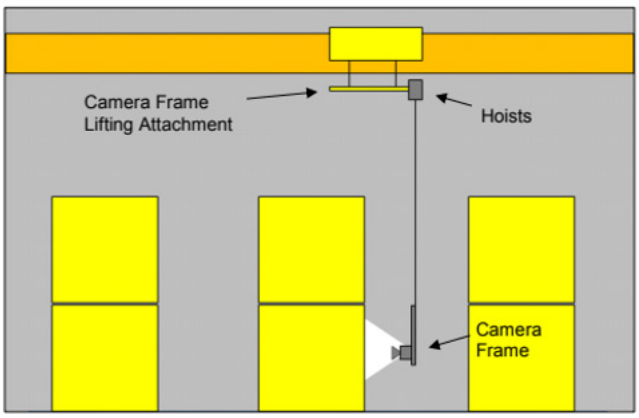

Figure 5 – Schematic of an example of a remote camera system within an ISF (not to scale)

There are several limitations with these in-situ visual inspection techniques:

- Wired systems are difficult to retrofit and wireless systems are difficult to use in areas with large metal containers
- The time required for manually reviewing large amounts of footage limits the number of packages inspected
- Crane mounted systems are bulky and time consuming to use

Magnox and Sellafield store monitoring

The temperature and humidity of storage areas are continually monitored at both sites. At Sellafield in-situ thermal imaging is also employed. At Magnox hydrogen concentration within the storage area is also monitored.

Magnox destructive testing

Assessment of carbonation depth and rebar condition of concrete boxes is carried out on test pieces and dummy packages containing a range of simulant wastes. This is carried out on a five-yearly cycle.

Corrosion coupons

These are test pieces that represent many of the critical parts of each container that are kept in the storage areas. These vary depending on container type but can include the following: filter units, seal and bolting arrangements, painted surfaces, bare metal surfaces and lubricants or greases. As these test pieces are not radioactively contaminated, they can be removed from the ISF for analysis.

Magnox ex-situ inspection

If in-situ inspection methods, dummy packages or test pieces indicate possible evolution of a waste container from its baseline condition, it will be considered for removal to an inspection area. This is an exceptional operation, undertaken on a case-by-case basis. It enables physical access for visual assessment of the exterior only. Radiation exposure during these assessments is minimized by limiting the frequency of inspections, conducting inspections from behind shielded glass and the employment of remote camera systems. The precise format of these assessments and the type of camera systems utilized varies between different ISF sites.

The assessments carried out on containers selected for ex-situ inspection include contact and one-metre distant radiation dose rates and measurement of corrosion products and accelerants. Depending on the container type, visual inspection criteria will include concrete efflorescence, cracking/spalling and deformation, galvanizing and deformation of mild steel casings, corrosion and particulate deposits on any visible vent assemblies, and corrosion of twist locks.

Sellafield ex-situ inspection

A limited number of SSBs are removed to the Receipt Inlet and Maintenance Area (RIMA) of the ISF, where they are subject to:

- External visual inspection
- Limited internal inspection, carried out endoscopically via a port in the container lid
- Testing of the leak rate of the lid seal and process port flanges
- Detecting the blockage of a filter
- Swabbing for radiation and contamination

Challenge Aims

The overarching aim of this challenge is to identify a suite of measurement and testing methods that enable the reliable assessment of the condition and integrity of waste and waste packages throughout the period of interim storage, ideally in-situ. The specific technical aims of this challenge are varied and several of them depend on the type of container under consideration. These are summarised in Table 2 and in the notes below and further detailed in the 'Functional Requirements' section.

PARAMETER	Magnox SS Drum	Magnox SS Box	DCIC Drum used by Magnox	DCIC Box used by Magnox	Magnox Concrete Box	Sellafield DCIC SSB
Temperature						✔
Humidity			✔	✔	✔	✔
Hydrogen concentration			✔	✔	✔	✔
Oxygen concentration						✔
Filter flow path			✔	✔	✔	
Wall expansion	✔	✔				
Wall thickness			✔	✔		
Corrosion and inner container integrity	✔	✔	✔	✔	✔	✔
Paint coating			✔	✔		
Concrete carbonation					✔	
Microbial activity	✔	✔	✔	✔	✔	✔
Approximate number of containers under consideration	1000	1300	500	300	500	500+

Table 2 – Summary of parameters of interest by container type

Temperature (Sellafield)

- The temperature of waste material within SSB containers would be a useful parameter to monitor over time

Humidity (Magnox & Sellafield)

- Some waste materials, such as slurries, have a high moisture content
- During storage, moisture evaporates within the container and condenses on the container lid. This can lead to pooling of water in the gap between the base of the skip or bin and the base of the external container
- In-situ measurement of relative humidity within the container ullage is required as this will indicate the likelihood of corrosion due to pooling of water

Hydrogen concentration (Magnox & Sellafield)

- Waste materials are expected to generate hydrogen and this exits the container through fine stainless steel sintered filters
- Magnox require in-situ assessment of the hydrogen concentration in the air surrounding the filters

- Sellafield require in-situ detection of hydrogen (1-13% v/v) within the ullage of the containers to accurately assess long term build up

Oxygen concentration (Sellafield)

- The oxygen concentration (0-21%) within the ullage of Sellafield SSBs would be a useful parameter to monitor over time

Filter flowpath (Magnox)

- The containers require venting throughout their lifetime, and this is provided by stainless steel sintered filters set in the walls of the containers
- The filter units should only corrode slowly, but the surrounding ductile cast iron may well corrode to an extent that reduces the vent pathway, though current estimates are that flow paths will remain adequate
- Monitoring the development of the flowpath over time and absolute determination of blockage is of interest
- Remote methods that can be deployed whilst the containers are stacked in storage are preferred
- There is possible interest in ex-situ testing allowing physical access to the filter, providing testing does not compromise the functioning of the filter

Wall expansion (Magnox)

- Waste is often cement grout encapsulated and the grout can react with the waste leading to either localised or general expansion
- The detection of early signs of expansion is required, in the order of 1mm, on a mill finish (2B) or wet bead blasted stainless steel finish
- Visual detection is preferred, although remote techniques would be of interest
- Methods that don't involve attaching items to the container are required

Wall thickness (Magnox)

- Although very thick walled, corrosion of the interior of ductile cast iron containers is of interest over a 100 year timescale, with detection of changes of 1-20mm being required
- Detecting signs of internal pitting from the exterior of the container would be of interest
- If physical access is required, the duration that the operator is required to be close to the waste package must be minimal

Corrosion and inner container integrity (Magnox)

- A measure of the corrosion or deterioration of the reinforcing steel re-bars of concrete boxes is required via non-intrusive, non-destructive inspection
- Some concrete boxes contain large "bins" which are constructed of galvanised and/or painted mild steel. Determining the corrosion or expansion of these remotely would also be of interest

Inner container integrity (Sellafield)

- The ability to monitor the integrity of the sides, base and trunnions of the skips that sit within the Sellafield SSBs would ultimately inform a disposal strategy
- A suitable method (visual or otherwise) that gives confidence in the integrity of the skip base would be highly desirable
- Both in-situ and ex-situ methods are of interest and ideally would be deployed once a year

Paint coating (Magnox)

- The coating consists of a 3 layer, 2 part epoxy/polyurethane paint system
- It is not known whether this system will last 100 years
- Predictive methods for determining the lifetime of the paint or ways of spotting early signs of degradation are desirable
- Methods should be non-destructive in-situ (preferably without human access) or simulated models

Concrete carbonation (Magnox)

- A measure of the degree of carbonation of the concrete is required
- Non-intrusive, non-destructive inspection is needed

Microbial activity (Magnox and Sellafield)

- Wastes in packages range from metal components, to oily sludges and ion exchange resins. These are vacuum dried during processing so microbial action is thought to be unlikely
- The detection of microbial action in any package would be of interest however
- Access to the waste is limited, but all containers of interest have a filter unit which allows movement of air from the inside to the outside of the container

Benefits to Sellafield and Magnox

Novel or innovative methods for the assessment of waste packages presents a massive opportunity for all organisations holding wastes in interim storage over decadal timescales. The numbers of each type of container under consideration are approximated in Table 2.

In addition to increasing regulator confidence, there are huge potential savings and benefits. Making inspections easier, safer, faster and cheaper due to:

- Early intervention and prevention of potential problems
- Avoidance of destructive analysis and rework
- Reduced worker exposure to radiation
- Reduced time required to carry out testing

The scale of some waste streams and the potential costs of remediation make early detection worthwhile. Resultant savings would be expected to be in the range of £10Ms.

Although not currently proposed for front-line monitoring, these methods could potentially supplant or supplement current accepted practice.

Constraints

BOTH Sellafield and Magnox

Any equipment that requires location within an ISF, whether inside or outside of the waste package containers, must be radiation tolerant. The levels of radiation vary with position inside an ISF and the type of waste package. For example:

- Sellafield ISF vault is R4 (advisory upper bound whole body dose rate for area 500 μSv/hr)
- Sellafield ISF high level access and maintenance gantry is R3 (advisory upper bound whole body dose rate for area 100 μSv/hr)
- Magnox stainless steel containers 1 μSv/hr to 10 Sv/hr
- Magnox ductile cast iron containers and concrete boxes 0.1 to 1 mSv/hr

Further hazards, such as the potential to lose equipment, must not be introduced to any containers or the ISF.

The fabric of the waste packages must be completely unaffected by any procedures or methods applied.

Equipment within an ISF can have a 110V or 240V supply. However, there are no power supplies within any of the waste packages, so any equipment located within waste packages would need to be powered externally or independently. The crane mounted systems are limited to a 12V supply.

Monitoring equipment inside a waste package would need to send a signal out to a receiver.

Close human contact with the waste packages must be minimised and preference will be given to all methods which can be carried out remotely.

Magnox

Close human access to Concrete Boxes and Ductile Cast Iron Containers is possible when they have been removed from the ISF, but not for most stainless steel containers.

Clearances between containers in storage vary depending on the facility. In general Magnox ISFs have around 400mm clearance between stacks of containers. Stainless steel boxes at Hunterston have approximately 450mm between inspection stacks and 150mm for other stacks. Harwell Drum store does not have access to stacks.

Methods that don't interfere with the operation of the ISF are preferred.

Methods that don't require items to be left behind in the ISF are preferred.

Access to the inside of the concrete box packages is possible only by removal of the filter. Some concrete box packages are unvented and therefore permanently 'sealed' by the concrete lid. Those that are vented have between 1 and 4 through-lid vent ports, these are completed with removable filter units held in place by circlips.

Destructive testing on analogues or test pieces is possible but must be accurate enough to work with a very small sample number and in extreme just one test container.

Sellafield

The humidity in the ISF is 35-65% and the temperature under normal operating conditions is 15-25°C, though under fault conditions the temperature could be as high as 43°C.

SSBs are stacked three high and the maximum nominal gap between stacked SSBs is 82mm. The gap in between stacks of SSBs is 400mm. This tightly constrains access to the sides of all SSBs and lids of all but the top layer of SSBs. Access to the skip within the SSB is similarly constrained (see Table 1 and Figure 4).

Any equipment that needs to be operated from within an SSB would either need to be situated prior to the fitting of the SSB lid or deployed via one of two process ports on the lid. The specifications of the process ports are as follows:

- Fully removable from the lid of the SSB
- Circular diameter 200mm, depth through the lid ~250mm
- Helix shaped 20mm channel though the length of the port plug
- Equipment could be deployed on the base of the process port where there is 40mm clearance between the base of the port and the top of the skip within the SSB

Functional Requirements

Magnox

Hydrogen concentration: from 1 vol% in air (i.e. 25% of the lower flammable limit) to an upper concentration no less than the lower explosive limit.

Container expansion: millimeter changes in 800mm and 1800mm diameter containers.

Wall thickness determination: loss of 1-20mm over a nominal 150mm thick cast iron, painted wall. Possibly pitting of the order 10-100mm width.

Filter flow path will be dependent on container type and design. Reductions of 10-99% of the flow path are of interest.

Container corrosion functional requirements are broad but would encompass any corrosion (i.e. expansive, localized, general) which would challenge the integrity of the box over long time periods.

Ideally inspection systems would be compatible with current arrangements. If not, they would likely have to offer a simplified, smaller, cheaper, more reliable method to supplant current systems.

The functional requirements for the detection of microbial action are likely to be broad. At this time there is no specific definition of what the nature of the microbial action will be or if there are any detectable by-products. As such the knowledge and expertise of the proposer would be used to frame this section along with the proposed method.

Frequency of use of testing methods will depend on the ease of use. Ranging from annually for in-situ or easy to carry out measurements, and up to every five years for more involved methods.

Sellafield

Skip integrity:

- The equipment must be able to provide an image of the SSB in question
- Ideally the equipment would image the base of the skip inside the SSB
- The equipment would be used once per year

Hydrogen / oxygen requirements:

- The equipment must be able to provide a numerical reading of the hydrogen and oxygen concentration. How often is negotiable depending on other considerations
  - o Measure hydrogen concentration within a range of 0 – 13%
  - o Measure oxygen concentration in air between 0 – 21%
- The equipment will have the ability to log the data over the lifetime of storage or if that isn't possible, less frequent sample points preferred in order to maintain monitoring over as long a period as possible

Temperature:

- The equipment must be able to provide a numerical reading of once per day of the temperature of the waste package or if that isn't possible, less frequent sample points preferred in order to maintain monitoring over as long a period as possible
- The sensor will have a minimum range of 25°C to 50°C
- The equipment will have the ability to log the data for ideally 50 years. However if this is not possible, this can be reduced

What Next?

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 **Wednesday 6th October 2021 at 12 noon**.