Nuclear
Decommissioning
Authority

NDA Higher Activity Waste Treatment Framework

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Contents

Executive Summary

Nuclear site operations, site decommissioning and remediation generate significant quantities of Higher Activity Waste (HAW) and the successful performance of these tasks is dependent on the availability of robust, suitable waste management infrastructure. HAW includes High Level Waste (HLW), Intermediate Level Waste (ILW) and a relatively small volume of Low Level Waste (LLW) that is unsuitable for disposal at the Low Level Waste Repository (LLWR) or the LLW facility at Dounreay. Effective waste management is required for the delivery of our mission and is a significant part of our programme. HAW cannot be simply retrieved and directly disposed of. It requires a series of lifecycle steps throughout which it is important to consider the waste hierarchy: pursuing opportunities for waste minimisation, re-use and recycling, before undertaking treatment, packaging and storage. The waste must then be safely and securely stored pending future transport and disposal, when a disposal facility becomes available. This NDA HAW Treatment Framework concerns the intermediate step of waste treatment whereupon raw waste is conditioned into a form that is suitable for long term interim storage and disposal. The framework is a means of communicating broad areas of work that NDA is pursuing and under this framework, specific projects are undertaken. This approach is intended to show how tasks within the framework are supporting strategy and the wider estate.

Waste treatment baseline plans are often dominated by cement encapsulation on the basis that it is a tried and tested approach that can deliver an acceptable product, suitable for storage and disposal. Cement encapsulation has an important role to play in the future treatment of radioactive waste. In practice, cement encapsulation can sometimes be more challenging to implement than has been assumed, *e.g.* it leads to overall waste volume increase, which impacts on subsequent storage and disposal costs and might not represent an optimal solution for wastes with a significantly reactive component. In addition, the nature of the waste arising across the estate is changing as operations progress from support to reprocessing through to treatment of legacy wastes, decommissioning and site remediation. Alternative treatment technologies could offer advantages over the baseline approach, in terms of cost savings, risk reduction, waste product quality, and volume reduction. For this reason NDA is exploring the strategic opportunities.

NDA Strategy describes how we explore the development of alternative waste treatment capability to provide a flexible and cost effective approach to the management of HAW. Broadening the available technology options also serves to reduce risk by providing a level of contingency to the baseline treatment position. Work to date has focussed on determining where the main strategic opportunities exist across the NDA estate, with particular attention given to development of thermal treatment technology.

This high-level HAW Treatment Framework describes the programme of tasks specifically aimed at developing alternative treatment options for HAW. The NDA HAW Treatment Framework is a planning and communication tool to set out our activities and to help to inform SLCs, Regulators, the research community and the supply chain. It describes those key areas that the NDA is interested in and explains why. It describes the challenges faced in terms of:

- Waste volume reduction
- HAW disposal
- Treatment technology development
- Our high level plans for expanding the toolkit available to waste producers

The overall aim of the work is to develop an estate-wide programme approach to waste treatment that makes best use of available treatment options. This approach needs to reflect the estate capability as it evolves over time; the needs of the non-NDA estate waste producers and the possible future role that Sellafield can play. We also use this HAW

Treatment Framework to publish our strategic position in areas such as thermal treatment technologies and decay storage, as the work progresses.

The NDA mission will involve the investment of significant sums of money for the treatment of HAW arising from decommissioning and site remediation. It is unlikely that cement encapsulation will provide the best long-term solution for the diverse range of wastes to be treated. Similarly, no single waste container design will be appropriate for the packaging and storage of the UKs radioactive wastes. Reliance on a narrow range of technologies reduces flexibility and will deliver a suboptimal treatment programme. The NDA believes that work to develop alternative treatment technologies can give a number of potential benefits including:

- Developing the necessary technical underpinning for alternative treatment routes that would deliver targeted improvements and provide resilience and contingency for current plans for legacy and decommissioning wastes
- Supporting a multi-stage approach to tackling hazard and reducing the risk posed by legacy facilities sooner than the baseline plan
- Pursuing alternative treatment routes that consider optimisation of the whole lifecycle by focussing on treatment plant design, operation and decommissioning with respect to cost and overall waste volume reduction
- Looking to develop waste management approaches that deliver a step-change in risk reduction, i.e. treatment techniques that can destroy chemical hazards or reactivity
- Understanding and improving the long-term performance of the conditioned wasteform to help address uncertainty with respect to interim storage timescales and the development and implementation of HAW disposal solutions. For example, a chemically inert wasteform would carry less risk than a more chemically reactive product in terms of the possibility of rework being required to ensure transport and disposal compliance

Throughout this paper, treatment is presented in the context of making higher activity waste suitable for long term storage and eventual disposal in a geological disposal facility (GDF), unless treatment facilitates disposal by an alternative route due to a change in waste classification (i.e. LLW or Out of Scope). The NDAs HAW Treatment Framework considers at a high level, our planned activities over a range of timescales, from near-term R&D and the provision of strategic guidance, to longer term options such as the development of potential waste treatment services and waste treatment centres. It describes the current reference position and then sets out NDA's aims and the intended outcomes of pursuing strategic options in the following scenarios:

Scenario	NDA Aims	Intended Outcomes
Waste Encapsulation, *e.g.* cement encapsulation	Ensure a coordinated approach to encapsulation capability across the estate.	A reduced number of encapsulation facilities compared to baseline, a selection of suitable cement formulations, established encapsulation service and a range of alternative encapsulants.
Thermal Treatment Technologies	Provide leadership to enable coordinated development of thermal treatment capability (through an Integrated Project Team).	Appropriately underpinned technology being used across the estate. Some streams treated in the near-term.

Scenario	NDA Aims	Intended Outcomes
Physical (Non-Intrusive): Non-Encapsulation	Provide leadership as appropriate *e.g.* through the development of industry guidance on container selection.	Support effective application of containerisation across the estate. Making best use of currently available and approved containers.
Physical and Chemical (Intrusive): Decontamination	Provide leadership as appropriate *e.g.* through the development of decontamination industry guidance.	SLCs decontaminating where there is clear benefit, using techniques known to be effective and that deliver appropriately disposable products.
Problematic Waste Management	Leadership to enable development of coordinated approach (through an Integrated Project Team).	Build our understanding of the inventory across the estate and a programme of work to manage it. Some streams treated in the near-term.
Decay Storage	Provide leadership through additional guidance on time as a treatment.	SLCs identifying and implementing opportunities where the case can be made. Clear position established with respect to the use of risk-based approach and disposal by safety case argument.

In addition to setting out these aims and outcomes the HAW Treatment Framework includes an implementation plan that captures the specific near-term actions that will be pursued in the programme period. The document summarises the current situation and the case for change, it describes our planned work, how we will change the landscape and what success looks like. Delivery of the work will be led by NDA supported by Radioactive Waste Management Limited (RWM), Site Licence Companies (SLCs) and the supply chain.

Background

Nuclear site operations, site decommissioning and remediation generate significant quantities of HAW and the successful performance of these tasks is dependent on the availability of robust, suitable waste management infrastructure. HAW includes HLW, ILW and a relatively small volume of LLW that is unsuitable for disposal at the LLWR or the LLW facility at Dounreay. Effective waste management is essential for the delivery of our mission and is a significant part of our programme. HAW cannot be simply retrieved and directly disposed of. It requires a series of lifecycle steps throughout which it is important to consider the waste hierarchy: pursuing opportunities for waste minimisation, re-use and recycling, before undertaking treatment, packaging and storage. The waste must then be stored safely pending future transport and final disposal, when a disposal facility becomes available. This NDA HAW Treatment Framework concerns the intermediate step of waste treatment whereupon raw waste is conditioned and/or immobilised into a form that is suitable for long term interim storage and disposal. Typically waste treatment involves cement encapsulation of raw waste within a stainless steel container. The NDA recognises that cement encapsulation does not always provide the most optimal solution for HAW. It results in overall waste volume increase and there are often significant waste product quality and wasteform performance challenges posed by the chemistry of the cement encapsulants and the waste. NDA's Strategy is to pursue the development and implementation of alternative waste treatment capabilities that will broaden the toolkit available to SLCs and help to provide a more flexible and cost-effective approach to the management of HAW.

SLC practices already adopt different approaches in a number of instances, such as:

- Vitrification of Highly Active Liquor to produce High Level Waste
- Use of thick-walled containers that can remove the need for encapsulation
- Use of polymers as an immobilisation agent

The purpose of this paper is to provide a strategic overview of HAW treatment, highlight the areas where NDA believe there is further opportunity and describe how NDA will drive the delivery of these opportunities to optimise this critical waste management step. It should be noted that the timescales for delivery of the work will be subject to the availability and prioritisation of funding.

Treatment of HAW is an important aspect of the waste management lifecycle. HAW by its nature comprises hazardous[1] components that that need to be controlled in order to minimise the associated risk as appropriate. Radiological and chemical factors to take into consideration in the development of treatment solutions include:

- Dose rate
- Activity concentration
- Half-life
- Type of radiation, *e.g.* alpha, beta, gamma
- Shielding and containment requirements
- Chemical reactivity
- Solubility
- Chemotoxicity
- Gas generation

[1] In this context "hazard" is used to describe something (e.g. an object, a property of a substance, a phenomenon or an activity) that can cause adverse effects. A risk is the likelihood that a hazard will actually cause its adverse effects, together with a measure of the effect.

In addition to the chemical and radiological properties to be managed, hazards are present as a result of the physical properties of the wastes.

- Liquids and powders are mobile, presenting challenges in terms of containment and transfer. Treatments here focus on controlling the physical aspects of mobility and provision of containment in addition to addressing the chemical reactivity and ensuring radiological protection.
- Sludges can be potentially mobile and heterogeneous presenting challenges in terms of retrieval and transfer. Treatments here often focus on homogenising and controlling mobility in addition to addressing the chemical reactivity and ensuring radiological protection.
- Solids can have complex geometry and are often large, bulky and heavy items that present challenges in terms of movement and packaging efficiency for storage and disposal. Solids have greater potential for heterogeneous distribution of radioactivity and potential for self-shielding. Treatments here focus on size reduction, void filling, packing and handling in addition to addressing the chemical reactivity and ensuring radiological protection.

Methods of Treatment

HAW treatment is a key process for controlling the hazardous properties of wastes and reducing the level of risk to enable safe long-term management. Waste immobilisation is an effective means of converting mobile material into a form that has greater physical and chemical stability[2]. Waste product stability is an important consideration in the long term storage, transport and disposal of HAW.

Waste treatment combined with safe modern storage under appropriately controlled conditions will reduce the requirement for near-term intervention and progress toward a longer-term sustainable management situation. This will ultimately remove the need for costly and resource intensive waste management activities. It will lead to waste packages which are compatible with modern storage facilities with robust safety measures in place that can accommodate various disposal timeframes. HAW treatment can also enable overall packaged waste volume reduction through decontamination, radioactive decay, size reduction, compaction, thermal and chemical treatment. However, traditional methods of encapsulation involve the addition of new materials that will increase the overall volume for disposal especially if no pre-treatment or waste diversion is undertaken. As part of the waste management lifecycle, treatment should also take due cognisance of the future transport and disposal requirements. This is typically achieved through pursuing a Letter of Compliance (LoC) by undertaking RWM's disposability assessment process.

NDA Strategy promotes hazard and risk reduction through effective waste management in a timely manner which will help to achieve our mission of decommissioning the estate. NDA Strategy relies on successful waste treatment programmes and also recognises that a single step approach to waste treatment is not always possible, in particular, when dealing with the unique challenges of legacy wastes at the Sellafield site.

An example of this multi-stage approach is the treatment of waste from the Magnox Swarf Storage Silo (MSSS) at Sellafield. The previous strategy for MSSS was for the retrieval of sludge (the most hazardous component of the MSSS inventory) and encapsulation in cement using Sellafield Direct encapsulation Plant (SDP). The timescales to deliver SDP were lengthy. This resulted in a gap of approximately 8 years between the capability to retrieve

[2] The level of passivity that can be achieved is dependent on the initial hazard and the process deployed to chemically alter the waste.

(though the installation of the retrieval machines) and the ability to export the highest priority waste.

The R&D to underpin the SDP programme resulted in a fundamental change in understanding of some of the hazardous properties of the MSSS waste, especially with respect the chemical reactivity and hydrogen generation. This presented an opportunity to manage the waste downstream of the Silos differently. By storing the waste in an unconditioned form and reinforcing the safety features of the package it is possible to accelerate the capability to export waste for storage, pending future treatment. The current schedule now gives the capability to retrieve the most hazardous wastes sooner, through Box Encapsulation Plant (BEP) with a further opportunity to accelerate the programme if a direct import route into the Engineered Product Stores can be established.

NDA SLCs are responsible for delivery of waste management solutions and have to underpin their decision making in accordance with regulatory and strategy requirements.

Waste treatment to enable long-term interim storage, transport and disposal is enshrined in UK Government Policy and Regulation, addressing all aspects including safety, environmental protection and security. The Government White Paper, Implementing Geological Disposal; A Framework for the long-term management of higher activity radioactive waste, highlights the importance of waste packaging.

Waste packaging and passive safety

Existing higher activity radioactive waste must be stored in advance of disposal. Early conditioning of this waste into an appropriate form for storage is a significant part of its management. This is designed to reduce its hazard and to make wastes passively safe as soon as practicable, such that they are physically and chemically stable and stored in a manner which minimises the need for control and safety systems.
A key role for the developer, Radioactive Waste Management Limited (RWM), is to provide advice to waste producers on the compatibility of their waste conditioning proposals with future geological disposal, with the objective of avoiding the need for repackaging and the 'double handling' of wastes. This is undertaken using an established process, which is subject to scrutiny by the Office for Nuclear Regulation and the relevant national environmental regulators.

A system of robust storage arrangements, together with disposability advice, provides confidence that packages will be disposable at the end of the storage period. Progress with packaging of higher activity radioactive waste is reported annually by RWM and the Environment Agency.

The treatment and packaging of waste by immobilisation is also supported by guidance including that produced internationally by the IAEA, the Joint regulatory guidance on waste management [1], and a suite of waste packaging and treatment guidance documents produced by RWM[3]. Immobilisation of HAW within a suitable matrix leads to improved safety by reducing the potential for transfer of radionuclides in the environment. The aim of immobilisation of radioactive waste is to significantly reduce its potential to do harm during storage, transport and disposal.

A range of immobilisation agents are used across the nuclear industry, both nationally and internationally. The waste producers determine the most appropriate treatment method to deploy, taking into account the nature and quantity of the waste. Cement is the most commonly used immobilisation agent in the nuclear industry but it is recognised that this matrix can be suboptimal. Cement can react with some common metals to generate gas leading to pressurisation or voidage. The wasteform is the first of the multiple barriers to protect humans and the environment and hence encapsulation needs to be carefully

[3] http://www.nda.gov.uk/rwm/waste-producers/detail/#packaging-specifications-for-higher-activity-waste

considered. Where wastes have a significant chemically reactive component, limitations on waste loading can result or there may be a need for other preventative measures such as bespoke container designs [2].

The industry continues to explore alternative immobilisation technologies such as thermal treatment to remove chemical reactivity and novel encapsulants (*e.g.* resins) that are able to tolerate chemical reactivity.

For some specific wastestreams there may not be a need to immobilise the waste due to the inherent chemical and physical stability of the material or the integrity and robustness of the proposed container type. This presents an opportunity for simplified treatment, which can introduce associated cost savings. In these circumstances, containerisation alone might provide adequate long-term performance where the case can be made by the SLC. RWM have prepared guidance in this area and can inform decision making around waste container selection [3].

The following table summarises some potential opportunities and threats associated with the pursuit of alternative treatment technologies. Thermal treatment technologies and containerisation are presented here as examples to demonstrate some potential considerations when adopting alternative treatment technology.

	Typical Waste Characteristic	**Reference position, i.e. Cement encapsulation**	**Development of alternative treatment solutions, *e.g.* thermal**	**Containerisation**
Physical aspects	Mobile • Wet wastes • Sludge • Friable Immobile • Large items • Concrete • Metals	Fixes wastes Fills voidage Provide structural integrity Overall volume increase	Fixes wastes Remove voidage Provide structural integrity Opportunity for volume reduction	Greater reliance on the container to achieve an acceptable safe storage position Need to consider impact of voidage for disposal
Chemical aspects	Reactive Inert	Can sustain undesirable chemical reactivity *e.g.* gas generation, wasteform expansion Limited sustained chemical interaction with inert waste	The potential to destroy many chemically reactive species Opportunity to achieve long-term chemical stability for reactive waste Secondary waste and offgas needs to be considered	Can sustain chemical reactivity *e.g.* gas generation, wasteform expansion Inert material has limited interaction with the container

	Typical Waste Characteristic	Reference position, i.e. Cement encapsulation	Development of alternative treatment solutions, *e.g.* thermal	Containerisation
Radiological aspects	Contact handled alpha-bearing waste Remote Handled strong beta Gamma emitter	Fixes contaminants Provide self-shielding	Potential for concentration of radioactivity, *e.g.* CHILW to RHILW Can provide some self-shielding	Thin walled containers are sufficient for predominantly alpha-bearing wastes Usually reliant on thick-walled containers to provide shielding – limited self-shielding afforded by the waste

Case for Change

The NDA's mission will require a HAW treatment programme that will involve many £Bn's of expenditure from now until the completion of final site clearance and the disposal of HAW. This cost includes the construction, operation and decommissioning of facilities for the retrieval, treatment and storage of wastes, labour costs and the cost of consumables such as containers and encapsulant materials. The role for NDA Strategy is to provide leadership in key areas where there is a strong argument to challenge the reference position in order to deliver a substantially better approach. There is no doubt that a concerted effort to explore a different management strategy for HAW treatment could secure significant benefits by:

- Developing the necessary technical underpinning for alternative treatment routes that would deliver targeted improvements and provide resilience and contingency for current plans for legacy and decommissioning wastes
- Supporting a multi-stage approach to tackling hazard and reducing the risk posed by legacy facilities sooner than the baseline plan
- Pursuing alternative treatment routes that consider optimisation of the whole lifecycle by focussing on treatment plant design, operations and decommissioning with respect to cost and overall waste volume reduction
- Looking to develop waste management approaches that deliver a step-change in risk reduction, *e.g.* treatment techniques that can eliminate chemical hazards or reactivity
- Understanding and improving the long-term performance of the conditioned wasteform to help address uncertainty with respect to interim storage timescales and the development and implementation of HAW disposal solutions. For example, a chemically inert wasteform would carry less risk than a more chemically reactive product in terms of the possibility of rework being required to ensure acceptability for transport and disposal

The nuclear industry, the supporting research community and supply chain are developing alternative treatment methods to compliment the use of traditional cement encapsulation systems. NDA welcomes innovation and also recognises that the development of alternative treatment approaches is often a long-term rather than a short term initiative and therefore NDA leadership is required in helping to secure programme and lifetime benefits, taking a view that extends beyond the timescales of typical waste management projects. The case for change in terms of the potential impact of NDA intervention can be summarised as follows:

- Provide a co-ordination capability for the whole UK Nuclear Industry and leverage innovative approaches including building relationships with the supply chain, other waste owners, academia and international organisations
- Provide sustained funding for certain initiatives, over longer timeframes than SLC projects that are often constrained by site specific, near-term focused delivery programmes
- Provide a high level framework that establishes standard approaches to waste treatment without stifling innovation and helps to address the need to balance innovation with pragmatic programme implementation
- Demonstrate the overall impact of the development of alternative waste treatment solutions by monitoring SLC and RWM implementation plans
- Where the case can be made, establish centres of excellence for HAW treatment that could involve access to waste management services for other SLCs or waste owners.

NDA's Strategy (published April 2011) [4] included a commitment to consider alternative treatment capabilities, including thermal treatment, for HAW. When developing new approaches to waste treatment it is worth acknowledging that the timing of waste arisings is a key strategic driver as the specific opportunities, the strategic aims and the ability to change the landscape all evolve over time. The overall strategic approach addresses the following timeframes;

- The near-term strategy (less than 10 years)
- The medium to longer-term (between 10 years and 50 years)
- The long-term (beyond 50 years)

Timescale	Programme
Near-term	NDA investment in R&D initiatives, including funding specific tasks and demonstration facilities. The NDA expect SLCs to consider making best use of current and future planned treatment facilities, including sharing of capability between sites on a case-by-case basis.
Medium to longer-term	A programme approach to HAW treatment has been established and is being implemented at an estate level. This could include treatment centres of excellence.
Long-term	At this stage NDA effort would be limited to high-level planning and modelling of a range of potential scenarios.

In the near-term it is difficult to establish significant waste treatment changes at a programme level and it is more appropriate to make best use of existing facilities on a case-by-case basis. As a starting point an NDA treatment framework has been created that considers a number of scenarios that will continue to help the industry to move away from reliance on cement systems. The scenarios are broad ranging as they need to reflect the complexity of wastes needing to be treated from relatively inert low-end ILW to chemically reactive, mobile, challenging legacy ILW.

In the near to medium-term the majority of NDA sites will be heading towards a quiescent state of Care and Maintenance whereupon site operations, and therefore waste treatment opportunities, are limited. Sellafield is a clear exception where waste treatment will continue for many decades, making it the largest centre for HAW management in the UK until Final Site Clearance activities start on the Magnox and EdF Energy sites. Therefore, medium term strategies are dominated by Sellafield programmes where their extensive waste treatment capability could be made available to other sites subject to a compelling strategic and economic case including an acceptable stakeholder position.

In the long-term, the 2060's and beyond, the impact of Magnox and AGR decommissioning activities is pronounced in terms of waste arisings [5]. Unless the current decommissioning strategy changes significantly resulting in Magnox and AGR programme acceleration, it does not seem appropriate to focus on investigating an alternative treatment strategy that could involve centralised treatment of final site clearance wastes. However, this does not rule out a high level financial analysis and even the possibility of considering a HAW treatment facility within a disposal concept for decommissioning wastes or at another NDA site that could support site clearance activities.

NDA HAW Treatment Framework

The purpose of the NDA HAW Treatment Framework is to support SLCs and RWM in the long term by undertaking specific activities to progress the development of treatment technologies suitable for the wide range of wastes the estate has to manage and store, pending disposal. In the nearer term, the consideration of any multi-SLC waste treatment option will require investigation on a case-by-case basis, and will be subject to the NDA's Strategy Management System and a developed Business Case. Taking into consideration the case for change, the NDA HAW Treatment Framework will consider the following:

- SLC HAW programme approach to waste treatment where any opportunities should be highlighted within the individual SLC Integrated Waste Strategy (IWS)
- NDA directly sponsored R&D initiatives that help to underpin novel waste treatment and conditioning technologies
- The creation of NDA Integrated Project Teams (IPT) that support technology development and/or estate-wide solutions
- Evaluation of the role of the Sellafield Site in the medium to long-term including the possibility of establishing a treatment and conditioning service where the case has been made

The main focus of the NDA HAW Treatment Framework is waste treatment requirements between 2025 and 2060, where it is assumed it could take at least ten years from 2015 to develop an appropriate level of underpinning to be in a position to implement novel waste treatment routes. The programme will also support simplified solutions for some of the inventory in the near-term.

The HAW Treatment Framework scenarios supported by NDA are as follows:

A. Waste Encapsulation, *e.g.* cement encapsulation
B. Thermal Treatment Technologies
C. Physical (Non-Intrusive): Non-Encapsulation
D. Physical and Chemical (Intrusive): Decontamination
E. Problematic Waste Management (Orphans)
F. Decay Storage

The aim of the treatment framework is to develop a technology ‘toolkit’ to help our SLCs implement optimal solutions by considering factors such as volume reduction, wasteform performance, radioactive decay and ways to overcome the potential barriers to full-scale implementation including technology insertion schedules. As the work develops through time it might be appropriate to widen or narrow the number of scenarios being explored noting that Scenario E could consider all treatment options and in addition, chemical dissolution.

The Forward Plan

The NDA summary position for each of the scenarios of key tasks is described below including the current status with respect to IPTs, tasks performed under the NDA’s Direct Research Portfolio and work undertaken by SLCs and RWM. The desired outcomes are also described as this sets out what NDA would see as success criteria for each scenario. The HAW Treatment Framework table in Appendix 1 describes specific anticipated key milestones in each scenario, for example, the publication of strategic guidance or the timescales for outputs from IPTs.

Stakeholder engagement is an important aspect of the NDA’s work and we anticipate significant interaction with our stakeholders around the HAW Treatment Framework itself as well as the tasks set out within it. The table at the end of this section provides a summary position for each Treatment Scenario, where the following sections provide further background detail, expected outcomes and key tasks within the Forward Plan.

Waste encapsulation

NDA Strategy aims to expand the toolkit of available treatment options that SLCs can deploy. A part of this is expanding the available cement encapsulation capability, for example Direct Research Portfolio projects to understand the waste acceptance criteria of existing waste treatment plants with a view to establishing if some of these facilities can be used to encapsulate other wastes. In addition, the NDA has undertaken work to investigate some potential alternative encapsulants materials. These novel encapsulants are undergoing initial tests to evaluate their ability to tolerate the reactive nature of some HAW. Work has also been undertaken to develop superplasticisers that can be used in waste treatment to achieve a disposable waste product, assuring the NDA of a robust strategic position. Establishing an estate-wide overall programme approach to encapsulation delivers value for money, making best use of existing assets.

Within this scenario, NDA aims to ensure that a coordinated approach to HAW encapsulation is being taken across the estate. This means that in developing waste treatment capabilities, SLCs are also looking beyond their specific project and considering the potential to develop a capability that serves a number of wastestreams, making the best use of existing facilities, and maximising the effectiveness of planned new facilities. This could include the development of an appropriate encapsulation capability for the estate as a whole.

The anticipated outcomes of this approach would be a reduced number of encapsulation facilities across the estate when compared to previous baseline plans, an encapsulation service that can serve the needs of other sites and a range of alternative encapsulants that can be used to treat a broader range of HAW.

Thermal treatment

Current thermal treatment initiatives are fragmented, and are being taken forward by different organisations to address differing requirements. They involve a variety of thermal treatment technologies, and are directed at treating a range of waste types. Some good progress is being made in this area but the impact of this innovative technology has been limited and NDA believe this can be addressed though greater overall coordination. Work has typically been small-scale and on a project-by-project basis.

The vitrification of highly active liquor to convert it into HLW is an established process and the vitrification of HLW at Sellafield has been in operation since 1991. Although thermal treatment of ILW, is being deployed at industrial scale in other countries, existing UK initiatives for treatment of ILW are at the proof of concept stage, and no thermal treatment technologies specifically for UK ILW have been validated in a full-scale, active operational environment in the UK.

The NDA has assessed the requirements for a thermal treatment capability and concluded that there is a business case for the development of such a capability for ILW and other radioactive materials as appropriate (including the possibility of co-processing LLW). NDA aims to provide leadership in this area to enable the development of thermal treatment capability and is pursuing this through the development of an IPT. To facilitate SLC delivery, and to complement future research and development (R&D), a NDA-led IPT has been launched to establish a demonstration facility on the Sellafield site, which is a necessary enabler to the development of an operational full-scale thermal treatment capability. The demonstration facility is required to increase the Technology Readiness Level (TRL); the initiative could also be leveraged to provide UK-wide coordination and a focus for future R&D in this area. The longer-term outcome anticipated is that appropriately underpinned technology can be used across the estate and in the near-term, it is entirely credible that some wastestreams could be treated using a thermal treatment process.

Containerisation

Long-term performance of a waste package relies on the behaviour of the waste and the role that the waste container plays. For some wastestreams, their chemical and radiological properties are such that destroying reactivity or using an immobilising matrix represents the most effective way of assuring long-term performance. For other wastestreams that are comparatively inert, a robust container may satisfy requirements. Both the waste container and the wasteform contribute to the achievement of the required performance of the waste packages during normal operations and accident conditions. The relative importance of each contribution is generally dependent on the robustness of the other. The use of a more robust waste container can reduce reliance on the contribution of the wasteform to overall waste package performance. It should also be noted that it is the overall performance of the waste package, rather than that of its two individual components, is the governing factor in judging its disposability.

The use of containerisation can offer benefits in terms of acceleration of treatment programmes and the removal of the requirement for construction of encapsulation facilities and shielded stores. In this area, NDA sees benefit in the provision of leadership in order to help SLCs to make robust decisions on their tactics around waste container selection. This could be achieved through development of specific industry guidance on container selection to highlight the important decision making factors in each of the waste management lifecycle stages. This will enable SLCs to establish how they will assess and demonstrate whether potential container and waste combinations will perform adequately *e.g.* against the transport and storage requirements.

The intended outcome in this scenario is that we are in a position to clearly demonstrate appropriate application of containerisation across the estate and exploitation of containerisation opportunities.

Decontamination

Under certain circumstances it can be advantageous to remove surface contamination from HAW, applying the waste management hierarchy, and minimising HAW volumes by diverting waste to lower category routes, potentially enabling re-use of materials. In some cases however, decontamination has not been effective enough to enable reclassification or else has resulted in a waste product that cannot meet relevant requirements for disposal without further treatment. The main doubt about the acceptability for disposal of materials used to fix and remove radioactive contamination relates to the presence in some detergents and cleaners of sequestrating agents that have the potential to adversely affect radionuclide and non-radioactive chemical species mobility during the post-closure phase of a GDF. Recently, LLWR and RWM have assessed the potential effects of decontamination agents on post-closure safety, and work is currently ongoing to investigate the effectiveness of a range of decontamination techniques. Inventory analysis could be undertaken to identify the specific opportunities that are strategic, *e.g.* metals recategorisation.

In this scenario NDA will work with industry experts from our SLCs to coordinate the development of decontamination industry guidance. This will follow on from the studies highlighted above, to show which decontamination techniques can be successfully deployed in a range of applications to give effective decontamination which results in disposable waste products.

The guidance would help SLCs to deploy decontamination techniques and apply the waste hierarchy where a clear cost benefit has been established, using techniques known to be effective and that deliver appropriately disposable products.

Problematic radioactive wastes

All NDA sites have wastes that are not suitable for treatment in existing processing plants or those currently planned at a detailed level. These wastes can be referred to as ‘problematic’ radioactive wastes. They may also be known as ‘orphan wastes’ or ‘wastes requiring additional treatment’ (WRATs).

There are several reasons that wastes may be problematic, for example the waste may:

- Have an unknown provenance or inventory (*e.g.* concrete lined drums originally destined for sea disposal)
- Have a specific hazard (*e.g.* pyrophoric material or asbestos containing)

- Be unsuitable for a standard treatment process (*e.g.* reactive metals which are unsuitable for encapsulation by standard cementitious grout)
- Pose issues to the disposability of a waste package (*e.g.* loose particulates)
- Pose operational or interim storage issues (*e.g.* radon emanating waste)
- Be suitable for managing by a means other than disposal (*e.g.* lead may potentially be recycled if enough treatment is undertaken)

The management of most problematic radioactive waste is not currently planned in detail, as most treatment will not occur in the near term. For some sites, the treatment of problematic radioactive waste is, or could soon become, a critical path activity for site clearance. If an estate-wide strategy for problematic radioactive waste is developed in the near-term, there is a potential to not only save time and money on the treatment of these wastes, but also the potential to remove these activities from the site critical path, saving even more time and money. Even if these activities cannot be removed from the critical path, SLC risks and uncertainties could be reduced.

For some categories of problematic radioactive waste, each SLC has a relatively small volume (*e.g.* batteries, solvents and pyrochemical waste), which would make site-by-site treatment very expensive per unit volume. Individual project budgets at sites may not be able to afford a solution, but an estate-wide approach could potentially be utilised to develop a much more cost effective proposition. There are a range of possible outcomes depending on the particular options that are progressed. In order to enable the treatment of some problematic radioactive wastes it may be possible to:

- Move the waste
- Move the technology
- Share LoCs, designs and safety cases

NDA is focused on evaluating the potential for a coordinated approach to the treatment of problematic radioactive wastes. Again, we are looking to provide coordination and leadership in this area to enable development of a strategic approach through an IPT; build our understanding of the inventory across the estate; and reduce the level of uncertainty before developing a strategic programme to treat these wastes. This is another area where NDA believes it is entirely credible that some problematic radioactive wastestreams can be treated in the near-term.

Decay storage

Some wastes, particularly those in which the main radionuclide constituents are relatively short-lived (i.e., half-life less than ~30 years) will undergo significant radioactive decay, so that they could potentially become amenable to near-surface disposal at sometime within the next 300 years. Based on the waste volumes currently in existence and scheduled to arise before 2113, wastes potentially amenable to decay storage could be in the region of 38,000 m^3 or 13% of the 290,000 m^3 total ILW inventory by raw waste volume (based on the 2013 UKRWI) [5].

Although current reactor decommissioning strategy involving deferred final site clearance is underpinned by the principle of *in situ* decay storage[4], and such an approach is under consideration in the development of NDA Site Decommissioning and Remediation Strategy, there are relatively few wastestream-specific examples that take advantage of decay storage as a means to divert waste away from a GDF.

For some wastestreams (*e.g.*, the Ministry of Defence (MOD) resins held at Rosyth), benefit could potentially be gained, through reclassification of ILW as LLW, from decay storage of as little as a few years [6]. In others cases, many decades of storage would be needed to achieve the same level of radioactive decay. For wastes in Scotland, a period of time to allow for decay through storage on short (a few years) and long (several decades) timescales could enable them to manage some ILW as LLW and prepare it for eventual near-surface disposal.

NDA support SLCs pursuing opportunities at a tactical level and we are looking to a forthcoming update to the industry guidance on storage to achieve that buy-in across the estate. In the longer term we hope that this results in greater visibility of SLCs identifying and implementing decay storage opportunities where the case can be made. NDA would also like to see greater clarity with respect to the use of a risk-based approach resulting in disposal by safety case argument.

Summary Table

Scenario	NDA Aims	Intended Outcomes
Waste Encapsulation, *e.g.* cement encapsulation	Ensure a coordinated approach to encapsulation capability across the estate.	A reduced number of encapsulation facilities compared to baseline, a selection of suitable cement formulations, established encapsulation service and a range of alternative encapsulants.
Thermal Treatment Technologies	Provide leadership to enable coordinated development of thermal treatment capability (through an IPT).	Appropriately underpinned technology being used across the estate. Some streams treated in the near-term.
Physical (Non-Intrusive): Non-Encapsulation	Provide leadership as appropriate *e.g.* through the development of industry guidance on container selection	Support effective application of containerisation across the estate. Making best use of currently available and approved containers.
Physical and Chemical (Intrusive): Decontamination	Provide leadership as appropriate *e.g.* through the development of decontamination industry guidance.	SLCs decontaminating where there is clear benefit, using techniques known to be effective and that deliver appropriately disposable products.

[4] *In situ* decay storage refers to leaving the waste in place, rather than carrying out demolition, treatment and packaging of waste, before the period of decay storage. With regards to Magnox decommissioning strategy it refers to leaving the reactor buildings and pressure vessels so that any radioactivity will decay in place until final site clearance.

Scenario	NDA Aims	Intended Outcomes
Problematic Waste Management	Leadership to enable development of coordinated approach (through an IPT).	Build our understanding of the inventory across the estate and a programme of work to manage it. Some streams treated in the near-term.
Decay Storage	Provide leadership through additional guidance on Time as a treatment.	SLCs identifying and implementing opportunities where the case can be made. Clear position established with respect to the use of risk-based approach and disposal by safety case argument.

For each treatment scenario a number of key projects or tasks have been highlighted and periodic updates will be provided by the NDA:

- Published technical work including conference papers/presentation
- Articles on NDA or SLC websites
- Published NDA Strategy Management System reports
- Presentation to stakeholders (e.g. Theme Overview Groups, Nuclear Waste and Decommissioning Research Forum)

Implementation Plan for NDA's HAW Treatment Framework

Scenario	Description	Overview of strategic opportunities	Forward programme
A. Waste Encapsulation Waste encapsulation using cementitious grout to produce a disposable waste package	Cement encapsulation is commonly considered to be the technical baseline for the immobilisation of waste. However, assumptions regarding the performance of encapsulated waste and therefore the ease of obtaining an LoC in some instances may be unreliable. The normal approach for encapsulation is on a project by project basis. The HAW to be treated in the medium term and beyond is dominated by the Sellafield site.	The main opportunity is to create a coordinated waste encapsulation programme in the medium term that will ensure the best use of current and future planned facilities and would explore: • Reducing the number of encapsulation plants required across the estate • The potential creation of a waste encapsulation service if the case can be made • Knowledge transfer across the estate regarding cement formulations and encapsulants • Supporting SLCs in the continued development of alternative encapsulants A programme approach to waste encapsulation is being pursued where Sellafield continues to explore opportunities to reduce the number of plants by sharing facilities between projects and allowing the import of waste from other sites for treatment on a limited case-by-case basis where the potential impact on the Sellafield delivery programme has been carefully assessed. Alternative encapsulants may broaden the applicability of this treatment technology or give improved long-term performance.	• NDA to continue to sponsor alternative encapsulants DRP tasks in support of the NDA Estate or strategic initiatives, *e.g.* 'tolerant cement systems' • All SLCs to provide technical input via the NWDRF and working groups, *e.g.* alternative encapsulants • Sellafield to continue to explore alternative encapsulants in support of their own HAW programmes • RWM to continue to provide support to all SLCs in terms of LoC coverage of existing and future treatment plants • RWM to continue active trials on superplasticisers to optimise cement encapsulation approaches

Scenario	Description	Overview of strategic opportunities	Forward programme
B. Thermal Treatment Application of thermal processes to promote oxidation of reactive metals, degradation of organics and combustible materials. Waste volume reduction and conversion of product to disposable form.	Cement-based systems will not be the most appropriate treatment route for all HAW streams and alternative approaches must be developed to ensure the HAW treatment strategy remains robust. Currently there is an ILW thermal treatment plant in the NDA site lifetime plans, which is the WTC2 plant at Sellafield, planned to start operations in 2036. The Waste Vitrification Plant at Sellafield is an operating plant used in the conversion of highly active liquors into HLW glass products. There are a range of R&D initiatives being undertaken across the industry and the supply chain.	The NDA estate is largely reliant on cement encapsulation as the waste immobilisation agent. One promising treatment solution is the use of thermal technologies. Little investment is currently planned in the near-term but at the same time, significant waste volumes are being accumulated without an underpinned final solution in place, *e.g.* PFCS containerised wastes, FGMSP fuel, FGMSP sludges, PCM, MBGW. The strategic opportunity is therefore to invest in developing a range of thermal treatment technologies. This will ensure future treatment projects are able to consider a broader toolkit of underpinned and implementable technologies and address barriers to implementation.	• Sellafield Ltd to progress the Integrated Project Team through implementation of the Project Initiation Document (PID). The PID establishes the scope of work in response to NDA specified requirements to investigate alternative treatment technologies • To continue to work with SLCs (in particular Sellafield Ltd) in the IPT to deliver an active demonstration facility to investigate: o A range of thermal treatment technologies o Research needs including product quality, off-gas treatment, radionuclide retention, volume reduction o Key issues and programme uncertainties o Regulatory aspects o Support from the non-NDA sites o Broader stakeholder views • Continue to fund underpinning DRP tasks as required • All SLCs to provide technical input *via* the NWDRF and working groups

Scenario	Description	Overview of strategic opportunities	Forward programme
C. Physical (Non-Intrusive): **Containerisation** Placement of waste in suitable robust containers to produce a disposable waste package. Use of interim containers to support accelerated hazard reduction.	Robust containers such as Ductile Cast Iron Containers and TRU-shield containers can be used for the packaging of certain wastes in place of encapsulation. Work by NDA Strategy[5] has indicated that a relatively small percentage of the radioactive waste inventory would be suitable for packaging using robust containers. Interim containers can be used as part of a multistage decommissioning approach for high-hazard facilities. This approach to packaging wastes expedites emptying old facilities. It also enables progress at pace as it can be implemented on shorter timescales than design and build of an encapsulation plant for high hazard wastes.	For the majority of ILW streams, NDA sites will deploy waste encapsulation and/or wasteform passivation technologies. However, there are opportunities to explore the use of robust containers, for example some graphite and activated steel wastestreams. In addition the use of 2m and 4m boxes should be explored. The NDA and RWM will support opportunities as required, and could form an important part of an overall treatment capability noting that pre-treatment may be a crucial prerequisite. This could also be supported through the development of guidance on container selection. In the medium to long term the aim is to support smaller scale applications rather than wholesale use as waste immobilisation. This is the preferred solution for the majority of wastestreams especially on the Sellafield site.	• Consider the need for development of further 'container selection' guidance

5 Robust Shielded Containers, Scenarios Report, August 2012, Assist.

Scenario	Description	Overview of strategic opportunities	Forward programme
D. Physical and chemical (Intrusive): **Decontamination** Use of mechanical or chemical techniques to remove surface contamination, then disposal via non ILW routes NDA expects the SLCs to implement effective HAW management routes including decontamination to optimise management of boundary wastes.	Decontamination of HAW could lead to a significant reduction in overall HAW volumes but the application needs to be understood in the context of any additional safety & environmental burden, impact on LLW management routes and costs in terms of (i) level of investment and (ii) ultimate lifecycle benefits. Decontamination can also provide improvements in terms of dose uptake for decommissioning activities	This could be a major opportunity especially in regard to those wastes at the ILW/LLW boundary. NDA has committed to investigate opportunities at the ILW/LLW boundary and work is underway in this area. Decontamination technology is available and further work is required in the use of mobile technologies and disposability of secondary wastes, including potential impacts on effluent streams.	• To continue to support the technical development of mobile treatment technologies via NDA DRP with support from NWDRF and its working groups • To consider the decontamination strategic position following recent disposability study and completion of ongoing study regarding availability and effectiveness • SLCs including LLWR to support relevant NDA strategic initiatives which will explore decontamination approaches at the NDA or UK level • As appropriate, NDA to consider future development of guidance for an industry wide approach to decontamination in support of waste management and decommissioning strategies. This will provide guidance on the disposability of secondary HAW

Scenario	Description	Overview of strategic opportunities	Forward programme
E. Problematic Waste Management Management of problematic wastes through a flexible approach considering: • Available estate-wide treatment technologies; • Applicability across the known inventory of problematic wastes; • Development of a bespoke facility(ies);	Most sites within their plans have to deal with 'problematic wastes', which are often termed as 'orphans' or 'wastes requiring additional treatment (WRATs)'. They tend to be small volume wastestreams that require specialised treatment. NDA sponsored a number of studies to understand the current situation and how the baseline plans could be improved through.[6] • Early characterisation of waste with an unknown inventory • Improving knowledge transfer regarding problematic waste • Sharing treatment facilities • Making better use of the supply chain to treat problematic waste	NDA funded studies have collated a large amount of data pertaining to orphan wastes located at nuclear licenced sites across the nuclear industry. This information has been used to define generic orphan waste groups, based on commonalities such as their physical, chemical and radiological properties and helped us to consider technologies applicable to their treatment.	• RWM to lead an NDA IPT in collaboration with LLWR, developing the preferred strategic option(s) in response to NDA specification: o Gate B for near term opportunities complete by March 2017 o Gate B for longer term opportunities complete by August 2017 • All SLCs to provide technical input *via* the NWDRF and working groups, *e.g.* mobile technologies • SLCs to highlight to RWM any changes to their orphan waste registers • SL and RWM to consider whether any components of LP&S streams could be defined as problematic wastes, where treatment options exist in the NDA estate

[6] Support for NDA RWM GDF Programme Upstream Optioneering: Optimised Management of Orphan Wastes, Assist, C Hamblin, T Turner, 10th January 2013

Scenario	Description	Overview of strategic opportunities	Forward programme
F. Decay Storage Using time as a treatment to allow reactivity to subside or radioactive decay of short lived radionuclides to reduce specific activity levels, either in-situ or containerised.	The aim of the strategy is to deal with the wastes as they arise and tackle legacy wastes by converting them into a stable form for long-term management in a timely manner. Little national attention has been given to decay storage at this stage and any SLC activities are on a tactical basis, *e.g.* desiccant storage on Magnox sites. Storing waste and utilising time as a treatment can allow reactivity to subside or radioactive decay of short lived radionuclides. This decay then opens new potential options for treatment and disposal that could be significantly cheaper than management as ILW.	Decay storage should play an important role in the range of waste treatment capabilities the NDA needs to utilise. There are a range of potential beneficial impacts from this approach including: Disposal *via* non ILW route; enabling alternative treatment and packaging scenarios; or avoiding the generation of significant discharges or secondary wastes. It may have a limited application but could support Scottish Government HAW policy and those sites where long-term storage of waste is currently required, *e.g.* Magnox, Sellafield and disposal sites.	• RWM to include coverage of decay storage within the HAW Interim Storage Guidance update due for publication in 2016 • NDA to provide regular updates to the IWM ToG • SLC Best Available Technique assessments and IWSs should consider the decay storage opportunities, *e.g.* Magnox opportunity

1 Joint guidance from the Office of Nuclear Regulation, the Environment Agency, the Scottish Environment Protection Agency and Natural Resources Wales to nuclear licensees. *The management of higher activity radioactive waste on nuclear licenced sites*, February 2015. Revision 2.

2 Nuclear Decommissioning Authority. UK Radioactive Higher Activity Waste Storage Review. 2009. [Online] http://www.nda.gov.uk/publication/uk-radioactive-higher-activity-waste-storage-reviewmarch-2009/.

3 Radioactive Waste Management Limited. A strategic examination of the key differentiators influencing the selection of Robust Shielded Containers, May 2013.

4 Nuclear Decommissioning Authority. Strategy Effective from April 2011. 2011. ISBN 78-1-905985-26-5. [Online] http://www.nda.gov.uk/publication/nda-strategy-effective-from-april-2011/.

5 NDA & DECC, Radioactive Wastes in the UK: A Summary of the 2013 Inventory, URN 14D039, 2014.

6 Areva RMC (2013). Support for NDA RWMD GDF Programme Upstream Optioneering: Optimised Management of Orphan Wastes, R12 – 152 (A) Issue 2, January 2013.