# Progress in Defining the UK Highly Active Storage Tanks POCO Strategy – 16134

Steven Thomson, UK National Nuclear Laboratory
Tom Page, Sellafield Ltd

## ABSTRACT

In the UK Highly Active (HA) waste is stored in stainless steel tanks prior to encapsulation in glass in one of three operating vitrification plants. Significant progress has been made in recent years towards the reduction in the volume of HA Liquor (HAL) stored in these tanks and a number of the tanks are now operating at heel levels. As a result, a strategy is being developed to carry out Post Operational Clean Out (POCO) of some tanks while reprocessing operations continue, thus enabling accelerated and more cost effective clean-up of these HA facilities. This paper, and subsequent conference presentation, will highlight some of the key aspects of this strategy, including a description of the challenges and progress made so far to help facilitate the clean-up mission without having a detrimental effect on ongoing reprocessing operations.

## INTRODUCTION

The UK Sellafield nuclear site is one of the most complicated nuclear sites in Europe and indeed the world. It was home to the first ever commercial nuclear reactor, Calder Hall, and has housed the UK used fuel reprocessing operations and associated waste treatment facilities over the last 50+ years. This has included early experimental technologies and more latterly established plants such as Magnox Reprocessing, Thermal Oxide Reprocessing (Thorp), Highly Active Liquor Evaporation and Storage (HALES) and Waste Vitrification Plant (WVP). A variety of associated effluent and grout encapsulation plants are also located at Sellafield, alongside a number of fuel storage ponds, waste silos and miscellaneous support facilities. In recent years the focus on the Sellafield site has changed from primarily reprocessing operations to a combination of reprocessing and decommissioning missions as focus increased on cleaning up some of the legacy facilities on the site. A number of the current operational plants are also approaching the end of their operational lifetime.

The HALES plant fulfils a central role at Sellafield as it processes the nitric acid based aqueous waste raffinates from both the Magnox and Thorp reprocessing plants, which contain the vast majority of the fission products from the spent fuel. The raffinates are concentrated in HA evaporators to a pre-defined end point, producing HAL which is highly heat generating due to radioactive decay of many of its components. The HAL is stored in Highly Active Storage Tanks (HASTs), which are actively cooled via a combination of water filled coils and jackets, prior to onward processing in WVP where the waste is vitrified for long term storage. Early HALES operations were carried out in eight "old-side" HASTs, each equipped with their own small scale evaporator vessel and a small number of cooling coils. The old-side of HALES has not been used to receive new waste arisings for a number of decades. When scaled up operations were later required a new approach was adopted. Larger volume/throughput HA evaporators were built as were 13 “new-side” HAST tanks with increased volume, cooling capacity and agitation capability which the old-side vessels did not include. The HA evaporators and HASTs were built over a number of decades; including the present day as a new HA evaporator (evaporator D) is currently nearing completion. This new evaporator will have a key role to play in the POCO of the HASTs and this will be discussed further later in this paper. A high level illustration of the HALES plant process is shown in Figure 1, and a photograph of HA evaporator C, prior to installation, is shown in Figure 2.

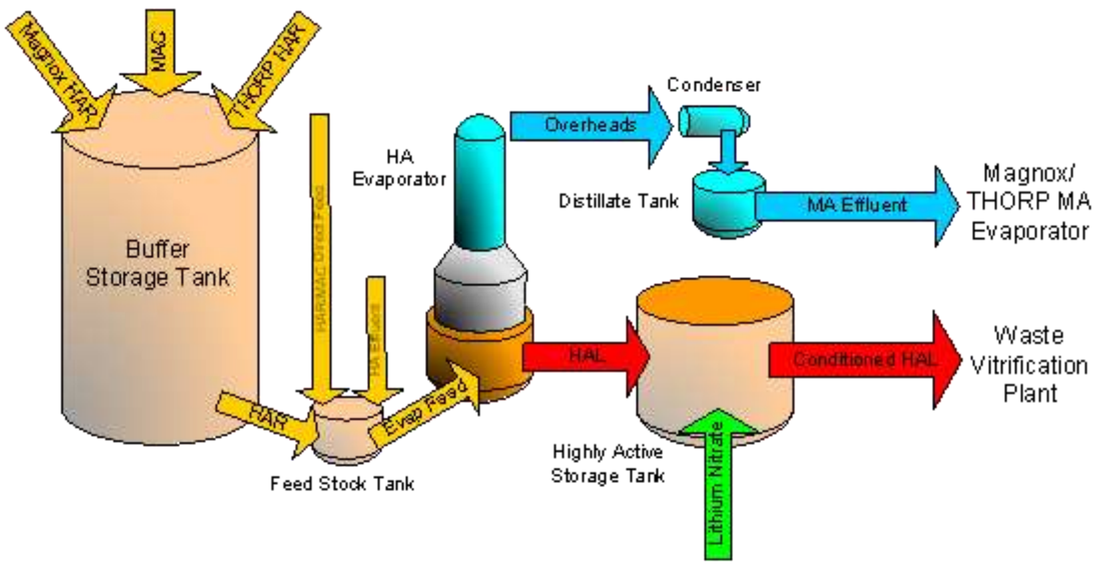


Fig. 1. HALES Process Schematic

(HAR = Highly Active Aqueous Raffinate, MAC = Medium Active Concentrate)

Fig. 2. HA Evaporator C

The UK National Nuclear Laboratory (NNL) is a Government owned organization that helps support primarily UK nuclear operations and carries out research and development work on behalf of UK and international customers. NNL was formed as part of the transformation of the UK nuclear industry over the last 10-15 years, and has its roots as the Research and Technology division within the now obsolete British Nuclear Fuels plc (BNFL). In its various guises, NNL has been involved in plant operational support work and associated research activities associated with the UK nuclear industry since its inception around 60 years ago, and continues to provide new and innovative solutions to deal with present day challenges.

As is often the case when considering challenges within the nuclear industry the POCO and subsequent decommissioning of the HASTs presents a complex scenario. Used fuel reprocessing will continue in the medium term with the need to simultaneously make progress in reducing the decommissioning challenge by optimising POCO operations within the same HA facility. Working alongside Sellafield Ltd plant operators NNL is able to provide multi-disciplinary support in areas such as HA chemistry, nuclear physics, plant inspection (Ref. 1), waste characterisation, plant lifetime assessment (Ref. 2), process modeling, statistics and corrosion, to name but a few.

The remainder of this paper will now discuss key aspects of the HAST POCO strategy in more detail, reflecting the detailed program of work which, out of necessity, has become an increased focus for the Sellafield site in recent years.

## DESCRIPTION

The following sections contain further details regarding smaller programs of work that all provide important contributions to the overall HAST POCO Strategy program,

### Current HAL Chemistry

The chemistry of HA liquors from the historical and ongoing UK reprocessing operations is well understood, following years of operations and associated research and development program. However, the imminent progression to POCO of the HASTs, where the HA liquor is stored, will result in some fundamental changes to the chemistry in these vessels. HA liquors are known to contain solids which, alongside the heat generating nature of the liquors, present the most significant challenges in handling and processing these wastes. The characteristics of these solids will change as a result of the POCO operations, and thus the way in which the HA wastes are treated will also change.

Current and historic HAL is a complex mixture of dissolved metal nitrates and a variety of solids such as cesium phosphomolybdate (CPM), zirconium molybdate

(ZM), barium/strontium nitrate, zirconium hydrogen phosphate (ZHP) and magnesium lanthanide nitrates (MLN). The majority of these solids are dense and fast settling, with the exception of ZHP which is flocculent and slow settling in nature. The exact chemistry of HAL is dependent on a number of things, most importantly the source fuel from which it has been produced, and the burn-up and cooling of the fuel prior to reprocessing. For example, Magnox reprocessing results in high MLN concentrations, whereas Thorp reprocessing results in HAL with low MLN concentrations but higher concentrations of barium/strontium nitrate and CPM. HAL is a nitric acid based waste and is maintained at a controlled acidity to help control the chemistry of the liquor and the solids it contains. HAL is significantly heat generating and is actively water cooled to below 60 $^{\circ}$C to reduce the corrosion rates in the HASTs and to prevent the HAL from boiling, which could overwhelm the ventilation system and potentially release significant quantities of volatile radioactive species.

The nature of the solids present in HAL is somewhat dynamic. Solids such as barium/strontium nitrate can dissolve or precipitate depending on the overall nitrate content of the liquor, but more importantly CPM is known to convert to ZM under normal HAST conditions. The kinetics of this conversion are controlled by a number of factors including acidity, concentration, temperature and agitation, however long HAL storage times result in complete conversion to ZM. The formation of ZM is beneficial because, unlike CPM, it does not produce radiogenic heat from decay of its constituents and hence does not present the same hotspot risk when settled on the tank base. Hotspots can form at the bottom of HASTs and unless mitigated and removed can potentially reach temperatures in excess of 100 $^{\circ}$C. These hotspots can present a significant corrosion risk if allowed to remain established for any period of time.

## Chemistry Changes due to Expected POCO Operations

The HASTs are of two fundamentally different designs, incorporating vastly different operating capacities, vessel shapes, cooling capability and agitation systems. There are eight old-side HASTs which each have a working HAL volume of 50m$^3$, limited cooling capacity and no installed agitation systems. The new-side HASTs have a working HAL volume of 140 m$^3$ and contain 7 cooling coils and various configurations of cooling jackets. Early new-side HASTs have only tank base jacket cooling, whereas later new-side tanks have a number of cooling water jackets installed circumferentially around the full side wall of the vessels. Each new-side tank also contains significant agitation capability via 7 installed jet ballasts and four airlifts. The jet ballasts are used to keep solids moving on the base of the HASTs, thus helping prevent hotspot formation, while the airlifts are used to thoroughly mix the tank contents at such times as immediately before liquor transfers, with the intention of ensuring homogenous tank contents prior to transfer. Figures 3 and 4 show photos of the old-side and new-side HASTs, respectively, during construction. If only new-side HASTs were present and requiring POCO then the challenge would be more straightforward as the installed agitation system could be used to transfer the bulk of the liquor from the tanks, including the solids such as CPM, ZM and ZHP that cannot be removed by simple water/acid dissolution. However, a significant amount of HAL solids require to be removed from old-side tanks which have no agitation system installed. Following consideration of all possible options the favored approach for removing these solids is currently chemical dissolution, potentially requiring retrofitting of an agitation system, and significant development work has been carried out to identify and test appropriate reagents.

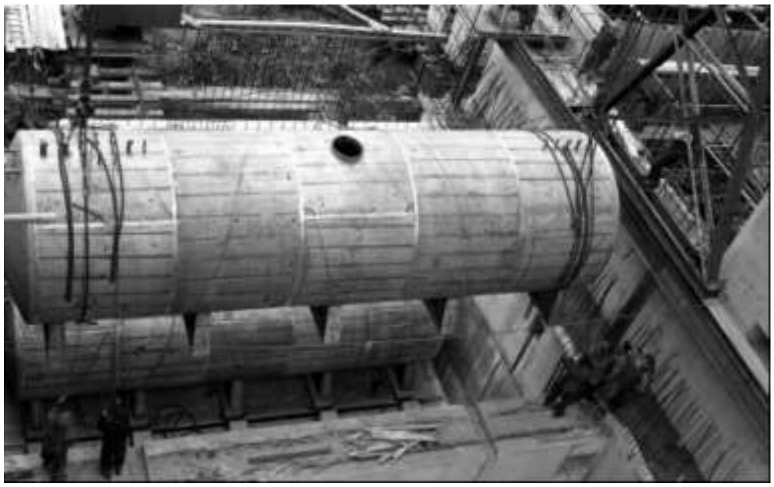

Fig. 3. Old-side HAST during construction

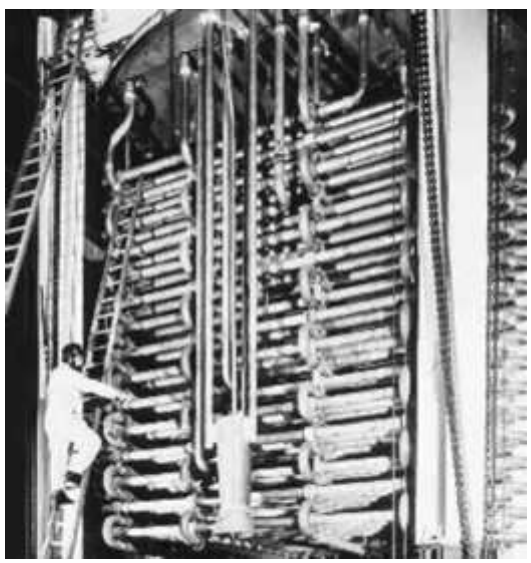

Fig. 4. New-side HAST during construction

Reagent assessments began a number of years ago where all options were initially considered and down-selected depending on operational constraints and overall effectiveness. A small number of viable options were quickly identified with two reagents emerging as front runners, which will be termed "Reagent 1" and "Reagent 2" hereafter. In recent years detailed programs of work have been carried out to evaluate the advantages and disadvantages of both reagents. Both reagents are alkaline in nature and this presents an issue as old-side HAST wash liquors will require re-acidification following transfer to the new-side tanks, prior to final processing through WVP to form a vitrified waste for final disposal. Key aspects such as solubility limits, solid dissolution rate, formation of secondary solids and the re-precipitation of solids on neutralization and re-acidification in the new-side tanks have been studied and work is still ongoing in this area to answer some of the questions that remain. Results have shown that both reagents have different advantages and disadvantages in relation to varying solids dissolution rates, by-products formed and the effect on the glass matrix used in the final vitrified waste form, which will be discussed in more detail later. Reagent 1 has the advantage that it effervesces and releases gas on mixing with HA liquors, thus assisting with the mixing of the chemicals/solids on contact and therefore at least reducing, if not eliminating entirely, the requirement for a retrofitted agitation system. Reagent 2 does not display such effervescence and hence consideration of possible engineered agitation methods, or acceptance of a lower dissolution rate, requires careful consideration.

## Possible Tank Wash Strategies

In addition to the reagent selection challenge discussed above different wash strategies have been assessed in order to investigate the most efficient and effective way of transferring solids from the new-side HASTs to WVP for encapsulation in glass. As reprocessing operations continue and POCO gets underway there is an opportunity to blend liquors to incorporate more solids in the glass and thus significantly reduce the number of vitrified product containers produced. This will help to make significant ongoing cost savings and reduce mission duration for HALES and WVP as a result. The opportunity to combine reprocessing liquors with POCO wash liquors, then evaporate and vitrify them together, as part of the drive to reduce container numbers has been termed "co-processing" by the teams involved.

A number of different new-side wash strategies have been assessed including variation of the tank volumes prior to liquor transfer and constant refilling of the tank following frequent transfer of small liquor volumes, in order to optimize the mixing of solids and hence transfer the solids more quickly. The generation of increased volumes of additional wash liquors (e.g. acid/water), depending on which wash strategy is chosen, have also been considered as these liquors will need processed alongside the solids removed.

Approximately five years ago a $4/10^{th}$ scale replica of the new-side HAST inner vessel was built in order to investigate solids clearance on the base of the tank. This rig initially included seven scaled operational jet ballasts and replication of the cooling coils within the tank, so that realistic trials could be carried out. Once this initial program of work was carried out the rig was modified to include additional tank furniture, such as the airlifts, in order to use the rig to investigate further tank mixing phenomena, including how to maximize the solids transfer efficiency when removing HAL from the HASTs. Figure 5 shows the 4/10$^{th}$ HAST jet ballast rig being assembled in NNLs Workington facility. The image shows the replica cooling coils being lowered into a Perspex tank vessel, the addition of which allows comparison with the full scale coils shown in Figure 4.

Fig. 5. 4/10$^{th}$ scale HAST Jet Ballast Rig during assembly

By combining some of the results from the aforementioned chemistry studies with results from the jet ballast rig trials investigating solids transfer efficiencies it is possible to investigate which wash strategy results in the most efficient solids transfer. Process modeling has been used to combine plant operating experience and known restrictions with the results of the chemistry studies and jet ballast rig trials to determine the most efficient operational strategy by considering all the options and evaluating different scenarios to find the best possible solution.

## Role of HA Evaporator D

Evaporator D is nearing completion and is a new HA evaporator of a very similar design to the existing evaporator C, although it has enhanced capability to receive POCO solids through its feed system. The existing HA evaporators, A, B and C, have been operating for a number of years and are currently reserved for operations in relation to used fuel reprocessing only. Corrosion of these vessels has occurred over years of operation and the remaining operational lifetime of these three evaporators is well understood from the ongoing inspection and lifetime assessments that are carried out on an ongoing basis (Ref. 1 and Ref. 2). The intention is that when evaporator D comes into full operation, which is expected within the next 1-2 years, it will not only be used to continue to support reprocessing operations, but will also have available capacity to start treating the POCO wash liquors generated within

HALES. Thus evaporator D has a key role to play in the co-processing of future re-processing arisings alongside POCO liquors, in order to maximize waste loading through WVP and hence minimize the number of glass waste containers generated. Significant cost savings are likely to be achieved as a result.

## Characterization and Monitoring Strategy

A common problem in all nuclear facilities when they reach the end of their operational lifetime is the characterization of the waste remaining within the plant prior to POCO and decommissioning getting underway. Both Sellafield Ltd and NNL have significant experience in inspecting operational plant and characterization of wastes, however the characterization of the waste remaining in the HASTs presents a unique and challenging problem. It is intended to use inspection, sampling and characterization equipment throughout the POCO operations in order to baseline the plant, monitor the waste removal efficiency and then determine when pre-determined POCO endpoints have been reached. Only very limited direct sampling capability is available in HALES, with no sampling currently possible in the old-side HASTs. The development of equipment to carry out inspection, sampling, characterization and monitoring is challenging as the plant design is complicated and difficult to access due to both shielding requirements and the highly active nature of the waste. The waste in the HASTs is very radioactive, with typical dose rates being around 1 kGy/hr (gamma) in the tank, and peaks as high as 7-8 kGy/hr (gamma) possible. As a result, high radiation tolerance is required within the HAST cell areas, and most existing radiation measuring devices are not appropriate because they quickly suffer radiation damage and are also designed to measure radiation levels at a far lower range than required. As a result, a number of new devices are being investigated to allow characterization and monitoring to take place in both the old-side and new-side HASTs. It is intended to use a combination of radiation measurements and knowledge about tank chemistry and inventory, alongside modeling techniques, to infer the physical properties of the solids present in the HASTs. It is also the intention to use existing access routes to deploy the new devices, even if the deployment is not the usual function of the identified route, as engineered plant modification are undesirable due to high cost impacts and time constraints.

## Impact on Vitrification Plant Operations

As mentioned previously two alternative wash reagents are being assessed as potential dissolution reagents for the removal of the solids from the old-side HASTs – termed Reagent 1 and Reagent 2 for the purpose of this paper. Both of these reagents are likely to be used in significant quantities and hence they have an impact on the chemistry of resulting HAL. This, in turn, affects the operations within WVP as this is the only disposal route for HAL. The use of either reagent introduces significant quantities of additional chemicals to the HAL and, depending on the reagent used, this is known to affect different aspects of the operation of WVP. As a result, plant operational changes will most likely be required and, following a period of underpinning laboratory and rig-scale trials, WVP will need to be carefully controlled and monitored to ensure no issues occur.

A significant amount of work has been carried out to mitigate the effects of using the two wash reagents on WVP operations and this will make a significant contribution to the decision regarding which wash reagent is selected. A further potential issue is the processing of high quantities of ZM from the old-side HASTs thought WVP. Molybdenum rich "yellow phase" formation is known to cause unstable glass matrices to form which break apart and thus my potentially leach radioactive species from the waste. Work is ongoing to maximize the allowable molybdenum concentration within the glass without compromising the structural integrity of the final glass waste form.

In 2005 NNL commissioned the Vitrification Test Rig (VTR) on behalf of Sellafield Ltd (Ref. 3). VTR is a full-scale non active rig that is an exact replica of a number of the key components with WVP, including the calciner, melter and off-gas system. Following the successful completion of small-scale trials, the plan is to use the VTR to carry out full scale non-active (but as far as practicable, chemically accurate) trials to underpin the new glass formulation chosen. Such trials have proven very successful in increasing the throughput and operational assurance of WVP over the last 10 years and work has already started with regards to the assessment of the possible POCO liquors to provide assurance that no unexpected issues will arise. Figure 6 shows the VTR calciner and melter vessels, respectively.

Fig. 6. VTR Calciner and Melter vessels

## Slurry Transfer Rig

The Slurry Transfer Rig (STR) has been built to understand potential challenges with the flow of high solids content liquors, such as those expected during POCO, through thin pipes with low gradient drops within the WVP and HALES plants. The rig has been built with the flexibility to change pipe diameters, lengths and gradients. It can also mimic a range of flow rates and can be used to investigate various chemical simulant recipes with different solids loadings. It also contains a variety of analyses tools, including cameras and pressure transducers, to monitor solids flows and blockages within the rig. This program of work is currently in its early stages but when complete it is expected to help determine future operational envelopes with regards to solids transfer when POCO liquors are being processed.

## Corrosion and HAST Lifetime Assessment

Lifetime assessment is an important aspect of operations at Sellafield (Ref. 2) as it helps dictate and underpin fuel and waste processing strategies across a number of operating plants. This is evident in HALES with regards to both the HA evaporators and more recently the HASTs where corrosion is known to occur within the process vessels containing HAL and in the cooling water systems. HAST lifetime assessment work is ongoing, where operational records are being considered alongside expected corrosion rates under plant conditions, in order to help underpin the integrity of the tanks and help inform the POCO strategy regarding whether some tanks should undergo POCO earlier than others due to plant lifetime expectations.

A large program of practical lab and rig-scale corrosion work has been ongoing for around 10-15 years in relation to HALES, together with complimentary plant inspection and modeling work (Ref. 2). This has primarily focused on HA evaporators in the past but is now becoming more orientated towards the HASTs. Reduced pressure operations within the evaporator, compared to ambient condition within the HASTs, result in different corrosion mechanisms in each, and hence different contributions from the variety of corrosion accelerators within the HAL. Careful consideration of the potential impacts of POCO operations are also required, as the introduction of new wash reagents and the formation of new and increased concentrations of solids may have a subsequent impact on the corrosion rates possible within the plant.

## Program Management

Over the last 10-15 years the UK nuclear industry has undergone significant change. BNFL plc was disbanded and a number of new organizations were formed as a result, including Sellafield Ltd and NNL. The Nuclear Decommissioning Agency (NDA) was formed, with the primary aim of accelerating the decommissioning of UK nuclear facilities, while driving efficiencies and reducing costs in the process.

These changes have resulted in different contracting arrangements between Sellafield Ltd and NNL, in contrast to the historic arrangements where both organisations were part of a single company, BNFL. Despite these changes significant efforts have been made over the last decade to sustain a strong partnership between Sellafield Ltd and NNL, while maintaining the formal contractual arrangements now required. This has been particularly successful within the HALES portfolio, within which the HAST POCO strategy development work is included.

Successful features within this partnership include the existence of program manager and technical program manager roles within NNL. The incumbents of these roles have overall responsibility for project delivery and technical co-ordination of work respectively, giving single points of contact against clear accountabilities. Complimentary features have included efficient interfacing of Sellafield Ltd staff with project managers and technical experts within NNL, and the facilitation of joint workshops to discuss recent results and agree future work programs. The process used to scope and endorse individual projects and overall programs of work has been streamlined, and various secondments and exchanges of technical staff have occurred, leading to increased understanding of the benefits of work programs, operational constraints and day to day challenges across the two organizations.

## Stakeholder Management

Stakeholder management has been and continues to be an important factor to consider alongside the technical challenges associated with the POCO of the HALES facility. The change in philosophy going from an operating facility to one that is undergoing POCO needs to be carefully managed, not just within the facility but wider, engaging with key stakeholders across the Sellafield site and beyond. One example of note is the need to communicate the complexity of the technical challenges to stakeholders at an early stage. Without early engagement there has been a tendency for some stakeholders to assume that POCO in HALES will simply be a case of switching off the operational reprocessing feeds and then washing down the vessels, which as this paper shows is clearly not the case. It therefore remains important to ensure that the scale of the challenge is disseminated properly, to obtain buy-in from those involved in the process and, where required, support for the preparations which are currently progressing.

## CONCLUSIONS

In partnership with WVP the Sellafield HALES plant operators have successfully reduced HAL stock levels in recent years and consequently attention has turned to the imminent POCO and subsequent decommissioning of the HALES plant.

A complex program of work is underway, which has involved close working between Sellafield Ltd staff, NNL and some key supply chain providers. Significant progress has been made in determining the POCO operating strategy but gaps in knowledge and practical solutions still remain.

The commissioning of HA evaporator D will be a key milestone in enabling HALES POCO operations to begin, in addition to continuing to support the vitally important reprocessing operations which will be ongoing at Sellafield for a number of years.

Despite the complexity of the clean-up mission the focus must always be on providing cost effective solutions, making best use of existing facilities and minimising volumes of waste for long-term storage.

So far the program of work carried out have successfully identified and investigated options such as chemical washing of the old-side HASTs and co-processing of POCO and reprocessing liquors through evaporator D. Changes to the glass formulation within WVP have also been investigated and the development of new characterisation and monitoring devices is underway. It is expected that such developments will have a significant contribution in ensuring the success of the overall HALES POCO and decommissioning mission, and that lessons learned will provide useful guidance and available technologies for use in clean-up work elsewhere on the Sellafield site, and further afield.

As is the case in other HALES/Sellafield programs, such as "Operational Plant Lifetime Assessment" (Ref. 2) the development of the HAST POCO strategy involves multi-disciplinary teams, primarily sourced from within Sellafield Ltd and NNL, working together to solve complex problems related to high hazard challenges on the Sellafield site. The development of a close partnership between Sellafield Ltd and NNL, including investment in project and technical program management, is a key enabler in this regard, along with the skills and dedication of the relevant subject matter experts and their technical teams.

## REFERENCES

1. Thomson, S. *"Black Cell Operations – UK National Nuclear Laboratory Experience"*, Waste Management 2014 Conference, March 2 – 6, 2014, Phoenix, Arizona, USA.
2. Thomson, S. *"Operational Plant Lifetime Assessment – UK National Nuclear Laboratory Experience"*, Waste Management 2015 Conference, March 15 – 19, 2015, Phoenix, Arizona, USA.
3. Roe, JI. *"Vitrification Test Rig: Supporting Vitrification at Sellafield"*, Waste Management 2014 Conference, March 2 – 6, 2014, Phoenix, Arizona, USA.

## ACKNOWLEDGEMENTS

The author would like to thank Sellafield Ltd for their agreement in allowing this paper to be published. The author would also like to thank NNL and Sellafield Ltd colleagues, too numerous to mention, who have worked tirelessly in recent years in support of the development of the HAST POCO strategy described herein.