Nuclear
Decommissioning
Authority

Higher Activity Waste

Operational Graphite Management Strategy Credible and Preferred Options (Gate A and B)

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Executive Summary

Background

The purpose of this work is to establish the strategic framework in which operators develop their strategy for the management of current arisings of operational graphite waste. It represents one part of Nuclear Decommissioning Authority's (NDA's) programme of work considering the management of graphite waste.

Approach

The paper follows the approach set out in NDA Strategy Management System (SMS) Guidance [1]. Note that the intention of this paper is to define the preferred management option in the near-term but not to preclude the adoption of other management options in the longer-term. This recognises the fact that some options that are not currently considered to be credible or preferred on the basis of their level of technical development may become more credible in the future. The existing Site Licence Company (SLC) arrangements for the review of Best Practicable Environmental Option/Best Available Technique studies (BPEO/BATs) and the NDA's arrangements for the review of Integrated Waste Strategies (IWSs) will ensure that these options are reviewed at the appropriate time.

A separate strategy position will follow this one and will provide the NDA's view on the strategy for the management of graphite waste from reactor decommissioning. This approach to graphite waste strategy, separating current operational arisings from reactor decommissioning waste, was determined following engagement with stakeholders representing the regulator community. A key factor that influenced this decision was learning from the investigation of near surface disposal of graphite sleeve waste at the Hunterston site. It was very clear from this work that the factors that would determine a coherent strategy for managing operational arisings are very different to those for reactor decommissioning wastes and that progress in strategy development would be improved by separating the two.

Conclusion

The preferred options for the management of graphite have been identified and are summarised below:

- **Berkeley Site** – to manage all the graphite waste as ILW for interim storage (in resilient, self-shielding containers) and assume unencapsulated final disposal in the GDF;

- **Hunterston A Site** – to manage all the graphite waste as ILW for interim storage (unencapsulated in stainless steel containers) with encapsulation at Final Site Clearance (FSC) prior to management in accordance with Scottish Policy; and

- **Sellafield Site** – to manage the graphite waste within the scope of this study as ILW for interim storage (in mild or stainless steel drums) with encapsulation prior to final disposal in the GDF.

The strategic objective of the paper has been met in the near-term as adoption of the preferred option at all three sites would result in a common baseline up until the point of disposal. It is recognised that further work is necessary to underpin the baselines with respect to disposal however through the non-foreclosure of options afforded by these preferred options the ability to select an appropriate disposal option (particularly within Scotland) is not constrained.

It should be recognised that site based decision making may result in the adoption of an option that differs from the preferred option set out within this paper. As described previously the purpose of this paper is to provide the strategic framework within which sites are then able to make these decisions. As such detailed site-based factors may influence ultimately which option is implemented. The consideration of such factors within further assessments will be undertaken by the sites separately due to the differing timescales over which decisions are required to be taken.

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1 Introduction

1.1 Purpose

The purpose of this document is to establish the strategic framework in which operators develop their strategy for the management of current arisings of operational graphite waste. It represents one part of NDA's programme of work considering the management of graphite waste. A separate strategy position will follow this one and will provide the NDA's view on the strategy for the management of graphite waste from reactors cores. Note that the volume of operational graphite is far less than that which will be generated by the management of reactor cores.

This approach to graphite waste strategy, separating current operational arisings from reactor decommissioning waste, was determined following engagement with stakeholders representing the regulator community. A key factor that influenced this decision was learning from the investigation of near surface disposal of graphite sleeve waste at the Hunterston site. It was very clear from this work that the factors that would determine a coherent strategy for managing operational arisings are very different to those for reactor decommissioning wastes and that progress in strategy development would be improved by separating the two. Table 1 details the scope and purpose of these two projects.

Another important factor in setting out this approach is that there is an established strategy for managing reactor graphite that is embedded in site lifetime plans and is broadly similar across them. For operational arisings, different approaches are being undertaken at different sites. One of the key objectives of this work is to determine whether a uniform approach would be appropriate or whether the different approaches at different sites are justified due to site specific issues.

This work is being delivered using NDA's Strategy Management System and will establish a preferred option for the management of current operational arisings of graphite waste (Gate B). It is not our intention to take the strategy for these wastes to Gate C at the NDA level. The expression of a preferred option for managing this waste will provide SLCs with the strategic envelope in which to determine the approach for specific waste streams, taking into account more site specific factors that will affect decision making. This is considered to be a proportionate approach given the limited number of waste streams affected by this strategy and the very specific factors that affect the approach to managing each of the waste streams.

The timescales for Site Licence Companies to respond to this expression of a "preferred option" differ. At the Hunterston A site Magnox are developing their position for the management of graphite sleeve waste, which is the subject of an Improvement Notice. The baseline strategy at Hunterston will be to encapsulate this waste during Care and Maintenance Preparations. Elsewhere, strategies are in place; however, any work to optimise those strategies will be informed by this position. Given the immediate relevance of this work, the desire to not unduly delay hazard reduction is a key criterion for developing the strategic approach to managing this waste.

1.2 Scope

The scope of this options assessment work is restricted to those operational waste streams for which it could be feasibly conceived that the strategy for their treatment and disposal would be determined based upon the fact that they contain a large proportion of graphite. Appendix A provides a summary of all of the operational waste streams across the UK which contains a graphite component. The waste streams which are highlighted in Appendix A are those which are considered to be of this nature. In summary these are operational waste streams at Berkeley[1], Hunterston A and Sellafield Sites.

It is recognised that reactor core graphite strategy forms another key component of overall NDA strategy. An assessment of options for these waste streams is being conducted separately to this study [2]. Table 1 below provides an overview of these two pieces of strategic options assessment work.

Title	Current Operational Graphite Waste Arisings	Graphite Waste from Reactor Decommissioning
SMS Stage	Stage B – Preferred Option	Stage 0 Research / Stage A – Credible Options
Inventory	• Magnox fuel sleeves at Hunterston • AGR fuel sleeves at Sellafield • Berkeley vault waste (as an example mixed waste stream)	• NDA research reactors (Harwell, Dounreay) • NDA Magnox reactors • EDF Energy AGR reactors
Arisings timescale	• Magnox fuel sleeves at Hunterston » 2013-2019 • AGR fuel sleeves at Sellafield » Now - 2030 • Berkeley vault waste (as an example mixed waste stream) » 2013-2017	• NDA research reactors (Harwell, Dounreay) » 2019-2030 » (Dounreay MTR 2015-2017) • NDA Magnox reactors » 2070-2101 • EDF Energy AGR reactors » 2102-2114
Target level of strategy development	Gate B – Preferred option (Gate C decisions made a waste stream / SLC level)	Gate A – Credible options

[1] Note that the waste at Berkeley has been included within this assessment despite its mixed nature as a significant proportion of the waste is graphite

Title	Current Operational Graphite Waste Arisings	Graphite Waste from Reactor Decommissioning
Purpose	Provide a strategic context within which SLC's can make waste stream level decisions (i.e. prevent a lack of strategy from unduly influencing decisions)	Determine the credible options for reactor graphite management and the effect of different decommissioning scenarios on those options. Clearly describe the relationship between Site Restoration strategy and reactor graphite waste management Provide an indication of what R&D work could be implemented to support the programme going forward.

Table 1 – Summary of Approach for addressing Graphite Waste Strategy

1.3 Context of the Work

1.3.1 Drivers for the Work

The principle drivers of this work are:

1. Governments response to CORWM Recommendation 8 [3];
2. "We will" statements in NDA Strategy (Higher Activity Waste section) [4] that commit NDA to investigate opportunities to share waste management infrastructure across the estate;
3. International work programmes on graphite management; and
4. The difference in management options currently planned to be implemented by different SLCs.

Note that there are also a number of site specific drivers for this work that are detailed throughout the paper.

1.3.2 Existing Strategy Position

Graphite strategy has been in development at NDA for several years as the main element of work under the Reactor Decommissioning work stream. However, investigation in graphite management outside of the NDA has been on-going for considerably longer including research & development programmes and international collaboration. Various aspects of this extensive wider effort seem to be driven by a number of factors, including:

- The large volume of this waste stream;

- The perception that the lack of a waste route prevents decommissioning of reactors. Although it is recognised that the Geological Disposal Facility (GDF) is the planned waste route (for England and Wales) there are perceived issues surrounding timing and whether deep geological disposal of this waste is the Best Available Technique (BAT) approach; and

- The aspiration to apply higher levels of the waste hierarchy to this waste.

As discussed in previous work [5], to date NDA's work on the Reactor Decommissioning Waste has focussed on developing understanding of technical options for management of graphite waste, essentially answering the question "what *can* be done with graphite?". More recently, NDA has shifted attention to addressing what "*should*" be done with graphite.

1.4 Strategic Interfaces

This work is being conducted under the Higher Activity Waste sub-section of the Integrated Waste Management Topic Strategy. In terms of significant interfaces with other Topic Strategies the following have been identified, noting that these Topic Strategy interfaces may or may not be realised dependent on the selected preferred option(s):

- **Site Restoration** – the Site End States Topic Strategy may be affected by the outcome of this work as if the preferred option for any of the waste within scope was determined to be on-site disposal then this may require a revision to the planned site end state;

- **Integrated Waste Management** – the Lower Activity Waste and Non-Radioactive and Hazardous Waste Topic Strategies may be affected by the outcome of this work. The options for managing the waste include conditioning of the waste to either LLW or exempt levels, which would mean that these topic strategies were relevant; and

- **Fuel Management** – it is noted that the preferred option for Sellafield FED graphite management strategy may have an impact upon AGR fuel reprocessing.

In addition there are interfaces between this paper and a number of Critical Enablers:

- **Research and Development** – the outcome of this paper will impact upon the research and development that will be pursued on the various options. Further it is recognised that the conclusions of this paper may need to be reviewed in light of future research and development;

- **Asset Management** – there are different asset management implications associated with adoption of the different options discussed in this paper. Some options would require assets to be managed for substantially prolonged periods when compared to current plans;

- **Funding** – there are significant differences in terms of funding (both in the near and longer term) between the management options under consideration; and

- **Transport and Logistics** – a number of the options under consideration would require significant effort in terms of transportation particularly those options involving removal of the waste off-site.

2 The Baseline

The baseline strategy for the management of graphite at Berkeley, Hunterston A and Sellafield is to retrieve the waste, condition (either promptly or following a period of containerised storage) and package in containers suitable for eventual disposal. The waste packages will be stored on-site prior to their eventual disposal to a future facility. For England and Wales disposal will be in a GDF, for Scotland this will be long-term management in near-surface facilities in accordance with Scottish Policy [6].

The following sub-sections outline how this baseline strategy will be implemented by each of the waste owners. A commentary is also given regarding the level of maturity and issues that have been identified with the existing baselines.

2.1 Berkeley Site

The baseline strategy for Berkeley Site operational graphite is retrieval during C&M Preps and packaging, unencapsulated, into resilient, self-shielding containers. The graphite is currently stored within two vaults and is mixed with FED Magnox, FED stainless steel, FED zirconium, drummed ion exchange resin and contaminated gravel. There will be minimal segregation of the graphite waste from the other waste streams during the retrieval process. The graphite waste will be conditioned (vacuum dried) as appropriate to allow eventual disposal to the GDF following a period of interim storage on-site. This position is currently being underpinned through the production of a BPEO[2] reasoned argument that considers the merits of waste segregation. Though yet to be completed there is an understanding that this BPEO assessment will conclude that these benefits of segregation are out-weighed by the technical and programmatic issues that achieving segregation (to allow any alternative management option) would present.

In terms of technical readiness the baseline is considered to be well developed in all respects. A well-defined programme of development work is on-going in this area to support delivery of the baseline, which is scheduled to commence during retrieval work in early 2013. Berkeley will progress through the Letter of Compliance (LoC) process, an endorsed Conceptual Stage LoC (cLoC) for the graphite waste (mixed with the other waste) having been achieved, and will be developing Interim Stage LoC (iLoC) and Final Stage LoC (fLoC) submissions for this waste.

Changes to the site LC35 Decommissioning Programme that enable this strategy have recently received regulatory agreement.

[2] Note that, at the time of writing, Magnox operates a BPEO and BPM regime to satisfy the requirement to demonstrate BAT. Environment Agency guidance states that BPEO and BPM are equivalent to BAT.

2.2 Hunterston A Site

Hunterston A Site graphite is currently stored within the Solid Active Waste Building (SAWB) bunkers. Bunker 1 contains almost all of the FED Magnox produced during station operation, together with small quantities of miscellaneous ILW. Bunkers 2, 3, 4 and 5 contain mainly Graphite and metallic debris[3], with only small quantities of miscellaneous ILW; there are also small amounts of FED Magnox in Bunkers 2 and 3. Bunkers 1, 2, 3 and 4 are full, but Bunker 5 is only about 25% full, and is still operational, receiving occasional items associated with decommissioning. There will be no further arisings of operational graphite.

The baseline strategy for Hunterston A Site operational graphite is retrieval during C&M Preparations and packaging into 3 m^3 stainless steel containers. The waste will then be encapsulated within the containers and the resulting waste packages stored on-site prior to their eventual disposal to a future facility[4].

There is an ONR Improvement Notice associated with the passivation of the potentially mobile wastes on site that includes some of the waste currently stored within the Bunkers (principally the Magnox FED).

In terms of technical readiness the baseline is considered to be well developed in all areas with all relevant technologies having proven up to a minimum the system commissioning phase [7]. An iLoC has been issued for Hunterston A graphite waste using the current encapsulation baseline[5].

In April 2009, a strategic review of the management of Hunterston A SAWB bunker waste was initiated in response to the policy consultation announcement by the Scottish Government. The strategic review remit was to reconsider the site strategy for the lifecycle management of solid ILW against industry good practice with reference to Scottish Government policy, regulatory requirements and Company policy. In considering the

[3] Note that a significant proportion of the activity associated with the waste stored in Bunkers 2-5 is associated with these non-graphite components.

[4] Note that the current baseline disposition for all ILW at Hunterston A Site is disposal to the GDF. Hunterston A Site is in the process of updating their Site baseline strategy to be in accordance with Scotland's Higher Activity Radioactive Waste Policy (2011). For the purposes of this Paper, it is assumed that this update has been agreed by the Office for Nuclear Regulation.

[5] It should also be noted that the baseline at Trawsfynydd Site is also to encapsulate solid ILW (FED). This process is underway at Trawsfynydd and a fLoC submission has been issued for Trawsfynydd FED using the encapsulation approach providing additional confidence that the Hunterston A Site baseline is deliverable.

combined process and endpoint options, the recommended outcome of the Solid ILW Strategic Review, 2011 [8] was:

- *"Dissolution of FED Magnox (Bunker 1 wastes). This applies significant volume reduction to that waste requiring future management and facilitates identification and segregation of fuel and fuel fragments; and*

- *Unencapsulated prompt on-site disposal of graphite (and other wastes in Bunkers 2 to 5). The benefits of this option extend across virtually all the attributes considered."*

On-site disposal in the near surface environment is a key opportunity for appropriate higher activity waste management in accordance with Scottish Government policy. It was recognised that this management strategy is new to the UK and that there are considerable uncertainties with the near surface disposal option at this time including:

- Regulatory risks associated with permitting the facility;
- Schedule risk – delays in the implementation could threaten the schedule for getting the site into Care and Maintenance;
- Cost – there was no overriding cost benefit; and
- The impact of such a facility on site end state and the associated impact on the ability to de-licence are not well understood.

Due to these uncertainties, NDA concluded that it was not possible at this stage to change the baseline strategy for bunkers 2-5 to become near surface disposal on site.

Following further review Hunterston A Site have submitted a proposal to ONR that confirms the continued application of their current prompt encapsulation strategy for all wastes in Bunkers 1-5

2.3 Sellafield Site

The Sellafield Site graphite waste, within the scope of this paper, arises as part of AGR fuel reprocessing operations. The graphite fuel sleeves are separated from the rest of the fuel element within the Fuel Handling Plant. Waste is expected to arise up to 2030. As waste arises, it is placed (unencapsulated) in mild or stainless steel 500L drums and stored within the Graphite Store and the Encapsulation Product Store.

The baseline strategy for the Sellafield containerised graphite is for the wastes to remain in their current stores (the Graphite Store and the Encapsulation Product Store) until a new encapsulation plant is expected to begin operations (~2040). This plant will encapsulate wastes from a number of facilities, including this waste and also waste from Miscellaneous Beta-Gamma Waste Store. As the GDF is currently planned be operational by the time of final packaging, only temporary buffer storage of the encapsulated waste packages is allowed for.

Given these timescales, Sellafield Ltd is currently exploring the processes that would need to be designed into the plant to produce disposable packages for all the waste streams. The Letter of Compliance process is being used to seek formal advice from RWMD to inform the optioneering process. Other opportunities, such as unencapsulated disposal of the graphite waste are also being considered by Sellafield.

3 Approach

3.1 Strategy Management System

This paper follows the approach set out in NDA Strategy Management System (SMS) Guidance [1]. Note that the intention of this paper is to define the preferred management option in the near-term but not to preclude the adoption of other management options in the longer-term. This recognises the fact that some options that are not currently considered to be credible or preferred on the basis of their level of technical development may become more credible in the future. The existing SLC arrangements for the review of Best Practicable Environmental Option/Best Available Technique studies (BPEO/BATs) and the NDA's arrangements for the review of Integrated Waste Strategies (IWSs) will ensure that these options are reviewed at the appropriate time.

For the purposes of this paper all waste management options that could feasibly be applied to the graphite within scope are included. These options have been assessed through the methodology shown in Table 2 below.

Step	Section of Document	Description
Identification of Options	Section 4.1	All feasible high-level options are identified.
Description of Options and Sub-options	Section 4.2	Sub-options (in terms of the tactical approach to delivery) identified.
Screening Assessment	Section 4.3 and 4.4	Options and sub-options screened to remove those that cannot credibly meet the objectives of the preferred option. Thereby producing a list of credible options.
Summary of Credible Options	Section 4.5	Summary of the options deemed credible.
Credible Options Assessment	Section 5	A detailed assessment of the credible options (based upon the NDA Value Framework). Identifies the preferred option(s).
Preferred Options Determination	Sections 6, 7 and 8	A consideration of the preferred option for each site taking into account additional factors that are not covered by the value framework (such as the site-specific assumptions and constraints).

Table 2 – Summary of Methodology Adopted in this Assessment

3.2 Assumptions and Constraints

The following high-level assumptions and constraints apply to the development and assessment of the credible and preferred options:

- **Current regulatory standards and requirements** – will apply at the time of implementation of any identified strategy. No attempt has been made to anticipate regulatory change;

- **Scotland's Higher Activity Radioactive Waste Policy, 2011** – includes treatment, storage and disposal. The presumption in the Policy is that the storage and disposal facilities will be as near to the site where the waste is produced as practicable, minimising the need for transporting the waste over long distances, and that the storage and disposal facilities will be in the near-surface environment;

- **Demonstration of disposability** – will be through the Radioactive Waste Management Directorate (RWMD) LoC process for the GDF. It is understood that for wastes that will be subject to interim or long-term storage the Scottish Environment Protection Agency's (SEPA's) expectation is that Scottish HAW producers will manage their waste in accordance with the RWMD LoC process [9]. As referred to in the joint regulatory guidance for the management of higher activity radioactive waste the policies for the disposal of higher activity waste differ in Scotland and in England/Wales. However SEPA consider that packages conditioned in anticipation of geological disposal are also suitable for long-term storage, as required by Government policy in Scotland; and

- **Implementation Timescales** – the technologies considered must have the ability to deliver within existing timescales (without causing undue delay to C&M Preps for Magnox Sites or no delay to operations at Sellafield). This is a fundamental constraint as the preferred option must not significantly alter affected sites' funding profiles.

Whilst the strategic objective of this paper is to achieve a common baseline across the NDA estate, for this waste there may be different constraints at each of the sites that affect which option is deemed to be preferred. As such the following sub-sections also define the site specific assumptions and constraints that apply and which are taken account of during the preferred options assessment that follows.

3.2.1 Berkeley Site Assumptions and Constraints

The implementation of any alternative options for Berkeley Site will be considered with the following assumptions and constraints:

- Berkeley operational graphite waste is intimately mixed with other waste streams (as described in Appendix A) and it is assumed that it can only be partially segregated in the near-term;

- Off-site transport and disposal of waste packages associated with operations and Care and Maintenance Preparations (to the GDF) is assumed to be between 2046 and 2049;

- An encapsulation facility will be built at Final Site Clearance (FSC) to encapsulate the decommissioning waste arising during 2070-2079 into 4m RWMD stainless steel containers;

- Entry into Care and Maintenance at Berkeley Site is scheduled for 2021; and

- LC35 Decommissioning Programme milestone requires that '*all ILW in active waste vaults retrieved and passivated ready for final disposal'* by August 2019. The graphite waste is within the scope of this milestone.

3.2.2 Hunterston Site Assumptions and Constraints

The implementation of any alternative options for Hunterston A Site will be considered with the following assumptions and constraints:

- Hunterston A operational graphite waste is intimately mixed with other waste streams (as described in Appendix A) and it is assumed that it can only be partially segregated in the near-term due to the timescales associated with meeting the Improvement Notice;

- Entry into Care and Maintenance at Hunterston A Site is scheduled for 2022;

- It is assumed that an encapsulation facility will be built at FSC to encapsulate the decommissioning waste arising during 2072-2080 into 4m RWMD stainless steel containers;

- Waste disposition in accordance with Scottish Government Policy is assumed to occur at FSC (2072-2080);

- LC35 Decommissioning Programme milestone requires that '*all solid operational ILW retrieved and passivated for final disposal'* by September 2019. The graphite waste is in scope of this milestone;

- ONR Improvement Notice requires that *"all potentially mobile ILW that has accumulated as waste in the Hunterston A Solid Active Waste Bunkers shall only be stored in a passively safe state by 31 November 2016";* and

- The preferred option at Hunterston A Site must allow implementation in accordance with Scotland's Higher Activity Waste Policy, 2011[6].

3.2.3 Sellafield Site Assumptions and Constraints

The implementation of any alternative options for Sellafield Site will be considered with the following assumptions and constraints:

- The existing stock of Sellafield graphite is a segregated waste stream, stored unencapsulated in mild steel and stainless steel drums. Future arisings will be placed in stainless steel drums only for storage;
- It is assumed that an encapsulation facility will be built ~2040 in line with planned GDF availability; and
- Off-site transport and disposal of waste packages (to the GDF) is assumed to commence in 2040 and continue until ca. 2070.

[6] Until the Scottish Government Policy Implementation Strategy is further developed, the presumption is that the waste at Hunterston A, will be stored on site, above ground such that the waste is monitorable and retrievable.

4 Options Identification and Screening

Options are identified and then screened to develop a list of credible options for the management of operational graphite at Berkeley, Hunterston A and Sellafield Sites.

4.1 Identification of Options

The NDA has previously outlined a number of strategic options for the management of graphite [10]. Note that these options were defined in relation to reactor decommissioning graphite waste however it is considered that the options are also applicable to the near-term arisings. For the purposes of this paper these high-level options can be summarised as:

- **Option 1** – Manage all graphite waste as ILW for interim storage[7] and disposal to a future facility (such as the GDF or a near surface disposal facility);
- **Option 2** – Prompt disposal in a near surface facility (possibly including a pre-treatment step); and
- **Option 3** – Condition the graphite waste to enable alternative disposal as a lower category of waste; as LLW at the Low Level Waste Repository (LLWR), release as 'out of scope' waste or storage followed by reuse where possible.

These high level options (and associated sub-options) are shown below in Figure 1 and summarised in the following sections along with further detail regarding the background of the options and how each might be technically delivered.

[7] Where interim storage of means storage of waste packages within a purpose-built facility (interim store), which aims to maximise the lifetime of waste packages, where there is the planned intention for a final management step, e.g. transport/transfer of the packages to an appropriate disposal facility.

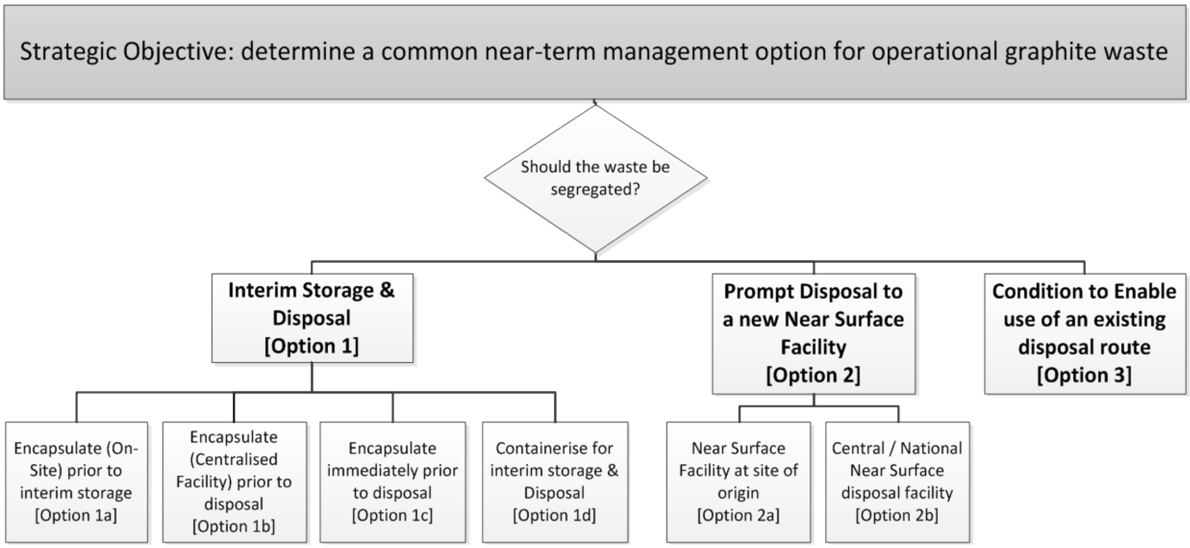

Figure 1 – High-level Strategic Options Diagram

Note that there are also variants of options 1c and 1d that would involve the addition of a void filling material, other than encapsulant, to the waste packages prior to their disposal. These variant options may offer the ability to avoid the foreclosure of options for disposal at FSC. However it is not considered that they are significantly different from options 1c and 1d in terms of their performance in this assessment and therefore are not considered further. It should be noted that this does not discount them from future decision making should either options 1c or 1d be implemented. It is recognised that void filling would be implemented to overcome potential structural integrity issues associated with disposal.

4.2 Description of Options and Sub-Options

4.2.1 Interim Storage and Disposal as ILW (Option 1)

As described in Section 2, this option is the baseline at each of the three sites considered within this assessment. This option requires the waste to be retrieved from its current storage location, packaged into an appropriate container[8] and conditioned (either dried or encapsulated) and interim stored prior to eventual disposal. It is recognised that all of these process steps will be conducted in accordance with the relevant LoCs.

Sub-options to be considered include:

[8] In this context an appropriate container is considered to be any container that either already has/or for which plans are in place to produce an RWMD Waste Package Specification document including for example 3 m^3 boxes, 4 m boxes, WAGR boxes, Type VI DCICs or MOSAIK DCICs.

- **Option 1a** – encapsulate (on-site) prior to interim storage;
- **Option 1b** – encapsulate (centralised facility) prior to interim storage;
- **Option 1c** – encapsulate immediately prior to disposal with the storage container being used as the disposal container; and
- **Option 1d** – unencapsulated disposal.

4.2.2 Prompt Near-surface Disposal as ILW (Option 2)

This option requires the retrieval of the waste from its current storage location, packaging it into a suitable container (for disposal in the near-surface environment[9]) and then prompt disposal of the waste package into a near-surface disposal facility.

For the purposes of this paper, it is assumed that for the near surface disposal option, there will be no requirement for a separate encapsulation plant. Grouting of the waste in the containers could take place (if required by the environmental safety case for the facility) in-situ within the disposal facility, as was assumed for the Graphite Pathfinder Project concept design and cost estimate.

Near-surface[10] disposal of irradiated graphite waste (of similar activity to that under consideration within this study) is currently being implemented in the US and is being developed in a number of countries including France and Japan [11]. Feasibility work has also been conducted in the UK with a graphite disposal pathfinder project having been conducted at Hunterston A Site during 2010 and 2011 that demonstrated that such a disposal facility could feasibly be delivered on-site subject to obtaining relevant permissions.

Sub-options to be considered include:

- **Option 2a** – prompt disposal at a near surface facility at site of origin; and
- **Option 2b** – prompt disposal at a central / national, near-surface facility.

Note that the opportunity of deferred near-surface disposal of graphite is not considered as an option within this study. This is because the decision regarding the disposition of these waste streams is likely to be made in conjunction with the decision regarding the deposition of reactor core graphite. As such it is not considered to be appropriate to consider in isolation the disposition of operational graphite waste streams as any decision would likely to be driven primarily by reactor core graphite considerations. As referred to in section 1.1 the issue of disposition of reactor core graphite will be explored in a separate Stage A SMS Paper.

[9] As defined by the safety cases associated with any such disposal facility.

[10] Note that near-surface disposal is considered to mean disposal at depths of tens of meters.

4.2.3 Treatment to Enable Use of an Existing Disposal Route (Option 3)

This option requires the waste to be retrieved from its current storage location, packaged into a transport container and despatched to a waste treatment facility. The technological methods by which this waste could be treated to enable it to be disposed of as either LLW or exempt waste can be divided into two distinct groups; thermal treatment techniques and chemical decontamination techniques.

4.2.3.1 Thermal Treatment

Thermal treatments for irradiated graphite have been previously considered as a method to significantly reduce the radionuclide inventory of waste material. In addition thermal technologies have been investigated with a view to reducing the volume of graphite waste requiring disposal. For example, for a typical incineration process, it is considered that the ratio of graphite to ash produced is approximately 160:1, so the overall volume of material to be disposed of would be considerably reduced [12].

4.2.3.2 Chemical Decontamination

Recent studies have identified it is possible to decontaminate large amounts of graphite waste through the use of chemical treatments [13]. The objective of the decontamination is usually to remove the bulk activity by dissolution.

The resultant solution would then be managed in accordance with a BAT assessment; it is assumed that this would involve capturing the vast majority of the radioactivity for waste management in solid form.

The CARBOWASTE project [14] has identified several options for chemical decontamination including:

- Acid treatment;
- Liquid decontamination agents; and
- Aggressive leaching.

Trials are being carried out on samples of legacy Magnox graphite, EU MTR graphite and EDF (Pechiney) graphite, to study the performance of these techniques.

In addition, a full characterisation and modelling program will take place under the CARBOWASTE programme [15] in order to determine the inventory of the nuclides in nuclear graphite before and after treatment. This will also identify the mechanisms by which impurities/radioisotopes may be removed from the nuclear graphite waste.

4.3 Screening Criteria

To determine which of the high-level options can be regarded as being credible options a set of screening criteria have been specified. The purpose of these criteria is to ensure that options carried forward for further consideration are credible in terms of meeting the strategic objectives associated with these wastes. A summary of the screening criteria used is given below:

1. The option must be capable of being delivered in a legally compliant manner and in accordance with relevant policy.

2. The option must be capable of being delivered without causing undue delay to C&M Preps for Magnox sites or no delay to operations at Sellafield (so as to prevent undue delay being caused to hazard reduction activities). For example a delay to the entry into C&M (caused by adopting a particular operational graphite management approach) for the two Magnox sites under consideration would cost in the region of £60M per year.

3. The technology underpinning the option must be known and require minimal research and development work to enable implementation due to the short amount of time available before this waste is planned to be managed.

4.4 Screening Assessment

The screening assessment within this section is divided into two parts:

- **Preliminary Screening Assessment** – considers the three high-level options detailed in Section 4.1 against the screening criteria; and

- **Sub-options Screening Assessment** – considers those high-level options that make it through the preliminary screening exercise by breaking the high-level options into sub-options (identified in Section 4.2) that consider the tactical manner in which the option might be implemented.

4.4.1 Preliminary Screening Assessment

A summary of the preliminary screening assessment, in which each of the high-level options are assessed against the screening criteria defined in Section 4.3, is detailed in Appendix B. It can be seen that only Option 1 is considered to be a credible option for all of the sites considered. Further it is considered that Option 2 (disposal of graphite in the near-surface environment) represents a credible option at Hunterston A and Sellafield Sites only. This option is considered to be credible at Hunterston A Site due to the near-surface disposal development work that has been undertaken at the site during the past three years as part of the Graphite Pathfinder Project and there is time within the decommissioning programme at Sellafield for this to be applied there also. For the Berkeley Site this option is not considered to be credible principally due to the development work that would be required to modify the

Hunterston A Site specific design and safety case. This work could not credibly be expected to be completed without affecting the Berkeley Entry into Care and Maintenance Date.

Option 3 is screened out at this stage of the assessment principally on the basis that both treatment to meet current LLWR acceptance criteria and to activity levels suitable for release as exempt material would require a substantial amount of development work for which there is insufficient time without causing an undue delay to hazard reduction. The following summarises the key arguments that support this decision:

Disposal to LLWR – Appendix C contains an assessment of the graphite inventory against the LLWR's current Conditions for Acceptance (CfA) and Environmental Safety Case (ESC). It shows that the majority of the graphite inventory exceeds the limits within the CfA and would be challenging with respect to the ESC, therefore this waste would not be suitable for consignment to the LLWR without treatment based on the current limits and the performance assessment in the latest version of the 2011 ESC.

One of the most significant radionuclides that would need to be removed from the graphite to allow disposal as LLW is tritium. Removal of the majority of this radionuclide would enable the waste to meet the 12 GBq/t beta/gamma limit at LLWR (based upon 2010 Radioactive Waste Inventory data). A suitable tritium removal technology has been investigated previously with respect to desiccant treatment and it was found that approximately 100 m^3 of waste would take ca. 2-3 years to process. Therefore, for the much larger volume of waste considered here it is considered that without substantial technological development (or substantial capital investment in multiple processing units) this process could not deliver within the existing decommissioning timescales. Further, even if the tritium could be removed from the waste a substantial proportion of the C-14 and Cl-36 would still remain. The amount of C-14 activity associated with these wastes means that its disposal to the LLWR is not considered to be feasible because the specific activity limit specified in the 2008 CfA for C-14 is 0.015 GBq/Te, which is approximately two orders of magnitude less than the C-14 specific activity of the lowest activity waste stream considered within this study. However, it should be noted that LLWR is working on less cautious assessment models for C-14 bearing wastes that may result in less restrictive limits than those from the 2011 ESC (although not to a level likely to affect the analysis presented here).

Treatment to allow disposal as exempt waste or possible reuse – All of the significant radionuclides would need to be removed from the waste before it could credibly be disposed of as exempt waste including H-3, C-14, Cl-36 and Co-60. Graphite incineration or pyrolysis could be utilised to achieve this aim through gasification of the graphite and capture of the resulting (radionuclide rich) gas. This technology has been investigated for graphite waste and it has been determined that the technology required to implement the process is not currently close to being implementable on the scale required. For example some of the key issues currently identified with graphite incineration include:

- the need to develop crushing methodology prior to incineration.
- the need to prevent/minimise the release of radioactive gases and particulate (particularly C-14, Cl-36 and residual H-3).

- the need to develop processing and disposal of the residual ash, in which other radioactive isotopes are concentrated.
- lengthy processing times.
- likely significant capital and operational costs.

It is therefore considered that this option could not deliver within the existing decommissioning timescales without substantial technological development.

In addition from it is considered that fundamentally the graphite treatment options considered offer negligible benefit at this stage. Irradiated graphite management is centred upon how to best dispose of the two long-lived radionuclides that are present in the waste (C-14 and Cl-36). Some of the technologies that deliver these options, such as thermal treatment, whilst offering a substantial reduction in waste volume do not appear to offer an improved solution for the management of C-14 and Cl-36. Such technologies would discharge these radionuclides into the environment or alternatively would require complex abatement plants that would capture and concentrate these radionuclides into secondary waste streams. When the relatively benign nature of the graphite waste is considered, any secondary waste might be more difficult to manage than the graphite. As such, it is not considered that there is any significant benefit at the present time to be gained by incurring the cost and environmental burden of separating radionuclides from the graphite through a treatment option when the graphite can be disposed of safely in its current form without treatment.

4.4.2 Sub-options Screening Assessment

As defined in section 4.4.1 there are two high-level options that have been identified for further screening assessment. Within each of these high-level options there are a number of sub-options in terms of the tactical approach to delivery (see Section 4.2).

For example different tactical approaches that could be adopted include whether the management option should be conducted at the site of waste origin or at a centralised management facility[11].

Appendix D presents this more detailed screening assessment, and concludes that a number of these sub-options are not credible for some of the sites.

4.5 Summary of Credible Options

A summary of the credible options for each of the sites is presented in Table 3. A high-level set of flow diagrams is then presented in Appendix E which details the component parts that make up each of the credible options at each of the sites.

[11] Note that consideration of centralisation for the purposes of this paper is restricted to centralisation of graphite processing/treatment and disposal facilities. Centralisation of interim ILW storage facilities is currently being considered on a wider scale through a separate Strategy Management System assessment and as such this is not considered further here.

Options			Berkeley	Hunterston A	Sellafield
Option 1 – Interim Storage & Disposal as ILW	1a	Encapsulate (on-site) prior to Interim Storage	✓	✓ (current baseline)	✓
	1b	Encapsulate (centralised facility) prior to Interim Storage	×	×	×
	1c	Encapsulate immediately prior to disposal	✓	✓*	✓ (current baseline)
	1d	Unencapsulated disposal	✓ In resilient, self-shielding containers (current baseline)	✓** In RWMD container	✓ In RWMD container
Option 2 – Prompt Disposal as ILW	2a	Near surface facility – at Site of origin	×	✓	✓
	2b	Central / National Near Surface Facility	×	×	×

Table 3 – Credible Options for each site following screening assessment.

* Note that this issue would need further discussion with the Regulators to prior to implementation being allowed to commence.

** Note that more development work would be required to ensure that this would be deliverable particularly in the areas of the LoC and safety case.

5 Credible Options Assessment

This section assesses the credible options for each site against the NDA Value Framework.

5.1 Assessment against Value Framework

The attributes defined in NDA Guidance document EGG08 [16] have been used to assess the credible options (and associated sub-options) against the existing sites' baselines to define a short-list of options suitable for more detailed further evaluation.

The attributes used within this assessment are: Hazard Reduction; Security; Safety; Environment; Socio-economic and Cost.

5.1.1 Hazard Reduction

For the purposes of this assessment it is considered that the rate of hazard reduction in relation to operational graphite waste (and also for other ILW waste streams) is directly proportional to the time taken to achieve passive safety of the waste.

Option 1 – Manage all graphite as ILW, interim storage and disposal to a future facility

With respect to this option it is considered that the rate of hazard reduction would not be substantially affected by selection of any of the option 1 sub-options when compared to the baselines at each of the sites.

The manner in which containerised waste achieves passive safety is detailed in

Appendix F. This presents an assessment against the engineering principles defined by the Office for Nuclear Regulation (ONR) Technical Assessment Guidance (TAG) with respect to the management and storage of radioactive waste [17]. This assessment concludes that the containerised storage of the graphite waste in question meets the passive safety principles.

It is considered that both the options which produce unencapsulated waste packages and also those options which produce encapsulated waste packages deliver hazard reduction at the same rate as they deliver passive safety at the same time.

Further, it should be noted that for all three sites under consideration the conditions for storage of graphite containing waste packages (and all other ILW packages) will not differ significantly whether the waste is encapsulated or containerised[12]. In both scenarios the storage conditions will be designed to ensure that the waste packages remain suitable for disposal in accordance with their relevant LoCs.

[12] It is noted that there may be some differences in terms of package handling and export arrangements.

Option 2 – Prompt disposal in a near-surface disposal

With respect to this option it is considered that the rate of hazard reduction when compared to the baselines at Hunterston A and Sellafield Sites is not different as both achieve passive safety within similar timescales. It is noted that implementation of this option would result in earlier disposal of the waste however the hazard reduction associated with disposal is considered to be minimal relative to the waste passivation step. This is supported when considering the relevant sites' Safety and Environmental Detriment (SED) reduction profiles which demonstrate that the significant hazard reduction is associated with waste passivation and that eventual disposal offers marginal further hazard reduction.

5.1.2 Security

Security is not considered to differentiate between any of the credible options as each of the sites have suitable security arrangements that ensure that the site is protected against foreseeable security threats. Further it is recognised that regardless of which option is pursued the waste will still represent a relatively small part of a much larger site that will continue to have suitable security arrangements.

5.1.3 Safety

5.1.3.1 Radiological

At this high-level stage of the assessment it is considered appropriate to assess operator dose in terms of number of high-level 'operations'[13] to be performed as it is assumed that all operations will be conducted in a manner that ensures that all doses remain Broadly Acceptable and ALARP. As such those options that require a greater number of operations than the baseline are considered to perform less well in terms of safety whilst those that require fewer operations are considered to perform better.

Note that with respect to public safety a preliminary Environmental Safety Case (ESC) was prepared for the Hunterston disposal cell concept for the disposal of operational graphite waste streams (Ref. 18), supported by a performance assessment (Ref. 19). These indicate estimated risks and doses to the public well within regulatory criteria set out in regulatory guidance (Ref. 20) during both the period of authorisation for the facility and post-closure.

Option 1 – Manage all graphite as ILW, interim storage and disposal to a future facility

In terms of comparison between the sub-options the major differentiation is between those sub-options that produce an encapsulated waste package (1a and 1c) and those that

[13] High-level operations in this context are taken to mean waste management steps such a retrieval, packaging, conditioning, storage and disposal. Note that it is not intended to define operations in a more detailed manner as this is not considered appropriate at this level of assessment.

dispose of the waste in a containerised form (1d). This is because the encapsulation sub-options include an additional step (encapsulation) when compared to the containerisation sub-options. It is however considered that any difference in terms of safety between these sub-options is minimal as all operations would be conducted in a manner that ensures doses would be kept ALARP. This would be particularly true of the encapsulation step as this process would be conducted in a remote manner meaning that anticipated operator dose would be minimal (restricted to maintenance/recovery activities).

In summary when the sub-options are compared to the current site baselines it can be seen that adopting a containerised disposal approach at Hunterston A and Sellafield Sites would offer a marginal safety benefit. At Berkeley Site no such benefit would be realised as containerised disposal is currently the baseline.

A further consideration with respect to safety are issues associated with the long term unconditioned storage of wastes. This is because of the need for additional waste movements and the risk that the wastes may undergo some degradation during the storage period that may make them more difficult to eventually treat and manage. For example the removal of waste from a container for ex-situ conditioning may become more difficult than conditioning at the time of retrieval. It is recognised however that such degradation would be unlikely to occur to the graphite waste streams under consideration here due to the wastes non-reactive nature.

Option 2 – Prompt disposal in a near-surface disposal

With respect to this option it is considered that near-surface disposal offers little safety benefit over the baseline at Hunterston A and Sellafield Sites as both require an encapsulation step and as such there is no avoidance of this operation. There may however be some safety benefit associated with the early disposal of the waste offered by the near-surface disposal option as the waste will have to be managed for a shorter period above ground than currently anticipated in the baseline. This shorter time period prior to disposal is associated with not having to interim store the waste. However, this interim storage does not represent a significant safety critical step as during storage the waste would be in a passive form and as such any safety benefit gained by disposal would be small.

5.1.3.2 Conventional

In terms of conventional safety there is a difference between the credible options under consideration in terms of the main source of risk. For those options that include a step of removal of the waste from the site to a disposal facility the major conventional safety risk is associated with transport whilst for those options that involve the use of additional waste treatment/disposal facilities on-site the major risk is associated with construction and decommissioning of the facilities. It should be noted that these risks are borne by different groups, with the transportation primarily being a risk to the public whilst the risks associated with the construction and decommissioning works are predominantly to the worker. It is however considered that both of these risks will be well managed and as such do not differentiate between the credible options.

5.1.4 Environment

5.1.4.1 Radioactive Discharges

For the purposes of this study it has been assumed that there would be no significant difference between the credible options under consideration and the sites' baselines in terms of radiological discharges. It is recognised that discharges would need to be demonstrated to be BAT however it is assumed that all discharges would be within the limits specified within the relevant regulatory authorisations/permits.

It is recognised that prompt encapsulation of the waste would lead to a release of tritium due to the exothermic reaction occurring during grout curing. However it is also recognised the containerised storage of the waste in vented containers (such as those proposed to be used by Hunterston A and Sellafield Sites) would be likely to result in a release of tritium over the storage period. It is noted that these discharges are considered to be negligible.

5.1.4.2 Non-radioactive Discharges

There is no significant difference between the credible options under consideration and the sites' baselines in terms of non-radiological discharges. It is noted that the options that involve the construction of additional waste treatment/disposal facilities will result in the production of CO_2 associated with construction, whilst those options that involve an off-site transport step will result in CO_2 being produced through transport.

5.1.5 Socio-economic

There is considered to be no significant difference between any of the credible options under consideration and the sites' baselines in terms of socio-economic effect. This is because none of the credible options would significantly alter the sites' decommissioning programmes for instance by accelerating or deferring entry into the Care and Maintenance period. Such a change to the decommissioning programme could be considered to have a significant socio-economic effect as the entry into C&M will result in the loss of a significant number of jobs. Implementation of any of the credible options would not result in any such change.

5.1.6 Cost

The cost analysis presented within this paper is based upon the Hunterston example. This approach has been adopted as suitable options comparison costs are available for this site. It should be noted that it is considered that the principle outcomes of the cost analysis made for Hunterston are also likely to be applicable to Berkeley and Sellafield sites. Discussion of the cost implications of adopting the different options at these two sites is presented in a more qualitative way.

5.1.6.1 Hunterston A Site

For Hunterston A there are four credible sub-options that are under consideration which are; the prompt encapsulation of the waste (1a), the containerisation of the waste until FSC when it would be encapsulated (1c), the containerised long term management of the waste (1d) and also the near-surface disposal of the waste on-site (2a). The costs of implementation of each of the option 1 strategies are presented in Table 4.

Option No.	Option Description	Near-term Cost	Lifecycle Cost – Disposal at FSC	Lifecycle Cost– 200 year storage
1a	Encapsulate (on-site) prior to interim storage	£50.1M	£85.7M	£130.8M
1c	Encapsulated immediately prior to disposal	£50.1M	£85.7M	£130.8M
1d	Unencapsulated disposal	£11.9M	£47.5M	£92.6M
2a	Prompt disposal at a near-surface disposal facility at the site of origin	£38M	£39M	£39M

Table 4 – Summary of Credible Option Costs (treatment and conditioning) for Hunterston A Site.

The costs presented for options 1a, 1c and 1d are derived from the costs presented in Reference 21 which presents the outcome of the Hunterston A solid ILW management assessment concluded in October 2012.

The costs for option 2a and also an estimate of the cost of implementing a 200 year storage scenario are derived from the costs presented in Reference 22 which presents a Gate C SMS Paper for the management of Hunterston A's solid ILW. The cost of £39M is considered to be a class B estimate and is underpinned by cost estimating work performed as part of the Graphite Pathfinder Project [23].

5.1.6.2 Berkeley Site

For Berkeley the three credible options that are under consideration are to encapsulate the waste promptly (1a), to containerise the waste for disposal (1d) or to containerise the waste until FSC at which point it would be encapsulated for disposal (1c). In terms of cost the key difference between these options is the cost of encapsulation of the waste (either during C&MP or at FSC). The cost of encapsulation at FSC is considered to be negligible as an encapsulation plant will be required at FSC regardless to encapsulate reactor decommissioning wastes.

It is noted that there may be some additional cost associated with the deferred encapsulation strategy as there would be a need to interim store the waste for an extended period. The current baseline of containerised waste disposal assumes that the waste will be transported to the GDF at ca. 2040 whilst a deferred encapsulation strategy would not result in the removal of the waste from site until an undefined date within FSC (2070-2079). As such the interim store for this waste will be required for an additional ca. 30 years. The increased cost associated with this extended interim storage period is considered to be minimal as the design life of the ILW interim store is 100+ years.

It is also recognised that there will be an increased cost when compared to the baseline in terms of materials and operation time for the encapsulation plant at FSC. The cost in terms of additional encapsulant and operating time is however considered to be relatively small due to the large volume of other wastes requiring encapsulation at FSC such as reactor decommissioning wastes.

In summary, in terms of cost it is considered that there is little difference between either of the credible options.

5.1.6.3 Sellafield Site

For Sellafield there are four credible sub-options that are under consideration which are; the prompt encapsulation of the waste (1a), the containerisation of the waste until a packaging plant is constructed in ca. 2040 (the baseline) when it would be encapsulated (1c), the containerised disposal of the waste (1d) and also the near-surface disposal of the waste on-site (2a). It should be noted that these options are not necessarily mutually exclusive as graphite waste which has already arisen could be treated differently to waste which is planned to arise in the future.

The cost of the baseline cannot currently be easily attributed for this graphite waste as the cost of its waste management is incorporated into the cost of waste management for a number of other waste streams that are planned to be processed through the yet to be constructed packaging plant in ca. 2040. The key point to note here is that from a strategic perspective (with cost as a key consideration) the decision on strategy for this waste will be likely to be determined by decisions taken for other waste streams on-site.

For the purposes of this assessment the capital cost of this packaging plant is considered to be negligible as this graphite represents only a small proportion of the volume of waste to be processed through this plant. It is noted that there will be operational costs associated with processing the graphite waste through this plant however these are considered to be significantly out-weighed by the capital cost savings achieved through using a shared plant.

5.2 Summary of Assessment

A summary of the assessment of the four Credible Options against the assessment criteria is shown in Table 5 below. The analysis shows that the majority of the attributes do not differentiate between the credible options except on cost and hazard reduction.

Assessment Criteria	Option 1 – interim storage and disposal			Option 2 – prompt disposal
	1a – Encapsulation prior to storage	**1c – Encapsulation immediately prior to disposal**	**1d – Unencapsulated disposal**	**2a – Near-surface facility at Site of origin**
Hazard Reduction	Passive safety and therefore hazard reduction achieved on similar timescales			
Security	No differentiation between the options – site have security arrangements.			
Safety	Production of encapsulated waste package introduces an additional step in the process. Minimal difference in worker doses.		Disposal in containerised form would not involve an encapsulation step.	
Environment	Options that include an interim storage step will result in discharges over a longer period of time than those options that involve prompt near-surface disposal however as discharges during interim storage are expected to be minimal this is not considered to be significant.			
Socio-economic	No significant difference between the options. No options will significantly alter the Sites decommissioning programmes.			
Cost (Near-term)	Medium – associated with building encapsulation facility. Hunterston A and Sellafield may already be building one for other wastes.	Medium – associated with building encapsulation facility at FSC.	Low – no encapsulation facility needed.	Medium – associated with building disposal facility (no encapsulation facility needed).
Cost (Lifecycle)	The cost of disposal at FSC or 200 year storage means that there are costs additional to the near-term costs which have to be taken into account to produce lifecycle estimates. As such on a lifecycle basis the options perform less well than in the near-term.			The cost of post-closure monitoring is relatively modest meaning that lifecycle and near-term costs are not significantly different.

Table 5 – Summary of credible options assessment.

Key -

Green = Good Performance
Amber = Average Performance
Red = Poor Performance

6 Preferred Option Determination – Berkeley Site

6.1 Discussion

6.1.1 Encapsulate immediately prior to storage or disposal (Options 1a & 1c)

The mixed nature of this waste stream would not cause a problem for encapsulation either prior to storage or disposal[14]. In line with the previous baseline strategy, Berkeley has received an iLoC for encapsulation of waste (with an additional shredding step) in stainless steel containers. However, if the encapsulation facility being built at FSC (2070-2079) was going to be utilised for encapsulation, then this would delay the disposal of the waste packages (currently planned between 2046 and 2049).

The current Berkeley baseline uses a resilient, self-shielding container for interim storage and disposal, therefore there is no requirement to encapsulate this container to form a disposable waste package and as such encapsulation is considered to be an unnecessary step.

6.1.2 Unencapsulated disposal (Option 1d)

This option presents the current baseline strategy for the Berkeley graphite waste. It can be achieved within timescale constraints and will meet the scope requirements of LC35 Milestone.

6.2 Decision

6.2.1 Preferred Option

The preferred option for the Berkeley operational graphite is: *to manage all the graphite waste as ILW for interim storage (in resilient, self-shielding containers) and unencapsulated final deposition.*

6.2.2 Risks and Opportunities

Should suitable segregation of the graphite waste be selected as the preferred strategy at a later date at Berkeley then other options for the management of the waste would become available. The implementation of the preferred option specified here would ensure that this opportunity would not be foreclosed.

[14] It is noted that there may be potential for the degradation of the waste during the period of containerised storage associated with adopting a strategy of encapsulation prior to disposal i.e. at FSC. Suitable work (such as LoC and safety case work) to underpin this position would be required before such a strategy could be adopted.

In addition there is a risk that it will not be possible to demonstrate the disposability of the chosen container (DCIC) for the mixed wastes. This risk is in the process of being mitigated through the application of the LoC process to provide confidence that the DCIC waste packages will be disposable.

7 Preferred Option Determination – Hunterston A Site

7.1 Discussion

7.1.1 Encapsulate (on-site) prior to Interim Storage (Option 1a)

The Scottish Government are currently developing an Implementation Strategy for the Scottish HAW Policy. Encapsulating the waste could foreclose some future options for management of this waste in accordance with Scottish Policy. However this option would provide waste in a form that is suitable for compliant disposal to either the GDF or a near-site, near surface facility.

As this option is the current baseline for Hunterston A graphite, it is well developed. Also this option supports the delivery of the ONR Improvement Notice. As an encapsulation facility is being constructed for the encapsulation of FED, along with the resources to operate and maintain it, use of this asset to encapsulate the other solid ILW, including the graphite, during the C&M Preparations Phase is attractive. Further, it provides the early removal of a significant hazard.

Encapsulation of the FED Magnox is preferred and an encapsulation facility will be built for FED Magnox waste. Therefore deferring the encapsulation of the graphite until FSC would not cause any additional costs as both plants would exist. It is therefore considered that the cost of encapsulation of the graphite waste would be the same if implemented during C&M Preps or at FSC.

7.1.2 Encapsulate immediately prior to disposal (Option 1c)

Not encapsulating the waste for interim storage would have additional benefits by not foreclosing options. This would allow review of the options available for this waste prior to encapsulation and enable opportunities for treatment or disposal facilities with different WACs to be considered. Conversely adopting such an approach would lead to the need to manage unencapsulated packages of graphite over the period until FSC. The ability to manage such packages has been considered previously at Hunterston and a case made to support such an approach for up to 10 years (Ref. 24). There is therefore confidence that such a case could be made for the C&M period.

7.1.3 Unencapsulated disposal (Option 1d)

Work investigating the feasibility of on-site disposal at Hunterston indicated that unencapsulated disposal would possibly lead to a reduction in the number of containers required for disposal. It was concluded that greater packaging efficiencies could potentially be achieved.

Not encapsulating the waste for interim storage would also have additional benefits by not foreclosing options, allowing time for the Scottish Government Policy Implementation Strategy to be developed.

7.1.4 Prompt disposal in a near surface facility at site of origin (Option 2a)

For Hunterston A to build an on-site near surface disposal facility would be less expensive (in the near-term) than encapsulating the waste for interim storage (1a), however, still more expensive than encapsulation prior to disposal (1c) or unencapsulated disposal (1d). Note that on a lifecycle cost basis this option is one of the least expensive.

Prompt disposal of the graphite waste in an on-site near surface facility would lead to earlier hazard reduction through earlier disposal of the waste. However, this will reduce the number of waste packages for interim storage in the Site ILW Store. A study is currently on-going to investigate the best use of ILW storage assets within South and Central Scotland and as such this is considered to be outside of the scope of this paper.

Hunterston have previously considered this option as part of their Solid ILW Strategic Review (2011). It was considered that there were considerable uncertainties with the near surface disposal option, particularly around the timescales to allow implementation. Due to these uncertainties, NDA concluded that it was not possible at this stage to change the baseline strategy to become near surface disposal on site.

7.2 Decision

7.2.1 Preferred Option

The preferred option for the Hunterston A operational graphite is*: to manage all the graphite waste as ILW for interim storage (in stainless steel containers) and encapsulation at FSC prior to management in accordance with Scottish Policy.*

The preferred option will not foreclose options. This strategy allows future review of any alternative options (such as unencapsulated disposal or near-surface disposal) prior to encapsulation.

7.2.2 Risks and Opportunities

There is a risk that Hunterston will not be able to demonstrate disposability (LoC process) or an ALARP case for the interim storage of unencapsulated waste in the ILW Store (safety case process).

An alternative option would be to encapsulate the waste onsite prior to interim storage and to manage the waste in accordance with Scottish Policy at FSC. It is recognised that this option meets the requirements of the ONR Improvement Notice which is interpreted as passivation of the Bunker 1 FED. Therefore the Site is constructing an encapsulation facility for the encapsulation of the Bunker 1 FED during the C&M Preparations Phase. A s this facility will be readily available, along with the resources to operate and maintain it, the Site’s current decision and plan is to encapsulate all of the solid ILW, including the graphite, during the C&M Preparations Phase. Any change to this plan would require the approval of the regulators and other stakeholders.

8 Preferred Option Determination – Sellafield Site

8.1 Discussion

8.1.1 Encapsulate (on-site) prior to Interim Storage (Option 1a)

The current stocks of Sellafield graphite are already in interim storage, unencapsulated. Encapsulation of this current waste stock and any future arisings would require the new encapsulation facility to be built earlier or use of an existing facility. It would not be preferable to build a facility earlier and existing facilities are being used for other encapsulation projects.

The packaged waste would then have to return to interim storage as the GDF would not be available to receive it at this time.

8.1.2 Encapsulate immediately prior to disposal (Option 1c)

Encapsulation prior to disposal would optimise the use of the new Site encapsulation plant(s). It is considered likely, that encapsulation (within drum or entombment within other containers) would be required for disposability, especially for the graphite stored in mild steel drums.

8.1.3 Unencapsulated disposal (Option 1d)

It is considered that as some of the waste is stored in mild steel drums, demonstration of disposability in an unencapsulated form may be difficult.

Unencapsulated disposal of graphite would be unlikely to result in a significant cost saving against the Sellafield baseline. As the graphite makes up a small percentage of the Sellafield waste requiring encapsulation, it is assumed that a new encapsulation facility would be built anyway. As such operational costs (and potentially a small capital contribution) would be the principal savings which would be made.

8.1.4 Prompt disposal in a near surface facility at site of origin (Option 2a)

There is a lack of space to build a near-surface facility on the Sellafield Site. There is a large operational and decommissioning programme at Sellafield; diverting funds and resources to construct a new facility might interfere with other high hazard reduction projects. This is not consistent with Sellafield prioritisation of hazard reduction for higher hazard facilities.

8.2 Decision

8.2.1 Preferred Option

The preferred option for the Sellafield graphite is: to manage all the graphite waste as ILW for interim storage (in mild or stainless steel drums) and encapsulation prior to final disposition.

8.2.2 Risks and Opportunities

There is a risk that Sellafield will not be able to demonstrate disposability (LoC process) for encapsulated disposal of the waste in the current storage containers. There is also a risk that the GDF Waste Acceptance Criteria that make the disposability of the waste difficult to achieve following a period of containerisation.

There is an opportunity that Sellafield could treat current waste stocks differently to future arisings i.e. current stocks stay in the containers in which they are currently stored which are not disposable whilst future arisings would go straight into a disposable container or would be encapsulated through an existing plant.

An alternative option would also be unencapsulated disposal. If disposability could only be demonstrated for the waste stored in the stainless steel drums, the waste stored in the mild steel drums could still be encapsulated via the Site encapsulation plant.

9 Summary of Preferred Options

The preferred options for the management of graphite are summarised below:

- **Berkeley Site** – to manage all the graphite waste as ILW for interim storage (in resilient, self-shielding containers) and unencapsulated disposal to GDF;

- **Hunterston A Site** – to manage all the graphite waste as ILW for interim storage (in stainless steel containers) and encapsulation at FSC prior to management in accordance with Scottish Policy; and

- **Sellafield Site** – to manage all the graphite waste as ILW for interim storage (in mild or stainless steel drums) and encapsulation prior to disposal to GDF.

The strategic objective of the paper has been met in the near-term as adoption of the preferred option at all three sites would result in a common baseline up until the point of disposal. The differences in approach at the point of disposal are due to a combination of the different containers which are planned to be used by the sites and also the differing policy positions regarding disposition of Higher Activity Waste between England & Wales and Scotland. It is recognised that further work is necessary to underpin the baselines with respect to disposal however through the non-foreclosure of options afforded by these preferred options the ability to select an appropriate disposal option (particularly within Scotland) is not constrained.

It should be recognised that site based decision making may result in the adoption of a strategy for managing these wastes that differs from the preferred option set out within this paper. As described previously the purpose of this paper is to provide the strategic framework within which sites are then able to make these decisions. As such detailed site-based factors may influence ultimately which option is implemented. The consideration of such factors within a Gate C-type assessment will be undertaken by the sites separately due to the differing timescales over which decisions are required to be taken.

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11 Glossary

AGR	Advanced Gas-cooled Reactor
ALARP	As Low As Reasonably Practicable
BAT	Best Available Technique
C&M	Care and Maintenance
CoRWM	Committee on Radioactive Waste Management
DCIC	Ductile Cast Iron Container
EA	Environment Agency (for England and Wales)
fLoC	Final Letter of Compliance
FSC	Final Site Clearance
GDF	Geological Disposal Facility
IAEA	International Atomic Energy Agency
ILW	Intermediate Level Waste
iLoC	Interim Letter of Compliance
LLW	Low Level Waste
LLWR	Low Level Waste Repository
LoC	Letter of Compliance
Magnox	short for MAGnesium Non-OXidising
NDA	Nuclear Decommissioning Authority
RWMD	Radioactive Waste Management Directorate
SLC	Site Licence Company
SMS	Strategy Management Strategy
SWTC	Shielded Waste Transport Container
UK	United Kingdom
WAGR	Windscale Advanced Gas-cooled Reactor

Appendix A: Graphite Waste Streams Within Scope

Data taken from the 2010 UK Radioactive Waste Inventory. Those waste streams which are within the scope of this study are highlighted below.

All Operational Intermediate Level Waste Streams Containing Graphite

Site	Waste stream identifier	Total Volume packaged (m^3)	Package Type	Graphite Total material mass (t)	% of Graphite in Stream
AWE Aldermaston	7A024	762.3	Half-height ISO	24	12
AWE Aldermaston	7A026	1,437.7	Half-height ISO	4	1
AWE Aldermaston	7A029	86.1	500 litre drum	0	1
Berkeley	9A031	205.6	3m³ box (round corners)	85	99
Berkeley	9A032	307.2	3m³ box (round corners)	127	99
Berkeley	9A033	361.6	3m³ box (round corners)	150	99
Berkeley	9A034	212.8	3m³ box (round corners)	88	99
Berkeley	9A035	88.8	3m³ box (round corners)	37	99
Berkeley Centre	9R002	13.3	3m³ box (round corners)	0	7
Berkeley Centre	9R004	0.7	Half-height ISO	0	1
Berkeley Centre	9R019	0.0	3m³ box (round corners)	0	100
Chapelcross	2C003	17.5	MBGWS box	2	44
Culham	5H008	12.3	Not specified	9	47
Dounreay	5B015	763.9	Half-height ISO	0	0
Dounreay	5B028	202.4	500 litre drum	105	95
Dungeness	9C012	152.3	Half-height ISO	0	1
Dungeness	9C912	1,583.6	Half-height ISO	4	1
Dungeness B	3J021	987.0	4m box (100mm concrete shielding)	263	46
Hartlepool	3K025	336.7	4m box (100mm concrete shielding)	10	10
Harwell	5C030	267.7	500 litre drum (with pre-cast annular)	1	1
Harwell	5C045	24.7	500 litre drum (with pre-cast annular)	0	0
Harwell	5C052	234.1	500 litre drum (with pre-cast annular)	0	0
Harwell	5C054	1.8	500 litre drum (with pre-cast annular)	0	63
Heysham	3L022	319.3	4m box (100mm concrete shielding)	58	60

Site	Waste stream identifier	Total Volume packaged (m^3)	Package Type	Graphite Total material mass (t)	% of Graphite in Stream
Hinkley Point B	3N013	331.2	Half-height ISO	2	1
Hunterston	9J018	4.9	$3m^3$ box (round corners)	5	100
Hunterston	9J019	619.2	$3m^3$ box (round corners)	602	100
Hunterston	9J020	568.5	$3m^3$ box (round corners)	552	100
Hunterston	9J021	552.3	$3m^3$ box (round corners)	537	100
Hunterston	9J022	107.3	$3m^3$ box (round corners)	104	100
Hunterston B	4B011	1,157.4	4m box (100mm concrete shielding)	21	10
Sellafield	2D007	8,164.2	Sellafield enhanced $3m^3$ box	324	20
Sellafield	2D008	12,694.9	Sellafield enhanced $3m^3$ box	70	1
Sellafield	2D009	10,487.1	Sellafield enhanced $3m^3$ box	48	1
Sellafield	2D012	528.7	Sellafield enhanced $3m^3$ box	26	4
Sellafield	2D025	1,453.5	Sellafield enhanced $3m^3$ box	73	10
Sellafield	2D058	63.6	Sellafield enhanced $3m^3$ box	0	0
Sellafield	2F007	13,883.0	500 litre drum	4609	100
Springfields	2E101	1,597.0	Half-height ISO;Not yet determined	12	1
Springfields	2E191	202,838.0	Not specified	1826	1
Torness	4C012	586.0	4m box (100mm concrete shielding)	11	10
Trawsfynydd	9G036/C	52.4	$3m^3$ box (round corners)	8	5
Trawsfynydd	9G037/C	52.4	$3m^3$ box (round corners)	8	5
Various sites (MWP)	2S010/C	59.0	WAGR Box	3	6
Various sites (MWP)	6H002	9,397.6	Third-height ISO;Half-height ISO; 2/3 height ISO	165	2
Wylfa	9H015	27.5	Half-height ISO	0	1
Wylfa	9H016	6.5	Half-height ISO	0	1
Wylfa	9H017	6.5	Half-height ISO	0	1

Summary of Waste Streams in Scope

Waste Stream ID	Storage Site	Waste Stream Description	Mixed/ Segregated Waste Stream
9A031	Berkeley	FED Graphite	Graphite waste is mixed with FED Magnox, activated and contaminated metallic components, ion exchange resin and sludge (both drummed and loose) within the Active Waste Vaults.
9A032	Berkeley	FED Graphite	
9A033	Berkeley	FED Graphite	
9A034	Berkeley	FED Graphite	
9A035	Berkeley	FED Graphite	
9J018	Hunterston A	FED Graphite	Graphite waste is mixed with FED Magnox and activated and contaminated metallic components within the Solid Active Waste Bunkers.
9J019	Hunterston A	FED Graphite	
9J020	Hunterston A	FED Graphite	
9J021	Hunterston A	FED Graphite	
9J022	Hunterston A	FED Graphite	
2F007	Sellafield (THORP)	AGR Graphite Fuel Assembly Components	Segregated waste stream stored in 500 l drums. A combination of current and future arisings.

Appendix B: Screening Assessment of High-level Options

<table>
<tr><th rowspan="2">Option No.</th><th rowspan="2">Option Description</th><th rowspan="2">Site</th><th colspan="3">Screening Criteria</th></tr>
<tr><th>Can the option be delivered in a legally compliant manner and in accordance with relevant policy</th><th>Can the option be delivered within existing decommissioning timescales?</th><th>Is the technology developed to a suitable level to credibly allow implementation?</th></tr>
<tr><td rowspan="3">1</td><td rowspan="3">Manage all graphite waste as ILW and dispose to the GDF (for the purposes of this paper this option is considered to include a disposal step for Hunterston A Site which is accordance with Scottish HAW Policy)</td><td>Berkeley</td><td>✓</td><td>✓</td><td>✓</td></tr>
<tr><td>Hunterston A</td><td>✓</td><td>✓</td><td>✓</td></tr>
<tr><td>Sellafield</td><td>✓</td><td>✓</td><td>✓</td></tr>
<tr><td rowspan="3">2</td><td rowspan="3">Near surface disposal option (possibly including a pre-treatment step).</td><td>Berkeley</td><td rowspan="3">✓
It is assumed that the principal of disposing of graphite waste in the near-surface environment is legally acceptable and in accordance with relevant policy as this has been demonstrated by the Hunterston A Site Graphite Pathfinder Project</td><td colspan="2">×
To enable the disposal of the Berkeley mixed waste in the near-surface environment substantial amounts of technological development would need to be undertaken to develop the existing design and safety case developed for the Graphite Pathfinder Project to make it suitable for Berkeley Site. Issues that would require development include, site location selection, geology/ground water issues and waste segregation/disposability issues based on the unique mixed nature of Berkeley Site's graphite waste. It is therefore considered that this option could not credibly deliver within the existing decommissioning timescales without substantial technological development.</td></tr>
<tr><td>Hunterston A</td><td>✓
The Graphite Pathfinder Project proposed a programme of work for the disposal of all solid ILW waste from the Solid Active Waste Bunkers (including all operational graphite waste) that would meet the existing decommissioning timescales.</td><td>✓
The Graphite Pathfinder Project attempted to demonstrate that it is technically credible to dispose of Hunterston Site's operational graphite waste in the near-surface environment. Some significant further development work would be required to allow implementation.</td></tr>
<tr><td>Sellafield</td><td>✓
The existing baseline date for treatment of this waste is that it will be encapsulated beginning in 2040, in the interim it will be stored unencapsulated. On this basis it is considered that delivery of near-surface disposal could credibly be achieved within the same timescales i.e. by approximately 2040.</td><td>✓
To enable the disposal of the Sellafield waste in the near-surface environment substantial amounts of technological development would need to be undertaken to develop the existing design and safety case developed for the Graphite Pathfinder Project to make it suitable for Sellafield. Issues that would require development include, site location selection, geology/ground water issues and waste segregation/disposability issues based on the different properties of Sellafield's graphite waste. It is considered that this option could be delivered within the existing decommissioning timescales as there is sufficient time available to allow this technological development to occur.</td></tr>
</table>

Option No.	Option Description	Site	Screening Criteria		
			Can the option be delivered in a legally compliant manner and in accordance with relevant policy	Can the option be delivered within existing decommissioning timescales?	Is the technology developed to a suitable level to credibly allow implementation?
3	Condition the graphite waste to enable alternative disposal; as LLW at LLWR, release as 'exempt waste' or reuse where possible.	Berkeley	✓ It is assumed that the principal of conditioning ILW graphite to produce an LLW or exempt waste form is legally acceptable and in accordance with relevant policy.	× Disposal as LLW: One of the most significant radionuclides that would need to be removed from the graphite to allow disposal as LLW is tritium. Removal of the majority of this radionuclide would enable the waste to meet the 12 GBq/t beta/gamma limit at LLWR (based upon 2010 Radioactive Waste Inventory data). A suitable tritium removal technology has been investigated previously with respect to desiccant treatment and found that approximately 100 m^3 of waste would take ca. 2-3 years to process therefore for the much larger volume of waste considered here it is considered that without substantial technological development (or substantial capital investment in multiple processing units) this process could not deliver within the existing decommissioning timescales. Further even if the tritium could be removed from the waste a substantial proportion of the C-14 and Cl-36 would still remain. The amount of C-14 activity associated with these wastes means that there disposal to the LLWR is not consider to be feasible as the specific activity limit specified in the 2008 Condition for Acceptance for C-14 was 0.015 GBq/Te which is approximately two orders of magnitude less than the C-14 specific activity of the lowest activity waste stream considered within this study. Release as exempt or reuse: all of the significant radionuclides would need to be removed from the waste before it could credibly be disposed of as exempt waste including tritium, carbon-14, chlorine-36 and cobalt-60. Utilisation of graphite incineration or pyrolysis could be used to achieve this aim through gasification of the graphite and capture of the resulting (radionuclide rich) gas. This technology has been investigated previously for graphite waste and it has been determined that the technology required to implement the process is not currently close to being implementable on the scale required. It is therefore considered that this option could not deliver within the existing decommissioning timescales without substantial technological development.	
		Hunterston A			
		Sellafield			

Appendix C: Radiological Capacity Considerations for the Disposal of C-14 Bearing Wastes to the LLWR

The annual limit for disposal of C-14 in the LLWR's current EPR Permit is 50 GBq/ year. The LLWR also has upper activity limits based on the classification of the waste as LLW at 4 GBq/ tonne total alpha and 12 GBq/ tonne total beta-gamma activity.

Relevant EPR Permit Limits for disposal of C-14 bearing wastes

Annual limit for disposal of C-14	50 GBq/ year
Total alpha limit for LLW	4 GBq/ tonne
Total beta-gamma (b/g) limit for LLW	12 GBq/ tonne

In addition to the upper activity limits based on the designation of the LLWR as a disposal facility for LLW, the 2011 Environmental Safety Case (ESC) for the LLWR (Ref. 1) which is currently subject to review by the Environment Agency (EA) includes risk based radionuclide specific and group limits for use in sum of fractions calculations to ensure that the radiological capacity of the site can be managed and is not exceeded.

The 2011 ESC includes the following upper limits for the disposal of C-14 for use in sum of fractions calculations:

- a limiting total site radiological capacity of 6 TBq for C-14 for the gaseous release pathway;
- a specific activity limit of 0.012 GBq/ tonne for consignments placed in upper stack positions in the vault at within 5m of the cap surface, for the human intrusion pathway; and
- at greater depths within a vault, the 2011 ESC radiological capacity limits applicable to all consignments are appropriate. C-14 along with other radionuclides, which for example include H-3, Co-60, Sr-90 and Cs-137, falls into the 'others' group that has a 300 GBq/ tonne radiological capacity.

It should be noted that LLWR is working on less cautious assessment models for C-14 bearing wastes that may result in less restrictive limits for use in sum of fractions calculations than those from the 2011 ESC.

Relevant limits for use in sum of fraction calculations from the 2011 ESC for disposal of C-14 bearing wastes

Site radiological capacity for C-14 for gaseous pathway	6 TBq
Specific activity limit for C-14 for consignments in upper stack positions, for the human intrusion pathway	0.012 GBq/ tonne

Specific activity limit for 'other radionuclides' group that includes C-14 and applies to all consignments	300 GBq/ tonne

The total and specific activity of C-14 bearing operational graphite wastes being considered as part of this study as summarised in the next table.

Total and C-14 activity of operational graphite waste streams based on 2010 inventory data

Site	ID	Description	Type	Mass (t)	C-14 (GBq)	C-14 (GBq/t)	Total alpha (GBq)	Total b/g (GBq/t)
Berkeley	9A031	FED Graphite	ILW	85.1	151	1.8	1.4	70.9
Berkeley	9A032	FED Graphite	ILW	127.1	450	3.5	1.4	70.9
Berkeley	9A033	FED Graphite	ILW	149.6	530	3.5	1.4	106.3
Berkeley	9A034	FED Graphite	ILW	88.1	468	5.3	0.2	354.4
Berkeley	9A035	FED Graphite	ILW	36.7	195	5.3	0.2	354.4
Hunterston A	9J018	FED Graphite	ILW	4.8	12	2.5	0.0	58.3
Hunterston A	9J019	FED Graphite	ILW	601.6	1504	2.5	0.0	41.7
Hunterston A	9J020	FED Graphite	ILW	552.4	1381	2.5	0.0	58.3
Hunterston A	9J021	FED Graphite	ILW	536.6	1342	2.5	0.0	166.7
Hunterston A	9J022	FED Graphite	ILW	104.3	261	2.5	0.0	166.7
Sellafield	2F007	AGR Graphite Fuel Assembly Components	ILW	5625.7	56214	10.0	0.0	393.9

All of the waste streams exceed the 12 GBq/ tonne beta-gamma limit for classification as LLW streams, due primarily to their high H-3 content. All of the waste streams except for the 9J018 Hunterston waste stream, which has a very low mass, also exceed the 50 GBq/ year annual limit for C-14 disposals to the LLWR under the current EPR Permit. The operational graphite waste streams could not be consigned to the LLWR under the current EPR Permit.

All of the waste streams also exceed the C-14 activity concentration limit for consignments to upper stack positions from the 2011 ESC. It should also be noted that for the gaseous release pathway, the Berkeley operational waste streams represent circa 30% of the total radiological capacity of the LLWR for C-14, the Hunterston operational waste streams represent 75% of the total site radiological capacity for C-14 and the Sellafield THORP operational graphite waste steam exceeds the total site radiological capacity for C-14. Given the above, it is concluded that it is unlikely that any of these waste streams would be considered to be suitable for consignment to the LLWR based on the performance assessment in the 2011 ESC.

LLWR Ltd. is working on less cautious assessment models for C-14 bearing wastes. This may result in less restrictive limits for use in sum of fractions calculations than those from the 2011 ESC. As a result there is a possibility that future versions of the ESC might indicate that the LLWR has sufficient radiological capacity for the disposal of some or all of the above waste streams. Changes to the overall upper activity levels for disposals to the LLWR might also be necessary, were waste streams to be above the 12 GBq/ tonne beta-gamma upper activity limit for LLW. This is regarded as a longer-term opportunity by LLWR Ltd. and if pursued would be subject to regulator and planning authority acceptance and local community views.

References

1. The 2011 Environmental Safety Case, Waste Acceptance, LLWR/ESC/R(11)10026, May2011

Appendix D: List of Sub-Options

Option No.	Option Description	Sub-Option No.	Sub-Option Description	Site	Screening Criteria		
					Can the option be delivered legally, and in accordance with relevant policy	Can the option be delivered within existing decommissioning timescales?	Is the technology developed to a suitable level to credibly allow implementation?
1	Manage all graphite waste as ILW, interim store and disposal to a future facility.	1a	Encapsulate (on-site) prior to interim storage.	Berkeley	✓	✓	✓
				Hunterston A	✓	✓	✓
				Sellafield	✓	✓	✓
		1b	Encapsulate (centralised facility) prior to interim storage.	Berkeley	✓	× Cannot be delivered prior to the commencement of packaging into resilient, self-shielding containers (retrievals are scheduled to commence in 2014). Therefore window of opportunity would be closed.	✓
				Hunterston A	✓	× Cannot be delivered prior to the commencement of encapsulation activities (construction is scheduled to commence in 2013). Therefore window of opportunity would be closed. Also would not support the delivery of the Improvement Notice.	✓
				Sellafield	× As the other two sites could not contribute to a centralised encapsulation facility and also because Sellafield has the largest volume of waste of all of the sites considered here (ca. 4000 m^3) and hence it is not considered credible to transport this waste to another site for processing.		
		1c	Encapsulated immediately prior to disposal.	Berkeley	✓	✓	✓
				Hunterston A	✓[15]	✓	✓
				Sellafield	✓	✓	✓
		1d	Unencapsulated disposal.	Berkeley	✓	✓	✓
				Hunterston A	✓[15]	✓	✓[16]
				Sellafield	✓	✓	✓

[15] Note that this issue would need further discussion with the Regulators to prior to implementation being allowed to commence.

[16] Note that more development work would be required to ensure that this would be deliverable particularly in the areas of the LoC and safety case.

Option No.	Option Description	Sub-Option No.	Sub-Option Description	Site	Screening Criteria		
					Can the option be delivered legally, and in accordance with relevant policy	Can the option be delivered within existing decommissioning timescales?	Is the technology developed to a suitable level to credibly allow implementation?
2	Prompt Disposal in a Near surface disposal option (possibly including a pre-treatment step).	2a	Near-surface disposal facility at the site of origin.	Hunterston A	✓	✓	✓
				Sellafield	✓	✓	✓
		2b	Centralised near-surface disposal facility.	Hunterston A	× Not in accordance with Scottish Policy. This is based on the assumption that a centralised near-surface disposal facility would be located at Sellafield (due to the significantly higher waste volume).	× To enable a centralised near-surface disposal facility to operate it would require waste from one of the sites to be transported to the other one. The assumption is that the waste would be packaged into an unshielded container and as such an additional transport container (such as an SWTC) would be required. The anticipated timescales associated with development of such a transport container are approximately 5 years which would mean that the programme for implementation of a centralised near-surface disposal option would be too long to avoid a delay to existing decommissioning timescales at Hunterston A Site. Also would not support the delivery of the Improvement Notice.	
				Sellafield	× This option is not credible as there are no other sites remaining that could contribute to a centralised near-surface disposal facility.		

Appendix E: Credible Options Flow Diagrams

Figure E1 – Berkeley Site Credible Options Flow Diagram

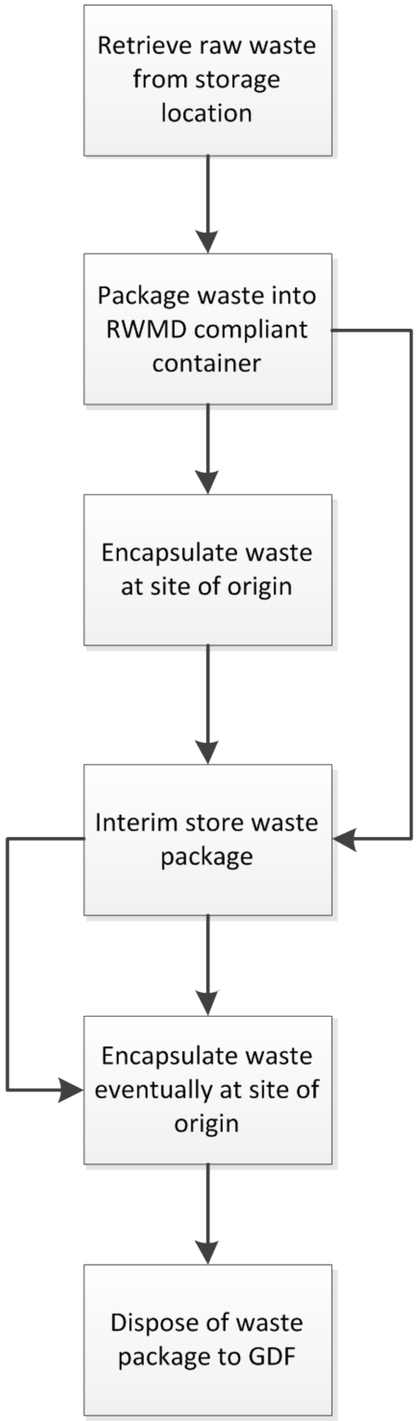


Figure E2 – Hunterston A Site Credible Options Flow Diagram

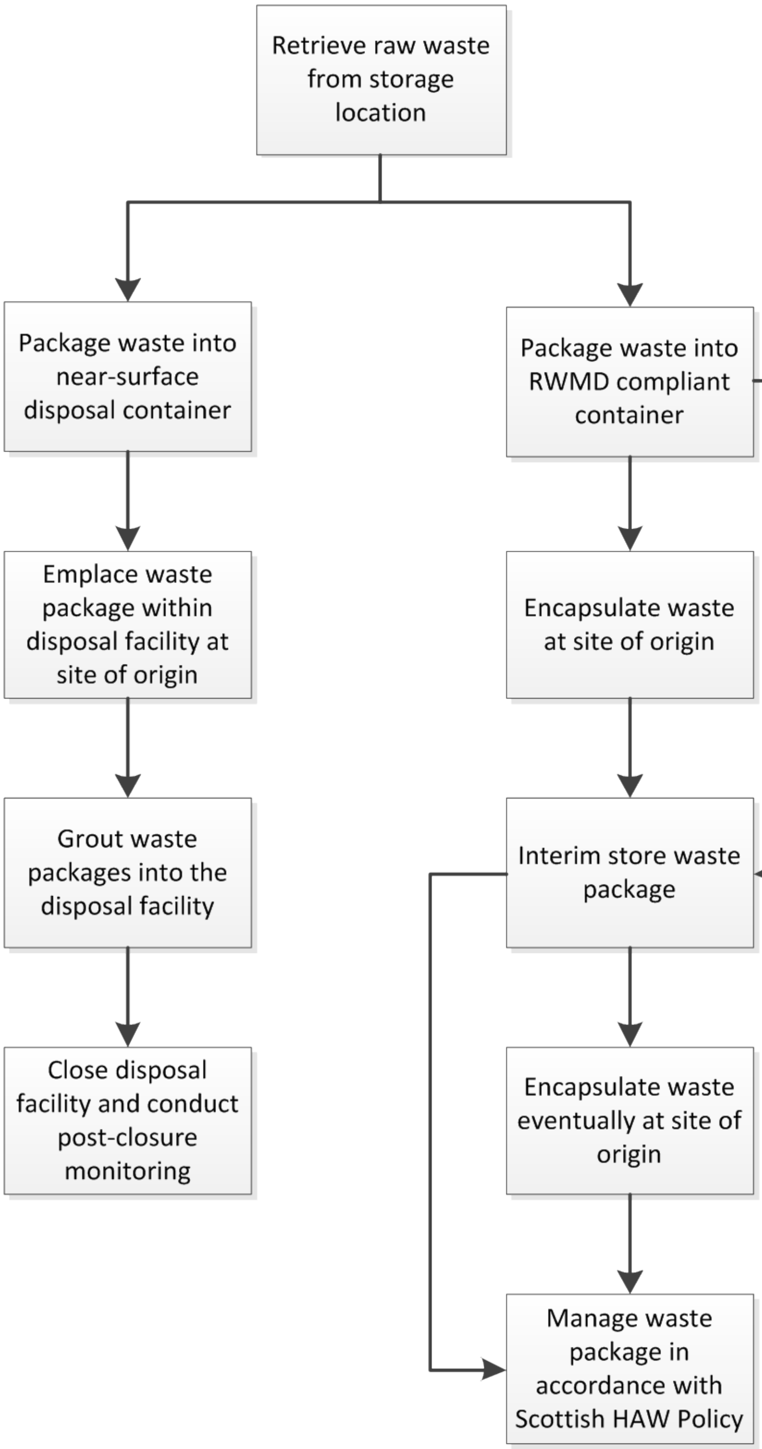
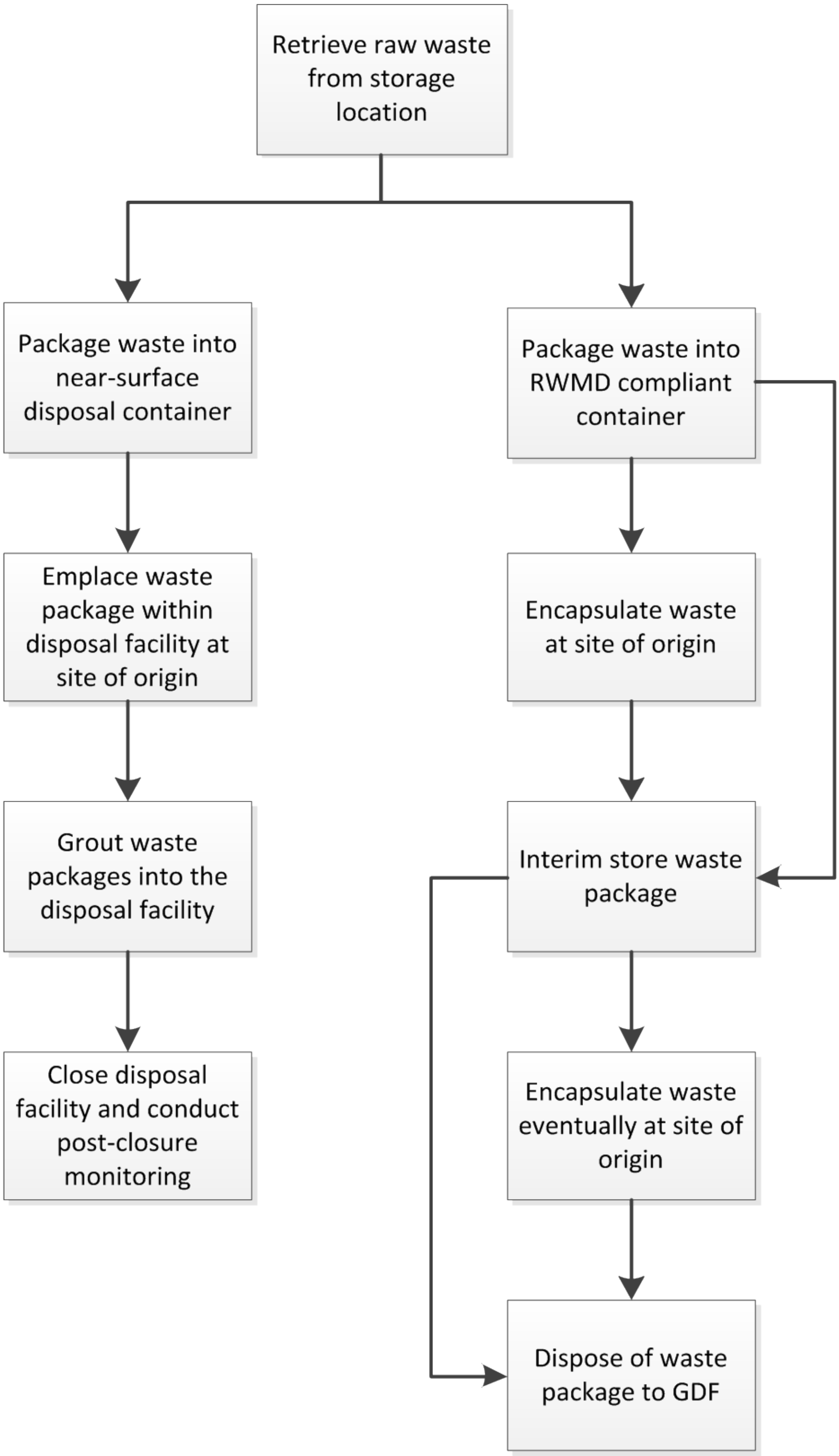


Figure E3 – Sellafield Site Credible Options Flow Diagram



Note that the type of container suitable for near-surface disposal would be determined by the design and safety case of the disposal facility. This may not require the container to be RWMD compliant. For example a suitable disposal container identified by the Graphite Pathfinder Project was a mild steel variant of the RWMD 3 m^3 box.

Appendix F: Assessment of Containerisation Concept in terms of Passive Safety

To help to underpin the statement that containerised operational graphite waste achieves passive safety at the same point as encapsulated operational graphite waste (as stated in Section 5.1.1) an assessment against the principles defined in reference [17] is provided below:

The radioactive material should be immobile

The operational graphite waste at all sites is assumed to be dry and in all cases will be stored in closed steel/ductile cast iron packages. The source of radioactivity within the waste is primarily through activation and the waste form is considered to be chemically and physically stable and as such the potential for release is considered to be minimal. Within the containerised waste it is recognised that there is potential for some radionuclide release (particularly at Hunterston A and Sellafield sites where thin-walled, vented containers are planned to be utilised) due to the migration of species such as C-14 containing CO_2 and also H-3. However the rate of this release is considered to be tolerable and this will be demonstrated through the relevant safety cases.

It is noted that encapsulation achieves a greater degree of immobilisation of the waste within the container however this is considered to be over and above the requirement to achieve passive safety (it does also offer benefit in terms of disposal with respect to voidage issues) and it is noted that encapsulation will foreclose future waste management options.

Further it is noted that in the case of Hunterston A Site operational graphite there is a relatively small amount (ca. 30 m^3) of graphite dust material associated with the waste however it is considered that this does not significantly challenge the immobile nature of the waste form as a whole. During normal storage operations the potential for release of any of this material is considered to be minimal as package will remain un-moved within the store, it is noted that during fault scenarios there is a greater potential for release of dust material if it is unencapsulated however the likelihood of such an event and as such the increase likelihood of release are considered to be tolerable. This issue is currently under assessment at Hunterston A Site and preliminary work has demonstrated that the release of seven containers' worth of unencapsulated graphite dust material is tolerable.

The waste form and its container should be physically and chemically stable

Graphite waste is recognised as being a very physically and chemically stable waste form. It is recognised that there is some potential for galvanic coupling between graphite and the metallic container however this coupling can only take presence in the presence of moisture and therefore the storage conditions required to meet the LoC will exclude moisture and therefore also the possibility of galvanic corrosion.

Potential energy should be removed from the waste form

Wigner energy is the main potential stored energy of concern with respect to operational graphite. All of the graphite under consideration experienced irradiation temperatures typical of commercial power stations (all in excess of 250 °C) and as such there is no concern regarding release of this energy under normal operating conditions. It is recognised that under fault conditions i.e. fire, the graphite may become heated to a temperature at which the stored Wigner energy would be released however the likelihood of fire in any of the sites storage facilities is considered to be low due to passive safety features such as arrangements to limit fire loadings and potential sources of ignition.

A further source of potential energy of concern in relation to the graphite waste is the explosivity of the graphite dust. This issue is currently being assessed by Hunterston A Site with preliminary work having demonstrated that the risk associated with explosion is tolerable.

Containment should be achieved by multiple barriers

The graphite waste containing packages will be stored within the respective sites' ILW stores which provide a second barrier against release to compliment the barrier provided by the containers.

The waste form and the building should be resistant to degradation

There will be minimal corrosion of the containers due to the storage environments in which they will be stored. There will also be minimal corrosion of the graphite waste due to its chemical stability.

The waste package and building should be resistant to foreseeable hazards above the nature of the store is not proposed to be changed by any of the options considered as such it is the nature of the waste package that is the focus here. In terms of resistance to foreseeable hazards it is recognised that containerisation of operational graphite waste does not offer the same level of protection in the event of a fault condition as an encapsulated waste form would, however the risk is still considered to be tolerable. However the nature of the storage conditions means that there is minimal reliance placed upon the waste package itself in terms of protection against hazards such as fire or dropped load. There is significant mitigation built in to the storage design and processes to limit the likelihood of realisation of such hazards and as such it is considered that containerisation of graphite waste does not significantly reduce resistance to foreseeable hazards and there would still be an adequate level of protection.

Access should be provided for response to incidents but the need for prompt remedial action should be minimised

The ability to retrieve containers in the event of an incident will not be affected by the decision to encapsulate or containerise operational graphite waste. As discussed above because of the low corrosion rates of both the waste and the containers there will be no need for prompt remedial action in the event that the onset of corrosion is detected.

The waste package and storage system should facilitate final disposal

The nature of the sites' storage systems is not proposed to be changed by any of the options and as such their ability to facilitate disposal is not affected. In terms of the waste package, by containerising the waste this prevents the foreclosure of alternative options that could be implemented in the future, this might include the ability to dispose of this waste to the GDF/in accordance with Scottish Policy in an unencapsulated form or could mean the implementation of a more treatment technique dismissed as being credible at the current time but which could be developed during the interim storage period.

The lifetime of the storage arrangements should be appropriate for the storage period

The building environment should optimise the life of the waste package

The need for active safety systems, monitoring, maintenance and human intervention to ensure safety should be minimised

Provision should be made for the inspection, retrieval and remediation of waste packages

These four principles are addressed together as they both relate to the nature of the store itself. There is no differentiation between containerised or encapsulated waste packages in terms of these four principles as there is no proposed change to any of their interim storage location or conditions.