REVIEW OF OPTIONS FOR MANAGING WASTE FROM THE HUNTERSTON A SOLID ACTIVE WASTE BUNKERS GIVEN ITS STATUS AT MAY 2021

WD/REP/0032/21 Issue 2

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Revision History	
Issue	Description of change(s)
1	First issue
2	Updated discharge assessments for options involving encapsulation following revision to the underpinning release fractions (see Appendix H). The statements made in Issue 1 of this report remain valid for the updated discharge figures. Other changes: Footnote added to page 33 to reflect on revised forecast for completion of physical works at Hunterston A. Terminology updated: NWS replacing RWM.

EXECUTIVE SUMMARY

Scope of Assessment

This assessment determines the management strategy for waste arising from the solid active waste bunkers ('the bunkers') at Hunterston A site. It is a strategic options assessment which forms part of the demonstration that Best Practicable Means (BPM) have been applied to manage the waste in scope.

The waste in scope is that identified in the radioactive waste inventory under waste streams 9J19 to 9J23 inclusive, arising from all five bunkers. Waste from Bunker 1 consists primarily of magnox fuel element debris (FED) and waste from Bunkers 2-5 consists primarily of graphite FED, though there are smaller quantities of miscellaneous activated components and contaminated items intimately mixed with these wastes along with sludge and graphite particulate contamination. Segregable fuel fragments were excluded from assessment as these are being considered by a separate study.

The starting point of this assessment takes account of the status of the waste as at May 2021, the majority of which had been retrieved and containerised into 3m^3 boxes (1,000 of ca. 1,100 boxes filled with only waste from Bunker 1 remaining to be retrieved).

The extant (baseline) strategy, supported by a 2012 strategic options assessment [1], is to encapsulate all waste for subsequent storage on-site until a final management route exists, with disposal in a future near-surface facility being the envisaged end point.

This new assessment was initiated in response to the Scottish Environment Protection Agency's (SEPA) challenges to the extant strategy. In November 2020 Magnox Ltd committed to review the BPM case and its supporting characterisation.

Method of Assessment

Existing characterisation data were reviewed prior to conducting the strategic options assessment to ensure that the data quality was appropriate for this exercise. This review concluded that the existing waste inventories had been developed to support the Letter of Compliance (LoC) and were appropriate for this purpose but included conservatisms. It was decided to produce new inventories to support the strategic options assessment so that potential management options were not obscured by the conservatisms of the existing inventories.

Credible options were then defined based on analyses of these revised inventories. This was achieved by considering the feasibility of treatment and disposal options for materials present within the waste. These analyses used existing waste acceptance criteria (WAC) where available, for example that of the Low Level Waste (LLW) Repository, else relied on best available information, for example the joint environment agencies' Guidance on the Requirements for Authorisation (GRA) of near-surface disposal facilities. These analyses concluded that the following credible options should be assessed:

Material	At-Depth Disposal		At-Surface Disposal		Treatment	
Graphite	Y	Disposal following storage	N	*Disposal criteria not met within 300 years*	Y	Gasification following storage
Magnox	Y		Y	LLWR disposal following decay storage	Y	Dissolution or vitrification following storage
Mild Steel	Y	Disposal following storage, only if packaged with the above.	N	*Disposal criteria not met within 300 years*	N	*No viable options identified*
MCI	Y		N		N	
S/Steel	Y		N		N	
Aluminium chromium	Y		N		N	

The treatment options shown above seek to reduce the volume of higher activity waste (HAW) requiring long-term management, of which only dissolution is commercially available today. No material recovery options were identified. Two forms of near-surface disposal were considered:

- At-depth disposal – where waste packages are disposed of in vaults or caverns which are constructed several tens of metres below the surface and accessed through a drift. No such facility exists currently, though it is planned to be implemented under Scotland's HAW Policy Implementation Strategy [2].
- At surface disposal – where waste packages are disposed of in vaults which are constructed at or close to the surface and backfilled when full (the protective covering is of the order of a few metres thick); this type of facility is typically for waste categorised as LLW. The LLW Repository is such a facility.

All alternative options to at-depth disposal require the waste to undergo further processing, e.g. sorting and segregation. A short-list of options was developed according to whether this processing takes place promptly or is deferred until the reactor decommissioning phase:

Option Group	Bunkers 2-5 (Graphite)	Bunker 1 (Magnox)	Waste remaining after processing or treatment
Baseline – no further processing	G1. Encapsulate then store for at-depth disposal	M1. Encapsulate then store for at-depth disposal	n/a
Prompt Processing	n/a	M2. Sort and decay store then encapsulate for at surface disposal M3. Sort and treat by dissolution M4. Re-package and store then treat by vitrification	Encapsulate, if necessary, then place into long-term storage[1]
Deferred Processing	G2. Store then sort and treat by gasification	M5. Store then sort and encapsulate for at surface disposal M6. Store then re-package and treat by vitrification	Encapsulate, if necessary, then place into long-term storage

In accordance with Company Standard S-391 [3], these options were assessed using an attribute comparison method to determine a 'lead option', by considering the relative strengths and weaknesses of each option within each attribute, then risks were considered in a 'management analysis' to identify a 'proposed option'.

This assessment separately considered options for managing waste from Bunkers 2-5 and Bunker 1. For waste from Bunker 1 this assessment also separately considered the waste remaining in bunker and that which had already been retrieved and containerised; this is because the waste remaining in bunker has a greater potential to be alternatively managed. For waste that has already been retrieved and containerised into $3m^3$ boxes (this applies to all waste from Bunkers 2-5 and roughly half of the waste from Bunker 1), all alternative options to at-depth disposal require the waste to be retrieved from these boxes for processing.

[1] Wherever possible this assessment has considered definite end points, however 'long-term storage' has been applied where no credible end points could be determined. This envisages up to 300 years of storage whilst final management solutions are developed. This assessment has assumed that wastes remaining after processing or treatment are unsuitable for at-depth disposal or any other end point that can be defined at present within the constraints of Scotland's HAW Policy [6].

Outcome of Assessment

The proposed option is to manage all waste within the scope of this review by encapsulation for interim storage then at-depth disposal (Options G1 and M1). This aligns with the baseline strategy[2].

Treatment options were judged to perform less well than disposal options because:

- All treatment options require new facilities to process the waste, requiring additional waste handling and resulting in increases to worker dose. There would also be conventional safety risks from the construction, operation and decommissioning of these facilities, and particularly for the scenarios where waste must first be retrieved from 3m^3 boxes.
- Most treatment options apply inherently high hazard processes and, aside from dissolution, all technologies have low technology readiness levels and credible development risks.
- All treatment options would result in gaseous and/or liquid wastes to manage. Even following abatement it was estimated that doses due to radioactive discharges would be two or more orders of magnitude greater than those with the disposal (encapsulation) options. The estimated total doses (following abatement) due to discharges for each option[3] are shown below in µSv/y:

G1	G2	M1	M2	M3	M4	M5	M6
2.8E-01	1.3E+01	2.6E-03	2.6E-03	2.3E+00	8.5E-01	2.4E-03	4.7E-01

  Applying BPM, as set out in SEPA guidance [4], presents an imperative to minimise radioactive waste discharged to the environment, a necessary consequence of which is that the amount sent to solid disposal facilities is maximised.

- All treatment options introduce technical challenges to adequately sort and segregate the waste to the requirements of the relevant process.
- All treatment options result in HAW which is unlikely to be suitable for at-depth disposal.
- Some treatment options would incur significantly greater cost. The estimated total cost of each option[3] is shown below:

G1	G2	M1	M2	M3	M4	M5	M6
£32.5M	£65.0M	£5.0M	£8.8M	£105.0M	£8.0M	£55.0M	£55.0M

Alternative disposal options were only identified for magnox from Bunker 1, however at-surface disposal performed less well than at-depth disposal because:

- The magnox would need to be segregated from the other waste from Bunker 1 and there are risks that a portion of the magnox cannot be adequately sorted to meet at-surface disposal WAC. Challenges are presented by the heterogeneity of the waste and presence of small, high activity items, as well as particulate contamination.
- Sorting the magnox and exporting it requires additional waste handling and results in increased worker dose due to this.
- For the waste remaining in bunker the requirement for a new sorting facility would present competition for resources at site and would impact the site schedule. This issue is significantly exacerbated for the waste that has already been retrieved and containerised.
- There is greater uncertainty with management of the segregated, non-magnox waste as this is unlikely to be suitable for at-depth disposal if packaged on its own.
- At-surface disposal would also incur additional waste-miles and cost.

[2] The baseline strategy is encapsulation for long-term storage until a final management solution exists, with disposal envisaged as the end point. The proposed option aligns with this though is clearer about the envisaged end point.

[3] Figures presented for Bunker 1 options (M1-6) are for the 'in bunker' portion of the waste only.

The proposed option, to manage all waste by encapsulation for storage then at-depth disposal, follows an underpinned waste management approach and is assured via the LoC process. The key risks with this approach relate to disposability and foreclosure of options. The possibility to defer encapsulation has been considered as one tactic to mitigate these risks, however this review has identified no grounds for pursuing such an approach. Prompt encapsulation is proposed to ensure that the waste packages are manufactured in accordance with the design intent of the 3m^3 box, to provide better long-term performance during storage and during the disposal facility's operational and post closure phases. During storage the grout limits waste and container degradation, assuring their ongoing performance; following disposal the grout provides retardation of release of radionuclides into the biosphere and stabilises chemically reactive or mobile materials, as well as providing a structural function.

Implementation of this strategy will continue to be managed using the Hunterston A site Radioactive Waste Management Case, which will be updated to reflect the findings of this review.

BPM Summary Statement

This document presents a strategic options assessment. The proposed option is considered to represent BPM and supports the requirement to optimise public exposures as:

- it results in minimal generation of further radioactive wastes (secondary wastes are limited to operational and decommissioning wastes associated with existing retrieval and encapsulation processes/equipment, which has arisen/will arise in any case); and
- it minimises the potential for radioactivity to be discharged to the environment (discharges would arise primarily from encapsulation off-gassing, which would be similar in all disposal options assessed; treatment options would result in comparatively significant discharges).

The strategic assessment presented in this document has not addressed how the implementation of the proposed option will be optimised. To clarify how this is being achieved an optimisation summary report will be produced. This will set out how the radiological effects of radiological discharges on the environment and people have been or will be minimised.

ALARP Summary Statement

The proposed option is considered to represent ALARP. No additional handling of the waste is proposed (whereas all other options would involve this) and it makes use of the site's established HAW management route which is remotely operated by and large. There would be minimal off-site doses due to discharges compared with treatment options. There are other options which would result in fewer radwaste consignments, and potentially lower public doses due to transports, though these are overall less preferable due to other factors. Long-term risks are managed through prompt waste passivation and applying an underpinned waste management approach.

Forward Actions

No further work is proposed to support the outcome of this strategic options assessment. Forward actions may be needed to optimise its implementation, these will be identified upon completion of an optimisation summary report.

Whilst not forming a forward action from this review, it is noted that work is ongoing to support the NDA in developing a NSD capability and that this work, along with collaborations with other Scottish waste producers, will hopefully improve how disposal uncertainties are factored into near-term decisions.

Review Date

This is to be periodically reviewed every five years in accordance with company standard S-391, or sooner if prompted by a trigger (see below), until the waste is encapsulated. Following encapsulation this should only be reviewed if prompted by one of the triggers.

Review Triggers

This should be reviewed if:

- LLWR WAC change to enable disposal of the waste as packaged.
- Other alternative management routes become available and which challenge the assumptions used in this review.

SIGNATURES			
Prepared by:			
Signed: [redacted]		Date:	15/05/2023
Name: [redacted]		Role:	Senior Waste Consultant
Confirmation that adequate review and verification has been undertaken and that the assessment is fit-for-purpose:			
Signed: [redacted]		Date:	15/05/2023
Name: [redacted]		Role:	Baseline Strategy & Integration Manager
Confirmation that environmental aspects have been properly considered.			
Proposed option agreed as BPM by:			
Signed: [redacted]		Date:	15/05/2023
Name: [redacted]		Role:	Site Provider of RSL Advice (BPM)
Confirmation that radiological aspects have been properly considered.			
Proposed option agreed as ALARP by:			
Signed: [redacted]		Date:	15/05/2023
Name: [redacted]		Role:	Site Accredited Health Physicist
If Management Analysis undertaken:			
Confirmation that wider implications have been taken into account[4] and approval of proposed option:			
Signed: [redacted]		Date:	15/05/2023
Name: [redacted]		Role:	Waste Strategy & Permissioning Manager
Proposed option and implementation requirements accepted by:			
Signed: [redacted]		Date:	15/05/2023
Name: [redacted]		Role:	Hunterston A Site Director

* Verification completed by Michelle Grist prior to leaving the company. Evidence of this verification has been confirmed by Elena Alcantara and minor amendments made since verification have been confirmed as appropriate.

SEND A COPY OF THE FULLY SIGNED REPORT TO ANY OPTIONS ASSESSMENT OVERSIGHT MANAGER.

4 After consulting all functions as appropriate (Asset Management Programme Manager; Decommissioning Director; EHSS&Q Director; Waste Strategy & Permissioning Manager) and affected sites as necessary.

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1 INTRODUCTION

1.1 Background

The Hunterston A Solid Active Waste Building (SAWB) is a large, two storey reinforced concrete building adjoining the south west corner of the Cartridge Cooling Pond facility. The SAWB was designed principally for the storage of solid intermediate level waste (ILW), comprising five large contiguous reinforced ‘bunkers’ for this purpose. Bunkers 1-3 were constructed in 1964 with Bunkers 4-5 having been added in the 1980s.

The waste stored in the SAWB arose from the removal of fuel furniture and associated fuel channel components, comprising both the primary materials and operational waste arising from these activities. Upon discharge from the reactors, the irradiated fuel assemblies were processed to separate the graphite sleeve from the fuel element; the graphite was primarily discharged to Bunkers 2 to 5. The element was then desplittered to separate the magnox splitters and fuel cans, and the waste magnox splitters were primarily sent to Bunker 1. A number of other waste items were also discharged to the bunkers and these became intimately mixed with the graphite and magnox fuel element debris (FED) (see Section 1.3 and 2.1.2).

The baseline strategy is to retrieve and place these mixed wastes into thin-walled, stainless steel containers (‘3m^3 boxes’) for encapsulation then storage on-site until a final management route becomes available. The basis for this strategy is set out in Reference [1], as amended by Reference [5].

Retrievals commenced in 2014 with the bunkers being accessed sequentially from Bunker 5 to Bunker 1. All the waste from Bunkers 2 – 5 has been retrieved and Bunker 1 retrievals are in progress. All waste retrieved has been ‘containerised’ and is planned to be encapsulated in the near-term.

The site Lifetime Plan (LTP) allows these encapsulated waste packages to be stored for up to 300 years whilst management options are developed in accordance with Scotland’s Higher Activity Waste (HAW) Policy – facilities for the storage, treatment and/or disposal of HAW will be developed as part of the Policy’s implementation. The Policy is that such facilities will be as near to the site where the waste is produced as practicable, and that the facilities will be in the near-surface environment [6]. In contrast to policy in England and Wales, Scotland’s HAW Policy prevents direct disposal to the Geological Disposal Facility (GDF).

1.1.1 Requirement for Review

In late 2019 an application was made to vary the site’s environmental permit to include a new authorised gaseous outlet for SILWE. As part of their assessment, the Scottish Environment Protection Agency (SEPA) presented Magnox with challenges to the SAWB waste strategy and Magnox committed to reviewing the BPM case and its supporting characterisation.

The history and basis for the extant strategy have been explored in previous engagements between Magnox and SEPA. This review is not required to address such history, only to consider the correct course of action given the current situation.

1.2 What is the Decision to Be Made?

What is the management strategy for the bunkers waste?

This review should identify the optimal management strategy and determine the near-term actions, such as whether to segregate the wastes or not, or whether to encapsulate the waste or not.

The conclusions may be specific to waste originating from Bunker 1 and waste originating from Bunkers 2 – 5, as the waste compositions differ between these subsets. The conclusions may also be specific to waste that is already retrieved and that which is yet to be retrieved.

1.3 Scope

The scope of this review is to identify the preferred strategy for managing waste from the SAWB bunkers ('the bunkers').

The scope of this review applies to waste defined within the radioactive waste inventory (RWI) waste streams 9J19–9J23. The waste types/materials present within these streams can be grouped as follows[5] [7], arranged by their percentage of total inventory (by volume):

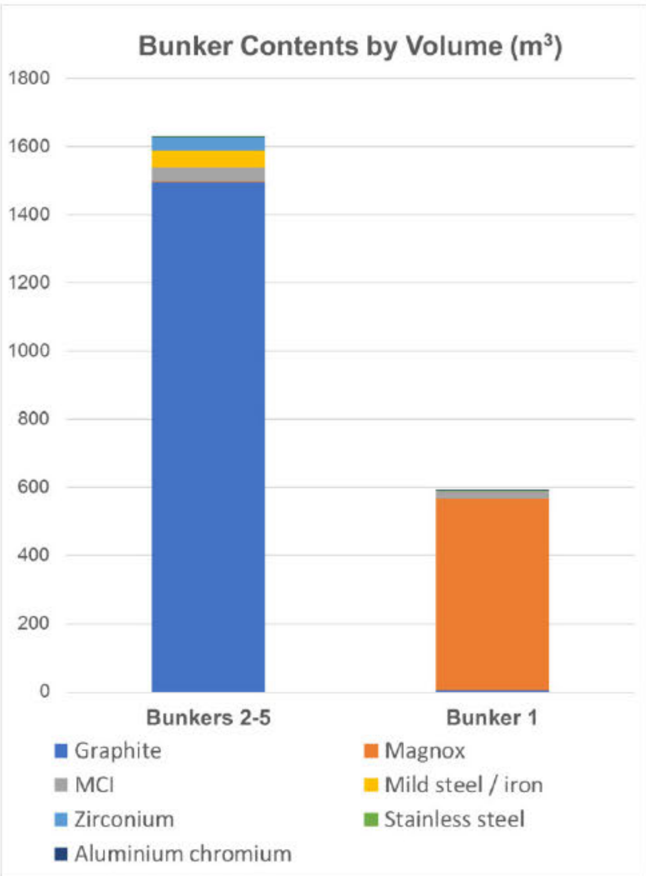
- Graphite (fuel element sleeves) (67.6%) (mainly present in Bunkers 2-5)
- Magnox (fuel element splitters) (25.5%) (mainly present in Bunker 1)
- Miscellaneous Contaminated Items (MCI) (filter dust bags, filters, incinerator waste, general waste, pond sludge, pond skips) (2.9%)
- Mild steel / iron (fuel support members (FSMs) and thermocouple reeling drums) (2.3%)
- Zirconium (D-bars) (1.7%)
- Stainless steel (thermocouples, burst cartridge detector (BCD) clips, contact assemblies, control rod wires, F.P. wires and bobs) (0.07%)
- Aluminium Chromium (thermocouple cables) (0.004%)

These waste items were stored together in the bunkers and became intimately mixed. In addition to the pond sludge there is particulate waste in the form of graphite dust.

The waste can broadly be described within two subsets: waste from Bunkers 2 – 5 and waste from Bunker 1:

Table 1: Summary of waste inventory

Summary of Bunkers 2-5 inventory (9J19-22)	
Total raw volume	1660 m³ (approx. 2,180 tonnes of raw waste)
Waste type	Mainly graphite and metallic debris, with only small quantities of misc ILW; there are also small amounts of magnox in Bunkers 2-3.
Dominant radionuclides	Ni-63, H-3, Co-60, C-14
Summary of Bunker 1 inventory (9J23)	
Total raw volume	595 m³ (approx. 160 tonnes of raw waste)
Waste type	Almost all of the magnox produced during the station's operation, together with small quantities of miscellaneous ILW
Dominant radionuclides	Ni-63, Cs-137, Sr-90, Pu-241



[5] N.B. Uranium is omitted from this breakdown (segregable uranium is excluded from the scope of this review) though, for information, it comprises <0.01% of the total inventory.

The starting point of this review takes account of the status of the waste at May 2021, where 890 boxes had been filled with waste from Bunkers 2 – 5 (these bunkers are now empty) and 110 boxes had been filled with waste from Bunker 1 (with an expected 100 boxes remaining to fill). All waste retrieved has been containerised into $3m^3$ boxes in accordance with existing Letter of Compliance (LoC) endorsements[6]. Figure 1 illustrates the bunkers and how waste has been / is being retrieved from them: a pile of mixed waste is shown on the floor of an emptied bunker, having been pulled through from the adjacent bunker, where it is sorted and loaded into metallic buckets for extraction to a separate location for packaging. The extent of graphite dust present in the waste is illustrated by the floor where the remotely operated vehicle has traversed.

Figure 1: Retrieval of waste from the bunkers

This review considers all options for managing these wastes throughout the remaining lifecycle such that any (residual) HAW could be safely stored for up to 300 years. This includes options which would reduce the amount of HAW requiring storage throughout this period (or a portion of it). Consideration is also given to the risk of foreclosing options and, more broadly, alignment with Scotland's HAW Policy.

This review considers which management options are available from this point forwards and what would be required to enable them. This review does not account for historical actions. As the site is set up to deliver the baseline option this therefore presents an inherent advantage for it and, whilst all options are assessed fairly given their respective statuses, this is acknowledged.

An encapsulation plant (the Solid ILW Encapsulation plant, SILWE) already exists on-site and is entering its commissioning phase, with active commissioning due to commence in mid-2023. A waste package storage facility (the ILW Store) already exists on-site and is operational.

[6] To provide assurance that *the future management of waste packages has been taken into account as an integral part of their development and manufacture* [2], and in accordance with regulator expectations, the LoC process has been followed during implementation of the project. Nuclear Waste Services (NWS) has issued Magnox with final stage LoCs (fLoCs) for the containerisation and encapsulation of waste from all bunkers.

1.3.1 Exclusions

A small volume, particulate waste stream (9J63), arising from processing the bunkers waste, is excluded from this review. No alternative management options have been identified for this waste.

Segregable[7] fuel debris is excluded from assessment. A separate study has been commissioned to determine how these should be managed.

1.4 Previous or Related Studies

Two previous related studies are noted that support the case to retrieve, package and encapsulate the waste, followed by long-term storage in accordance with Scotland's HAW Policy.

- Hunterston A Solid Active Waste Buildings Bunkers Waste (9J18–9J30 / 9J35–9J42 / 9J44) Best Practicable Environmental Option (BPEO) / Strategic Options Assessment, HNA/2981/PJ/SR/1131 Issue 1, November 2012 [1].
- LC35 Change Justification, Scottish Sites Long-Term Storage Strategy, M/WF/GEN/REP/0003/15, Issue 1, September 2015 [5].

1.5 Engagement

An options assessment panel has been used for this study, the details of which, along with other engagements, are included in Appendix A.

1.6 Characterisation Data Quality

A characterisation study [8] has been conducted to determine whether the existing data are suitable for this review.

This study determined the basis of the current inventories, which had been developed in support of LoC submissions and were principally based on neutron activation modelling, supplemented by measurement of magnox and pond sludge samples. This approach was deemed to be fit-for-purpose in respect of the LoC but based on conservative assumptions, principally the use of upper bound element precursor concentrations.

To ensure that the data did not obscure any waste management options for consideration it was recommended that the activation modelling be re-performed using best estimate element precursors and utilising modern modelling tools. Additionally, it was proposed that the data be further improved by using bunker filling histories to refine the decay times and irradiations experienced by the different waste materials deposited at different times in the bunkers. Of note, existing in-depth reviews of high dose rate items (activated components including thermocouples, FSMs, and D-Bars) could be consulted to provide accurate information on material compositions and deposition histories. The recommendations from this study have since been enacted. This has involved further characterisation through scrutiny of existing information and neutron activation modelling. The revised inventories, documented in Reference [9], have been used as the basis for this review.

As part of this review the option to take further sample measurements to support this re-modelling was evaluated but decided against. This was because the remaining waste being retrieved is principally magnox, which has already been sampled, and taking samples from containerised waste was viewed to be grossly disproportionate to the benefit gained for this review. Aside from ALARP and cost considerations, amongst others, retrieving samples from containerised waste is problematic from a statistical perspective; any data obtained are unlikely to be representative of equivalent components within the population as a whole, as these have experienced difference irradiation and decay histories. Neutron activation modelling, however, was viewed to provide data of sufficient quality to support this review.

[7] This review assumes the definition of segregable aligns with the installed fuel detection system which is configured to identify items of fuel debris greater than 380g during retrieval of waste from Bunker 1.

2 OPTIONS

2.1 Derivation of the Options for Assessment

2.1.1 Long-list of Options

The management options for the waste can be classified into three groups and summarised as shown below, where the waste is either managed in $3m^3$ containers per the current strategy or undergoes further processing, either now or in the future, to enable alternative management. The options for alternative management seek greater application of the waste hierarchy and include variations of treatment[8] and disposal.

Alternative management options can be grouped into two categories, prompt processing and deferred processing, where 'processing' refers to additional work performed on-site to enable alternative management, such as further waste sorting and/or packaging. The benefit of prompt processing is that the site is currently mobilised and could perform such work. The benefit of deferred processing is that it allows time for treatment or disposal routes to become available before processing is undertaken.

Table 2: Grouping of options within the long list

Option Group	*Description*
Baseline option	Prompt encapsulation in $3m^3$ containers (baseline option) and interim storage followed by at-depth disposal.
Prompt Processing options	Prompt processing of the waste for one (or more) of the following routes: a) Treatment (and management of by-products) b) Storage followed by treatment (and management of by-products) c) Encapsulation and at-surface disposal d) Decay storage followed by encapsulation and at-surface disposal Any waste that cannot be managed by one of the above routes will be managed by encapsulation and interim storage for at-depth disposal, if feasible, else managed by long-term storage. This also applies to any waste remaining following treatment.
Deferred processing options	Deferred processing of the waste for one (or more) of the following routes: a) Treatment (and management of by-products) b) Encapsulation and at-surface disposal Any waste that cannot be managed by one of the above routes will be managed by encapsulation and interim storage for at-depth disposal, if feasible, else managed by long-term storage. This also applies to any waste remaining following treatment.

Notes:

Scotland's HAW Policy requires facilities for the management of HAW to be in the near-surface environment; for disposal facilities this is referred to as near surface disposal (NSD). Two variations of NSD have been considered when generating the long list of options (see Appendix B for more information):

- At-depth disposal – where waste packages are disposed of in vaults or caverns which are constructed several tens of metres below the surface and accessed through a drift.
- At surface disposal – where waste packages are disposed of in vaults which are constructed at or close to the surface and backfilled when full (the protective covering is of

[8] For example, treatment to enable reuse or recycling of materials, or to achieve volume reductions to minimise subsequent demands on storage capacity etc.

the order of a few metres thick); this type of facility is typically for waste categorised as Low Level Waste (LLW).

For wastes that cannot be disposed of in the near-surface environment, and which cannot be otherwise managed by treatment, long-term storage is the only currently available management option[9]. The Magnox LTP allows for packaged HAW to be stored long-term, for up to 300 years, whilst final management solutions are developed.

2.1.2 Option Screening

The principal screening criterion is that deferred processing is sub-optimal for options that are currently feasible.

To further screen these options the following constraints have been identified:

- All waste that has been retrieved already is containerised within $3m^3$ boxes and stored within the ILW Store. Alternative management options which require the waste to undergo further processing will therefore require these containers to first be emptied.
- A deep geological disposal option, such as the GDF adopted in England and Wales, is not available within Scotland's HAW Policy. It will be considered in the management analysis as an opportunity, should Policy change to permit it. This is explored in Section 6.
- Encapsulation is required for all disposal options, and deferral of encapsulation is not considered as a distinct option. This is explored in Section 6.
- At-surface disposal is not credible for unsorted waste based on current criteria (see Appendix F).

The following key assumptions are also made:

- It is feasible to sort and segregate the waste into its constituent materials, to enable their separate management.
- It is feasible to dispose (NSD) of the waste as currently packaged.
- It is not feasible to dispose (NSD) of waste remaining following processing or treatment.

A full list of constraints and assumptions is included in Appendix B including a reasoning for each assumption.

2.1.2.1 Applicability of options to certain materials

The management options potentially applicable to each of the main materials present in the bunkers waste are shown in the following table. This is supported by:

- Reference [10], which reviews the feasibility of at-depth disposal using the Guidance on Requirements for Authorisation (GRA) [11] as its basis. See Appendix G.
- Reference [12] which reviews the feasibility of at-surface disposal using the current Low Level Waste Repository (LLWR) Waste Acceptance Criteria (WAC) as its basis. See Appendix F.
- Appendix B which reviews the feasibility of treatment options.
- Assumptions in Appendix B.

[9] Wherever possible this assessment has considered definite end points, however 'long-term storage' has been applied where no credible end points could be determined. Indefinite storage is not viewed as a strategy in its own right.

Table 3: Option Applicability by Material Type

Material	At-Depth Disposal		At-Surface Disposal		Treatment (see Appendix B)	
Graphite	Y	Disposal following storage	N	*Disposal criteria not met within 300 years*	Y	Gasification following storage
Magnox	Y		Y	LLWR disposal following decay storage	Y	Dissolution or vitrification following storage
Mild Steel	Y	Disposal following storage, only if packaged with the above.	N	*Disposal criteria not met within 300 years*	N	*No viable options identified*
MCI	Y		N		N	
Stainless steel	Y		N		N	
Aluminium chromium	Y		N		N	

As shown in Table 3, no viable alternative options were identified for managing mild steel, MCI, stainless steel, aluminium, and chromium. The remainder of this assessment therefore focusses on options for managing magnox and graphite, for which there are alternatives.

2.1.3 Short-list of Options

Based on the split of waste materials between the two bunker subsets, Bunkers 2-5 and Bunker 1, the following can be asserted:

- alternative management options for graphite only apply to waste from Bunkers 2-5, and
- alternative management options for magnox only apply to waste from Bunker 1.

This is because less than 1% of graphite is/was stored in Bunker 1, and less than 1% of magnox was stored in Bunkers 2-5. The detriment of retrieving these small quantities from either subset is viewed as grossly disproportionate to any benefit (additionally, it is not recorded whether any single package contains either of these materials, therefore targeted retrievals would not be possible for any waste already containerised). Accordingly, management of the other waste materials (mild steel, zirconium, MCI, stainless steel, aluminium chromium) will also be considered within these subsets.

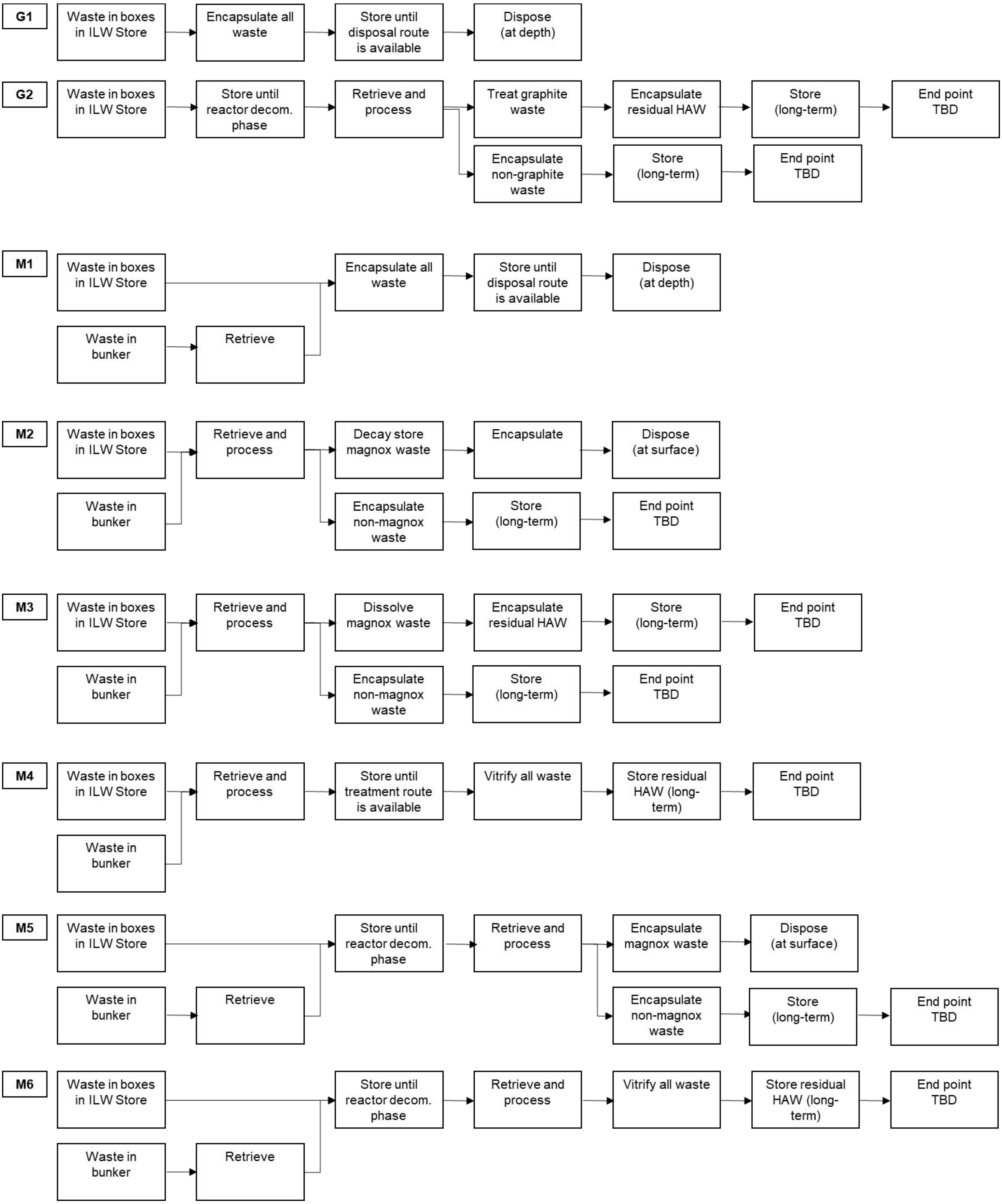
The options can therefore be presented according to the management strategy for the dominant waste material within each bunker subset. The short-listed options are summarised in the Table 4 and illustrated in Figure 2 (these have been assigned numbers for ease of discussion in the following sections). A description of these options is provided in Appendix B. A break-down of the steps involved with each of these options is given in Appendix E, which shows how all waste materials from Bunkers 2-5 and Bunker 1 will be managed, as well as any waste remaining following processing or treatment. The assessment summary within the main body of this document is presented separately for Bunkers 2-5 and Bunker 1; see Section 4 and Section 5 respectively.

Table 4: Shortlisted Options

Option Group	Bunkers 2-5 (Graphite)	Bunker 1 (Magnox)	Waste remaining after processing or treatment
Baseline – no sorting	G1. Encapsulate then store for at-depth disposal	M1. Encapsulate then store for at-depth disposal	n/a
Prompt Processing	n/a[10]	M2. Sort and decay store then encapsulate for at surface disposal M3. Sort and treat by dissolution M4. Re-package and store then treat by vitrification	Encapsulate, if necessary, then place into long-term storage
Deferred Processing	G2. Store then sort and treat by gasification	M5. Store then sort and encapsulate for at surface disposal M6. Store then re-package and treat by vitrification	Encapsulate, if necessary, then place into long-term storage

[10] Option of prompt processing for gasification eliminated as sub-optimal to deferred processing (see Appendix B).

Figure 2: Shortlisted Options



3 ASSESSMENT METHODOLOGY

3.1 Method

In accordance with Company Standard S-391 [3], the *lead option* for managing waste from each bunker subset will be determined by comparing the attributes of each option and using reasoned arguments, and the *proposed option* will be determined following a management analysis of the *lead option*.

3.2 Attributes

The selected attributes used in the assessment are shown below and Appendix C presents the rationale for any that are excluded.

Safety	Environment etc.	Technical	Socio-economic
S1: Worker Dose	E1: Volume of Radioactive Waste for Disposal	T1. Development Risk	SE1. Cost
S2: Public Dose: Site Discharges and Shine	E2. Activity of Radioactive Waste for Disposal	T2. Risk to Technical Cases	~~SE2. Impacts on Local Infrastructure~~
~~S3: Public Dose: Site Land Condition~~	~~E3. Volume of Hazardous Waste for Disposal~~	T3. Deployment Difficulty	SE3. Future Burden
S4: Public Dose: Transport	E4. Radiological Impacts on the Environment: Discharges	T4. Competition for Use of Shared Assets	~~SE4. Duration of Restricted Land Use~~
S5: Conventional Risk to Workers: Immediate Impacts	~~E5: Radiological Impacts on the Environment: Site Land Condition~~	T5. Risk of Failure to Meet Project Technical Objectives	
~~S6: Conventional Risk to Workers: Delayed Impacts~~	E6. Non-Radiological Impacts on the Environment: Discharges	T6. Long-Term Risk of Unplanned Intervention	
~~S7: Conventional Risk to the Public: Site Land Condition~~	E7: Non-Radiological Impacts on the Environment: Site Land Condition	T7. Impact of Loss of Corporate Records / Memory	
S8: Conventional Risk to the Public: Traffic Accidents	E8. Materials		
~~S9: Reliance on Active Systems and /or Prompt Human Intervention~~	E9. Disturbances		
S10: Time to Significant Hazard Reduction	E10. Energy Use		
S11: Novelty / Lack of Prior Use	E11. Waste-miles		
	~~E12. Loss of Amenity Value~~		

3.3 Assessment Data

See Appendix D.

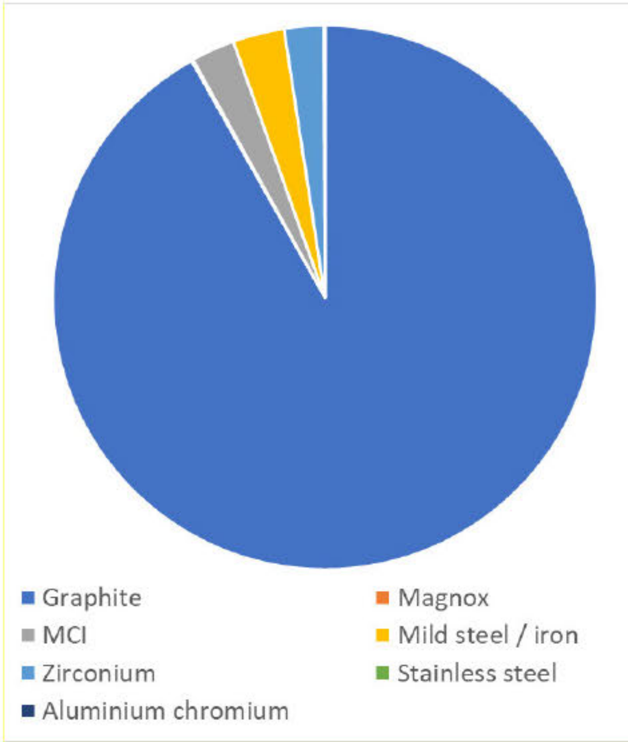
4 DETERMINATION OF THE LEAD OPTION FOR BUNKERS 2-5

4.1 Bunkers 2-5 Waste Summary

The inventory of waste from Bunkers 2-5 is summarised below. All waste has been retrieved and is in storage in 890 3m^3 boxes in the ILW Store. During packaging the waste was processed (sorted, size reduced, etc.) according to the requirements of the LoC Waste Product Specification (WPrS) [13] which includes limits on certain waste items, such as fuel support members and HEPA filters, and identifies measures to segregate particulate waste.

Table 5: Summary of Bunkers 2-5 waste inventory

Summary of Bunkers 2-5 inventory (9J19-22)	
Total raw volume	1660 m^3 (approx. 2,180 tonnes of raw waste)
Waste type	Mainly graphite and metallic debris, with only small quantities of misc ILW; there are also small amounts of magnox in Bunkers 2-3.
Dominant radionuclides	Ni-63, H-3, Co-60, C-14



4.2 Assessment of Options for Managing Waste from Bunkers 2-5

This section presents a comparison of options based on the attribute comparison table in Appendix E and the assumed steps involved with each of the options set out in Appendix B.

The attributes of each option have been assessed and 'scored' relative to each other by virtue of assigning a green/amber/red colour according to the system set out in Reference [3], where:

- **Red** is allocated where the performance of the option on that issue is significantly worse than at least one other option.
- Amber is allocated where the options is clearly, but not significantly, worse than at least one other option.
- **Green** is allocated in other cases.

The relative performance of each option is discussed within each attribute category as follows:

4.2.1 Safety Attributes

The RAG 'score' for each option against each attribute (from Appendix E) is shown below:

Option	S1	S2	S4	S5	S8	S10	S11
G1. Encapsulate then store for at-depth disposal							
G2. Store then sort and treat by gasification							

The key differences between these options are:

- Option G1 makes use of existing plant and processes without modification whereas Option G2 requires a new $3m^3$ box emptying facility and processes to sort, assay and export graphite in 200l drums and package the remaining waste into $3m^3$ boxes. These extra requirements for Option G2 present conventional safety risks due to construction and implementation. Considering the processes used with each option, Option G1 requires the encapsulation of 890 boxes with associated hazards, e.g. due to the use of cement. Option G2 requires far fewer boxes to be encapsulated (estimated at 132) but presents inherent hazards due to the gasification process which involves graphite crushing and a plasma furnace. On balance, and along with considering risks posed by its novelty, Option G2 is viewed to present the overall greater safety risk due to these inherent process hazards.
- In Option G1 the waste would be promptly passivated by encapsulation, minimising risks during the storage phase. In Option G2 the graphite would not be treated until the reactor decommissioning phase and so presents a comparatively long time at increased risk due to 'raw' storage (though see Section 6.3.1 for consideration of these risks).
- Greater worker doses would be expected with Option G2 because the waste would undergo further handling and, whilst the work would be managed in such a way as to ensure doses are ALARP, the overall ALARP option would be one which avoids the work in the first place, i.e. Option G1.
- Option G1 incurs the most radioactive transports (890) compared with Option G2 (323). Public doses are considered to be greater for the former, however this assessment has not considered the shielding properties of the different transport packages. Conventional traffic risks would be greater for Option G2 due to an increase in waste-miles and the need to import additional materials to site for construction.

In summary, Option G1 performs best on safety as it makes use of existing plant and processes, and the waste is promptly passivated (by encapsulation). Option G2 performs less well as it involves new facilities and processes being established at site, increased handling of the waste, an inherently high hazard process, and delays to passivation.

4.2.2 Environment, Waste and Sustainability Attributes

The RAG 'score' for each option against each attribute (from Appendix E) is shown below:

Option	E1	E2	E4	E6	E7	E8	E9	E10	E11
G1. Encapsulate then store for at-depth disposal									
G2. Store then sort and treat by gasification									

The key differences between these options are:

- Option G1 would dispose of all waste without first reducing its volume or activity whereas Option G2 would result in a greatly reduced volume of waste being disposed, the activity of which would be reduced (due to discharges during treatment). Option G2 would also result in greater secondary wastes including those arising from decommissioning of the additional facilities. It has been assumed that Option G2 is implemented with a carbon capture technology and there could be a significant amount of waste arising from this process.

- Option G1 would not require abatement to minimise radioactive gaseous discharges to the environment whereas Option G2 would. The unabated doses due to discharges have been estimated at 2.8E-01 µSv/y for Option G1 and 5.5E+02 µSv/y for Option G2. Following abatement this dose falls to 1.3E+01 for Option G2, which is still two orders of magnitude greater than the dose for Option G1. Option G2 is also reliant on a carbon capture technique to minimise discharges of carbon to the environment, the efficacy of which is unknown. In Option G1 there would be little interaction between the waste and the environment during encapsulation or storage. Interaction with the environment following disposal through radionuclide leaching is mitigated by the encapsulated waste package concept, which is well underpinned in this respect.
- Option G2 is also more demanding on materials and resources, including a highly energy intensive process, and incurs greater off-site disturbances and an approximate doubling of waste-miles compared with Option G1 (estimated at 17,800 (G1) vs 37,020 (G2)).

Overall, option G1 performs best as, although it results in a significantly greater volume of waste being disposed of, it has an otherwise much smaller impact on the environment as it avoids the materials and energy demands of a box emptying facility and graphite crushing and gasification process. Discharges to, and interactions with, the environment are comparatively small.

4.2.3 Technical Attributes

The RAG ‘score’ for each option against each attribute (from Appendix E) is shown below:

Option	T1	T2	T3	T4	T5	T6	T7
G1. Encapsulate then store for at-depth disposal							
G2. Store then sort and treat by gasification							

The key differences between these options are:

- Option G2 applies established techniques to the point of treatment, though it is not certain that sorting and segregation could be performed to the requirements for treatment and there is an increased risk due to ‘raw’ storage. There would be considerable competition for shared assets/space at site due to the requirement for a $3m^3$ box emptying facility and use of the reactor decommissioning encapsulation plant. The treatment process applies existing technology but in a highly novel manner and there is a credible development risk associated with this. The technical cases required to support management of the treatment by-products are unknown. In comparison, Option G1 applies a well-established management strategy and uses existing plant and processes, which provide high confidence that the technical objectives can be achieved.
- The key technical risk with Option G1 regards uncertainty over demonstrating at-depth disposal WAC, including whether sufficient information exists and will be retained to support this future assessment. This risk also applies to the final management of waste in Option G2, for a smaller number of higher activity packages. The information risk can be better mitigated in Option G2 as information deficiencies, if understood, could be addressed when the waste undergoes further handling.

Overall, Option G1 performs best as it presents the least challenging route to final management, applying a well-established management strategy and using existing plant and processes. Option G2 performs less well as it introduces additional complexity and risk, particularly as a novel treatment process is used, and presents significant competition for site assets. The key risk with Option G1 is demonstrating that at-depth disposal WAC, when they are established, can be met and that there is sufficient information about the waste to support this demonstration.

4.2.4 Socio-Economic Attributes

The RAG 'score' for each option against each attribute (from Appendix E) is shown below:

Option	SE1	SE3
G1. Encapsulate then store for at-depth disposal	(green)	(green)
G2. Store then sort and treat by gasification	(red)	(red)

The key differences between these options are:

- Option G2 requires a new facility for emptying 3m3 boxes and sorting/exporting waste for treatment, at great cost, whereas Option G1 makes use of existing plant and equipment. Overall, Option G2 is estimated to cost double that of Option G1 (£32.5M (G1) vs £65M (G2)).
- Option G2 would also defer management of the waste to a future generation whereas in Option G1 the waste would be promptly encapsulated with no future processing demand and, although the waste packages will require management through to disposal (which will be performed by a future generation), this demand is significantly less than that placed on future generations by Option G2. It is also not clear what this burden entails for Option G2 as the long-term management requirements for gasification by-products are unknown.

Overall, Option G1 provides the most cost-effective route to final management and leaves no further waste processing for future generations to do. Option G2 is greatly expensive and places a large burden on future generations due to the deferred sorting and management and the long-term management requirements of the treatment by-products are unknown.

4.3 Lead Option(s)

The option to encapsulate then store for at-depth disposal (Option G1) is the lead option for all waste from Bunkers 2-5.

This is because the alternative option of gasification performs worse in nearly every attribute, with the key differentiators being:

- Sorting the graphite and exporting it for gasification involves additional handling steps and increased worker dose. There would be greater conventional safety risks from activities associated with construction, operation and decommissioning of the $3m^3$ box emptying facility, and greater inherent hazards from the gasification process itself.
- Gasification would result in comparatively large radioactive and non-radioactive wastes to manage, reliant on abatement and carbon capture techniques to limit discharges to the environment. The process is also greatly energy intensive. By comparison, the at-depth disposal option would result in very little interaction with the environment.
- The burden placed on future generations would be significantly greater with the gasification option and it would place significant strain on site assets and resources, presenting a large scope of work to be conducted during the same phase as reactor decommissioning.
- Gasification technology is at a very low level of readiness and there is a credible risk that the technology will never materialise.
- Greater uncertainty with management of residual HAW which is unlikely to be suitable for near-surface disposal.

- Significantly greater cost (£65.0M vs £32.5M).

4.4 Sensitivity Analysis

This section considers the sensitivity of the lead option against the relative assumptions from Appendix B, replicated below:

Assumption	Sensitivity Analysis
Disposal requires the waste to be encapsulated.	Not sensitive. This is the basis of the $3m^3$ box packaging concept. Should it become possible to dispose of waste in $3m^3$ boxes without it being encapsulated this is not expected to preclude disposal of encapsulated wasteforms as these are superior products.
An at-depth disposal facility will not become available until after the reactor decommissioning phase.	Not sensitive. Storage can be provided until whenever this facility becomes available (up to 300 years is provided for).
The baseline waste packages are suitable for at-depth disposal in their current configuration (when encapsulated)	Sensitive. Disposal risks are considered in Section 6.
All waste in $3m^3$ boxes can be transported in the Standard Waste Transport Container (SWTC) (which is assumed to be available in time for use)	Not sensitive. The SWTC is being designed to transport such waste packages and they can be stored until transport is possible. Assurance of transport is provided by the LoC process.
Current policy and regulatory standards will apply at the time of implementation of any identified strategy.	Sensitive. The waste would not be disposed of for several decades over which time standards will evolve. Use of the LoC process provides confidence in this respect however there are risks associated with the foreclosure of options, as considered in Section 6.

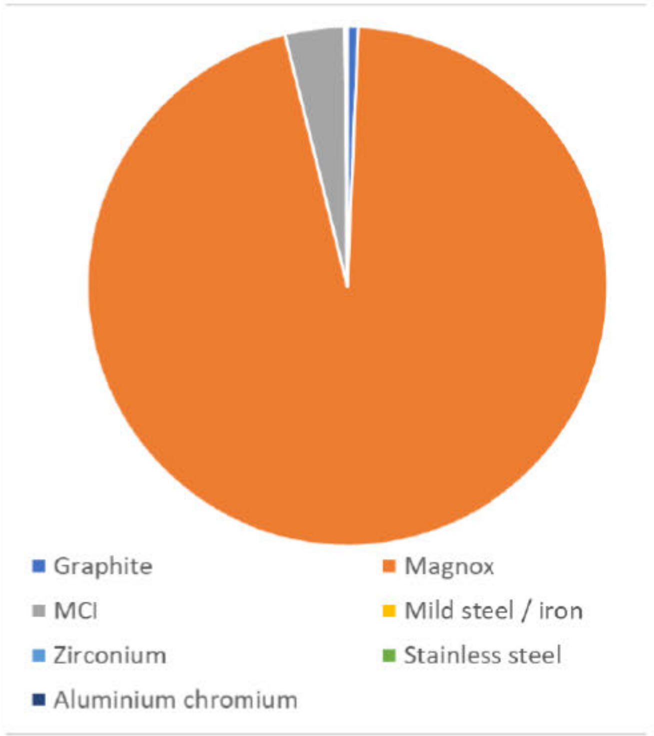
5 DETERMINATION OF THE LEAD OPTION FOR BUNKER 1

5.1 Bunker 1 Waste Summary

The inventory of waste from Bunker 1 is summarised below. Some of this waste has been retrieved and is in storage in 3m^3 boxes in the ILW Store, some of this waste remains in Bunker 1. For the retrieved portion, during packaging the waste was processed (sorted, size reduced, etc.) according to the requirements of the LoC Waste Product Specification (WPrS) [14] which includes limits on certain waste items, such as fuel fragments[11] and HEPA filters, and identifies measures to segregate particulate waste. Where possible low level waste items are segregated for separate management.

Table 6: Summary of Bunker 1 waste inventory

Summary of Bunker 1 inventory (9J23)	
Total raw volume	595 m^3 (25pprox.. 160 tonnes of raw waste)
Waste type	Almost all of the magnox produced during the station's operation, together with small quantities of miscellaneous ILW
Dominant radionuclides	Ni-63, Cs-137, Sr-90, Pu-241



To assess management options for waste from Bunker 1 it is necessary to consider the 'in-bunker' portion and retrieved portion separately. The potential for alternative management is greater for the in-bunker portion and so this is considered first. The implications of this assessment to the waste already retrieved from the bunker are discussed in Section 5.3.

5.2 Assessment of Options for Managing Waste from Bunker 1– In-Bunker Portion

This section presents a comparison of options for managing the in-bunker portion of waste from Bunker 1, based on the attribute comparison table in Appendix E and assumed steps involved with each of the options (set out in Appendix B).

The attributes of each option have been assessed and 'scored' relative to each other by virtue of assigning a green/amber/red colour according to the system set out in Reference [3], where:

- **Red** is allocated where the performance of the option on that issue is significantly worse than at least one other option.
- **Amber** is allocated where the options is clearly, but not significantly, worse than at least one other option.

[11] Reference [14] allows for the packaging of up to 1.0kg of segregated fuel fragments in a fuel handling vessel. This strategic options assessment has excluded segregable fuel fragments and so does not wholly align with Reference [14].

- **Green** is allocated in other cases.

The relative performance of each option is discussed within each attribute category as follows:

5.2.1 Safety Attributes

The RAG 'score' for each option against each attribute (from Appendix E) is shown below:

Option	S1	S2	S4	S5	S8	S10	S11
M1. Encapsulate then store for at-depth disposal	Green	Green	Amber	Green	Green	Green	Green
M2. Sort and decay store then encapsulate for at surface disposal (LLWR)	Amber	Green	Green	Amber	Green	Amber	Green
M3. Sort and treat by dissolution	Amber	Amber	Green	Amber	Amber	Green	Green
M4. Re-package and store then treat by vitrification	Amber	Green	Amber	Red	Amber	Amber	Red
M5 Store then sort and encapsulate for at surface disposal	Amber	Green	Green	Amber	Amber	Red	Green
M6. Store then re-package and treat by vitrification	Amber	Green	Amber	Red	Amber	Red	Red

The key differences between these options are:

- Option M1 makes use of existing plant and processes without modification. All other options require some degree of construction/modification with associated conventional safety risks due to construction and implementation. These risks are viewed to be greatest for options requiring new facilities for 3m3 box emptying (Options M5 and M6) or dissolution (Option M3). Options based on high hazard processes (Options M4 and M6) are viewed to present greater inherent conventional safety risks. Additionally, Options M4 and M6 present greater risks due to their novelty. All waste is encapsulated in Options M1, M2 and M5 and so encapsulation hazards are not viewed to be discriminating between these options but the additional facility requirements for Options M2 and M5 are. Due to the properties of magnox there are flammable gas hazards with each option, and this assessment has not discriminated between options on this basis (though some options are likely to require less active management than others).
- In Options M1-M4 the waste would be passivated by encapsulation or treatment in the near-term (20 years) whereas Options M5-M6 defer passivation to the reactor decommissioning phase and so present a comparatively long time at increased risk due to 'raw' storage (see Section 6.3.1 for consideration of these risks).
- The least worker dose would be expected with Option M1 because all other options require some degree of additional waste handling. Whilst any option would be managed in such a way as to ensure doses are ALARP, the overall ALARP option would be one which avoids the work in the first place, i.e. Option M1.
- Options M1, M4 and M6 make the most radioactive transports (100, 226 and 241) and Options M32, M3 and M5 make the least (36, 16 and 59). Public doses are considered to be greater for the former options, though the effect is likely to be small and this assessment has not considered the shielding properties of the different transport packages. Conventional traffic risks would also be greater for Options M3-M6 which have a greater number of rad-waste consignments and/or the need to import additional materials to site for construction.

Overall, Option M1 performs best on safety as it makes use of existing plant and processes, and the waste is promptly passivated (by encapsulation). Other options perform less well as they involve new facilities and processes being established at site, increased handling of the waste, greater number of transports and/or delays to passivation.

5.2.2 Environment, Waste and Sustainability Attributes

The RAG 'score' for each option against each attribute (from Appendix E) is shown below:

Option	E1	E2	E4	E6	E7	E8	E9	E10	E11
M1. Encapsulate then store for at-depth disposal	Red	Amber	Green	Green	Green	Green	Green	Green	Green
M2. Sort and decay store then encapsulate for at surface disposal (LLWR)	Amber	Amber	Green	Green	Green	Green	Amber	Green	Red
M3. Sort and treat by dissolution	Green	Green	Red	Amber	Amber	Green	Red	Red	Green
M4. Re-package and store then treat by vitrification	Amber	Green	Red	Amber	Green	Green	Amber	Red	Red
M5 Store then sort and encapsulate for at surface disposal	Amber	Amber	Green	Green	Amber	Green	Red	Green	Red
M6. Store then re-package and treat by vitrification	Amber	Green	Red	Amber	Amber	Green	Red	Red	Red

The key differences between these options are:

- Option M3 results in the smallest volume of waste for disposal / final management. Option M1 performs least well as it would dispose of all waste without first reducing its volume or activity. All other options achieve some degree of volume reduction. The activity of waste disposed of / finally managed is also reduced for Options M3, M4 and M6 due to discharges during treatment. Options involving further handling would also result in greater secondary wastes such as those arising from decommissioning of contaminated plant.
- Encapsulation options (M1, M2 and M5) have been estimated to result in doses due to radioactive gaseous discharges in the order of 10^{-3} µSv/y whereas treatment options (M3, M4 and M6) are estimated to result in doses which are two-to-three orders of magnitude greater, even after factoring abatement (see Appendix H). Non-radioactive discharges can also be expected with the treatment options. By contrast, the encapsulation options would involve little interaction between the waste and the environment during encapsulation or storage. Interaction with the environment following disposal through radionuclide leaching is mitigated by the encapsulated waste package concept, which is well underpinned in this respect.
- Options M4 and M6 apply the most energy-intensive processes. Whilst the process energy requirements are not expected to be as significant for Option M3 there would be a high demand during construction. Options M1, M2 and M5, by contrast, have a low energy demand. Material demand has not been judged to be discriminating between options; materials required for construction of new facilities are assumed to be recoverable though there would be off-site disturbances during these construction activities, most notably for Options M3, M5 and M6.
- Options M1 and M3 perform best on waste-miles, both involving on-site processing/treatment and near-site disposal/final management. All other options perform significantly worse, with Options M4 and M6 involving the greatest waste-miles. The waste-miles for each option have been estimated to range between 220 miles (M3) and 37,705 miles (M6).

Overall, Options M1 and M2 are viewed to perform best and similarly, with the latter disposing of a smaller volume but incurring far more waste-miles. Option M5 (the deferred variant of Option M2) performs less well primarily due to the disturbances associated with the construction, operation and decommissioning of the 3m^3 box emptying facility.

Options M4 and M6 have been assumed to result in a similar volume reduction as with super-compaction (Options M2 and M5) but with a high energy demand and increased radiological discharges to the environment, and so is viewed to perform less well than Options M2 and M5. Option M3 would incur similar detriments but with much improved volume reductions, however, and a case could be argued for it on environment, waste and sustainability grounds if minimising the volume of waste for disposal was a priority objective.

5.2.3 Technical Attributes

The RAG 'score' for each option against each attribute (from Appendix E) is shown below:

Option	T1	T2	T3	T4	T5	T6	T7
M1. Encapsulate then store for at-depth disposal	Green	Green	Green	Green	Green	Green	Amber
M2. Sort and decay store then encapsulate for at surface disposal (LLWR)	Green	Amber	Green	Amber	Green	Amber	Green
M3. Sort and treat by dissolution	Green	Amber	Red	Red	Red	Green	Amber
M4. Re-package and store then treat by vitrification	Red	Amber	Green	Amber	Red	Amber	Amber
M5 Store then sort and encapsulate for at surface disposal	Green	Amber	Amber	Red	Green	Amber	Green
M6. Store then re-package and treat by vitrification	Red	Amber	Amber	Red	Red	Amber	Amber

The key differences between these options are:

- Options M1, M2, M3 and M5 apply established techniques and represent low development risks, although Option M3 could have a significant greater deployment difficulty. Options M4 and M6 apply unproven technology and so have very credible development risks though the deployment risks are borne by others (not Magnox Ltd). Options M3, M5 and M6 represent the greatest competition for shared assets at site, and Option M3 is most likely to threaten the site schedule and C&M entry date.
- Option M1 is viewed to carry the lowest risk of failure as it applies a well-established management strategy and uses existing plant and processes, though the key risk regards uncertainty over demonstrating at-depth disposal WAC, including whether sufficient information exists and will be retained to support this future assessment. This uncertainty affects all options to some degree though for 'final management'. Options M5 and M6 allow more time for WAC or guidance to be established before the waste is processed though have the greatest risks due to 'raw' storage. Options M2 and M5 have technical risks relating to demonstrating at-surface WAC, due to the heterogeneity of the waste and presence of small, high activity items and sludge contamination. It may not be possible to sort the entirety of the magnox to enable alternative management, meaning that a greater volume of waste is routed for long-term storage in Options M2, M3 and M5.

Overall, Option M1 performs best as it presents the least challenging route to final management, applying a well-established management strategy and using existing plant and processes. Other options perform less well as they introduce additional complexity and risk, particularly where novel treatment processes are used. Another key detriment is over competition for site assets and threats to C&M entry, which are greatest for Option M3. The key risk with Option M1 is demonstrating that at-depth disposal WAC, when they are established, can be met. Further information cannot be as readily gained for this option as opposed to those which involve further handling of the waste.

However, unlike all other options, Option M1 does not concentrate the activity of the waste (either by treatment or segregation) and so represents the lowest risk option for meeting these WAC.

5.2.4 Socio-Economic Attributes

The RAG 'score' for each option against each attribute (from Appendix E) is shown below:

Option	SE1	SE3
M1. Encapsulate then store for at-depth disposal		
M2. Sort and decay store then encapsulate for at surface disposal (LLWR)		
M3. Sort and treat by dissolution		
M4. Re-package and store then treat by vitrification		
M5 Store then sort and encapsulate for at surface disposal		
M6. Store then re-package and treat by vitrification		

The key differences between these options are:

- Option M1 is estimated to be least costly. Options M2 and M4 are expected to be costlier, primarily this is due to the additional infrastructure needs at site. The costliest options are those involving construction of significant infrastructure at site, i.e. Options M3, M5 and M6; these could incur 10-20 times the cost of Option M1. The cost of each option has been estimated to range between £5M (M1) and £105M (M3).
- In Option M1 the waste would be promptly encapsulated with no future processing demand. Option M2 is similar though encapsulation would be deferred slightly. Both options would require future generations to manage waste packages through to disposal and Option M2 would require that some packages be long-term stored. Options M3 and M4 would treat the waste in the near-term but require that future generations manage waste packages for long-term storage, the requirements of which are uncertain. Options M5 and M6 entirely defer management of the waste to future generations and perform least well in this respect.

Overall, Option M1 provides the most cost-effective route to final management and leaves no further waste processing for future generations to do. Options M2, M3 and M4 reduce the volume of waste for future generations to manage but leave a long-term management burden which is unknown. The greatest future burden is associated with Options M5 and M6, and these are also high-cost options due to the need to retrieve waste from $3m^3$ boxes. The costliest option, however, is likely to be Option M3.

5.3 Assessment of Options for Managing Waste from Bunker 1 – Retrieved Portion

As it is simpler to retrieve and sort the in-bunker portion of the waste than that which has already been containerised, it can be inferred that if the lead option for managing the in-bunker portion of the waste to encapsulate then store for at-depth disposal then this will also be the lead option for the retrieved portion. See Section 5.4.

5.4 Lead Option(s)

The option to encapsulate then store for at-depth disposal (Option M1) is the lead option for all waste from Bunker 1 (both the in-bunker and retrieved portions).

Treatment options have been assessed to perform less well compared to disposal options. This is because:

- Option M3 (dissolution) would require substantial new facilities with associated construction, operation, and decommissioning hazards. This would also place considerable competition for resources at site and impact the site schedule. Dissolution is a complex process with credible development risks. This option would also incur the most cost by far, estimated at £105M for the in bunker portion alone.
- Options M4 and M6 (vitrification) apply inherently high hazard and novel processes. The vitrification process has high energy demands and increased waste-miles. The technology has a low readiness level and there is a credible risk that it will never become available or proven for the waste from Bunker 1.
- With all treatment options there would be greater discharges to the environment when compared against disposal (encapsulation) options, estimated to be two-to-three orders of magnitude greater. There is also greater uncertainty with management of residual HAW which is unlikely to be suitable for near-surface disposal. There would also be significant challenges to effectively sort and segregate to the requirements of these processes.

Of the disposal options, Option M1 is judged to perform best overall. The next best disposal option is Option M2 (to sort and decay store then encapsulate for at-surface disposal). This option is, on balance, judged to perform worse than the lead option due to the following key differentiators:

- The magnox would need to be segregated from the other waste from Bunker 1 and there are risks that a portion of the magnox cannot be adequately sorted to meet at-surface disposal WAC. Challenges are presented by the heterogeneity of the waste and presence of small, high activity items, as well as particulate contamination.
- Sorting the magnox and exporting it requires additional waste handling and results in increased worker dose due to this.
- For the waste remaining in bunker the requirement for a new sorting facility would present competition for resources at site and would impact the site schedule. This issue is significantly exacerbated for the waste that has already been retrieved and containerised.
- There is greater uncertainty with management of the segregated, non-magnox waste as this is unlikely to be suitable for at-depth disposal if packaged on its own.
- At-surface disposal would also incur additional waste-miles and cost.

5.5 Sensitivity Analysis

This section considers the sensitivity of the lead option against the relative assumptions from Appendix B, replicated below:

Assumption	Sensitivity Analysis
Disposal requires the waste to be encapsulated.	Not sensitive. This is the basis of the $3m^3$ box packaging concept. Should it become possible to dispose of waste in $3m^3$ boxes without it being encapsulated this is not expected to preclude disposal of encapsulated wasteforms as these are superior products.
An at-depth disposal facility will not become available until after the reactor decommissioning phase.	Not sensitive. Storage can be provided until whenever this facility becomes available (up to 300 years is provided for).
The baseline waste packages are suitable for at-depth disposal in their	Sensitive. Disposal risks are considered in Section 6.

current configuration (when encapsulated)	
All waste in 3m^3 boxes can be transported in the Standard Waste Transport Container (SWTC) (which is assumed to be available in time for use)	Not sensitive. The SWTC is being designed to transport such waste packages and they can be stored until transport is possible. Assurance of transport is provided by the LoC process.
Current policy and regulatory standards will apply at the time of implementation of any identified strategy.	Sensitive. The waste would not be disposed of for several decades over which time standards will evolve. Use of the LoC process provides confidence in this respect however there are risks associated with the foreclosure of options, as considered in Section 6.

6 MANAGEMENT ANALYSIS

The following sections explore the risks associated with the lead options.

6.1 Summary of lead options for consideration

The lead options are:

Waste Subset	Lead Option
Waste from Bunkers 2-5	G1. Encapsulate then store for at-depth disposal
Waste from Bunker 1	M1. Encapsulate then store for at-depth disposal

Both options involve the encapsulation of waste in $3m^3$ boxes and storage until a disposal facility exists. It is appropriate to consider them together within this management analysis.

For waste from Bunker 1 the next best option (M2, to sort and decay store then encapsulate for at surface disposal (LLWR)) is also considered to determine whether there is an overall advantage to adopting this option instead (see Section 6.3.4).

6.2 Risks Associated with the Lead Options

From the sensitivity analyses in the preceding sections, two key risks are highlighted for both options relating to disposal and foreclosure of options. These are considered below.

6.2.1 Disposal Risks

Disposal risks exist for all wastes which are planned to be disposed of in future facilities, whether that involves NSD or the GDF. The lead options propose that the bunkers waste be disposed of 'at-depth' in a Scottish facility yet to be designed or built. The LoC process has been followed to provide assurance that *the future management of waste packages has been taken into account as an integral part of their development and manufacture* [2] and a measure of disposal confidence can be taken from having secured fLoCs (as well as assuring deep geological disposal should policy change to permit this). This assurance applies not only to the waste packages but also to the quality of the information (including characterisation) held about them within the associated package records. Further assurance has been sought by assessing human intrusion scenarios for various at-depth disposal configurations (see Appendix G), which provides further confidence that the waste packages can be disposed of as intended.

6.2.2 The Risk of Foreclosing Alternative Long-Term Management Options

Scotland's HAW Policy notes that decisions need to recognise the risk of foreclosing alternative long-term management options. The lead options involve prompt packaging and conditioning by encapsulation, and this makes it difficult to change strategies away from disposal.

Should it later prove beneficial to extract materials from encapsulated waste packages it may be possible to adapt a process similar to that used for recycling concrete, though this would need further work to establish. In any case, the benefits of adopting an alternative strategy would have to outweigh the detriment of doing so.

This review has considered the possibility that alternative options become available in the future; the question is to what extent should such opportunities be enabled. Encapsulation would clearly make a strategy change more difficult than if the waste was not encapsulated. However, there is also a significant challenge associated with removing waste from $3m^3$ boxes, regardless of whether it is encapsulated or not. This review identifies the detriment associated with the task, highlighting that it is unlikely that an alternative strategy would be preferable; the desire to retrieve waste would have to be driven by some imperative not currently foreseen.

6.3 Risk Mitigations

6.3.1 The Potential to Reduce Disposal Uncertainty

The NDA is pursuing development of a NSD capability for England and Wales and, as set out in their strategy [15], this includes the investigation of *earlier opportunities for the implementation of near-surface disposal solutions* in Scotland. Magnox Ltd is supporting the NDA with this work and will continue to work with the NDA, other Scottish waste producers, and regulators to further how NSD considerations factor into near-term decision making. This is not recommended as a specific action from this review as it is captured by ongoing work and is not specific to the bunkers waste.

6.3.2 The Potential to Defer or Forego Encapsulation

One mitigation against disposal risks is to defer encapsulation until a disposal facility exists. The assumption in this review is that such a facility would not arise until after the Hunterston A site has been decommissioned. There is the possibility that a disposal facility would be available earlier than envisaged, however there is a greater possibility that the reactor decommissioning phase for the site will be brought forward[12]. The assumption used in this review is therefore viewed to be likely and that, if the intent was to encapsulate the waste only once a disposal facility was established, this would need to be done outside of a planned site decommissioning phase. The greatest potential to accommodate this could be if the disposal facility had an encapsulation capability, though this is not the current plan.

Encapsulation forms part of the design intent for waste stored in thin-walled containers such as the $3m^3$ box. During storage the grout limits waste and container degradation, assuring their ongoing performance. Following disposal the grout provides retardation of release of radionuclides into the biosphere and stabilises chemically reactive or mobile materials, as well as providing a structural function.

Reference [16] considers the risks associated with deferring encapsulation, from a waste package integrity perspective. Risks can generally be said to be greater for waste from Bunker 1 than for Bunkers 2–5, due to the greater reactivity of the magnox. Waste degradation could present challenges, particularly where corrosion products have formed which inhibit the ability for grout to infiltrate the package. Container degradation issues could also present.

It may be possible to forego encapsulation entirely. Nuclear Waste Services (NWS) waste package specification notes *the possibility to package certain types of waste [in the $3m^3$ box] without the use of an immobilising medium exists* [17], and Magnox Ltd has recently sought their expert view on the potential for the bunkers waste packages to be disposed of to the GDF without a grout encapsulant. This expert view is provided in Reference [18] concluding that *disposal in an unencapsulated state would be inconsistent with [NWS] requirements as currently understood for geological disposal* and highlighting several disposal risks, the most severe of which related to GDF operations safety (ALARP) and post closure structural/geological concerns (voidage). It was also noted that continued storage of the waste without encapsulation *may create an environment where the internal surfaces of the stainless-steel box are vulnerable to corrosion.* Whilst this expert view was provided with reference to the GDF these highlighted risks would apply a near-surface facility, and voidage risks are potentially exacerbated.

To defer (with the potential to forego) encapsulation goes against Magnox Ltd waste management principles, set out in Reference [19] and derived from regulatory guidance, best practice, etc. These combine to present a general imperative for prompt passivation. The significance of adopting a strategy of deferred encapsulation should not be understated. This review has not identified grounds for pursuing such an approach.

[12] Update for Issue 2 of this report: Magnox Ltd has formally changed its strategy to a rolling programme of decommissioning and physical work is now forecast to have completed at Hunterston A in the 2050s.

6.3.3 The Potential for Policy to Change

Whilst not considered as an option within this review, there is the potential for policy change to enable a GDF route for Scottish HAW, which would mitigate at-depth disposal risks and is supported by fLoCs for the bunkers waste packages.

6.3.4 Would Another Option be Preferable?

The assessments summarised in Sections 4 and 5 provide no indication that treatment options would be preferable to disposal options. The only alternative disposal options are identified for waste from Bunker 1 and the best of these was identified as Option M2: to sort and decay store then encapsulate for at surface disposal (LLWR).

In this option most of the waste (the magnox) would be decay stored pending encapsulation and disposal. The waste would be encapsulated at the disposal facility (LLWR) and so is not dependent on the availability of an encapsulation facility at the Hunterston A site. Greater flexibility is therefore provided with this option for the magnox until the point of encapsulation, which provides some mitigation against the risks considered above.

The non-magnox waste items would be packaged and promptly encapsulated and so this waste is subject to the same risks considered above, however these risks are exacerbated as although the magnox represents ca. 90% of the volume of waste from Bunker 1 it accounts for less than 3% of the total activity. The non-magnox waste is much less likely to be suitable for at-depth disposal if packaged on its own.

There are also risks with Option M2 by introducing further sorting and segregation. There is mixed experience with FED sorting at other sites. It proved possible to sort and divert a large portion of FED from Bradwell to LLWR. It was not proven possible for FED at Hinkley Point A, which is being managed as ILW and has significant challenges even sorting to IP-2 transport requirements. The strategy for managing FED from Oldbury and Sizewell A is being reviewed in part due to learning from Hinkley Point A. For the FED from Bunker 1 it would not be possible to segregate materials without cross-contamination, especially given the presence of pond sludge and graphite particulate waste, and the ability to effectively segregate small volume, high-activity MAC would also need to be tested. It is not a given that the waste could be sorted to the requirements of the LLWR WAC, and probable that a portion would need to be routed for at-depth disposal in any case.

In general terms, options M1 and M2 apply similar strategies, i.e. to package and store pending disposal, and the key differentiator is the additional sorting and segregation for Option M2. Option M2 would provide greater disposal certainty for the portion of magnox which can be effectively segregated (as this can be assessed against established WAC) however it exacerbates disposal risks for the remaining waste, whereas Option M1 appears to provide greater overall assurance that all waste can be disposed of.

From this consideration it is judged that no alternative options are preferable to those identified as the lead options, Options G1 and M1. It is recommended that these be taken forwards as the proposed options (and, as these options apply the same strategy, this can be expressed as a singular proposed option).

6.4 Contributors to this Management Analysis

Contributors are listed in Appendix A.

6.5 Proposed Option

The proposed option is to manage all waste within the scope of this review via encapsulation for interim storage then at-depth disposal.

This assessment identified alternative options for treatment or disposal of the waste from Bunkers 1-5. All treatment options were judged to perform less well than disposal options because:

- All treatment options require new facilities to process the waste, requiring additional waste handling and resulting in increases to worker dose. There would also be conventional safety risks from the construction, operation and decommissioning of these facilities, and particularly for the scenarios where waste needs retrieving from $3m^3$ boxes.
- Most treatment options apply inherently high hazard processes and, aside from dissolution, all technologies have low technology readiness levels and credible development risks.
- All treatment options would result in gaseous and/or liquid wastes to manage. Even following abatement it was estimated that doses due to radioactive discharges would be two or more orders of magnitude greater than those with the disposal (encapsulation) options. The estimated total doses (following abatement) due to discharges for each option[13] are shown below in µSv/y:

G1	G2	M1	M2	M3	M4	M5	M6
2.8E-01	1.3E+01	2.6E-03	2.6E-03	2.3E+00	8.5E-01	2.4E-03	4.7E-01

  Applying BPM, as set out in SEPA guidance [4], presents an imperative to minimise radioactive waste discharged to the environment, a necessary consequence of which is that the amount sent to solid disposal facilities is maximised.

- All treatment options introduce technical challenges to adequately sort and segregate the waste to the requirements of the relevant process.
- All treatment options result in HAW which is unlikely to be suitable for at-depth disposal.
- Some treatment options would incur significantly greater cost. The estimated total cost of each option[13] is shown below:

G1	G2	M1	M2	M3	M4	M5	M6
£32.5M	£65.0M	£5.0M	£8.8M	£105.0M	£8.0M	£55.0M	£55.0M

Alternative disposal options were only identified for magnox from Bunker 1, however at-surface disposal performed less well than at-depth disposal because:

- The magnox would need to be segregated from the other waste from Bunker 1 and there are risks that a portion of the magnox cannot be adequately sorted to meet at-surface disposal WAC. Challenges are presented by the heterogeneity of the waste and presence of small, high activity items, as well as particulate contamination.
- Sorting the magnox and exporting it requires additional waste handling and results in increased worker dose due to this.
- For the waste remaining in bunker the requirement for a new sorting facility would present competition for resources at site and would impact the site schedule. This issue is significantly exacerbated for the waste that has already been retrieved and containerised.
- There is greater uncertainty with management of the segregated, non-magnox waste as this is unlikely to be suitable for at-depth disposal if packaged on its own.
- At-surface disposal would also incur additional waste-miles and cost.

The proposed option, to manage all waste by encapsulation for storage then at-depth disposal, follows an underpinned waste management approach and is assured via the LoC process. The key risks with this approach relate to disposability and foreclosure of options. The possibility to defer encapsulation has been considered as one tactic to mitigate these risks, however this review has identified no grounds for pursuing such an approach. Prompt encapsulation is proposed to ensure that the waste packages are manufactured in accordance with the design intent of the $3m^3$ box, to

[13] Figures presented for Bunker 1 options (M1-6) are for the ‘in bunker’ portion of the waste only.

provide better long-term performance during storage and during the disposal facility's operational and post closure phases.

Implementation of this strategy will continue to be managed using the Hunterston A site Radioactive Waste Management Case, which will be updated to reflect the findings of this review.

6.6 Consistency with Scotland's HAW Policy

The proposed option aligns with the baseline strategy which was recently reviewed for its consistency with Scotland's HAW Policy. This review was documented in Reference [20], concluding that the baseline strategy demonstrated good alignment. This review is supported by the analysis of *this* options assessment which has considered all long-term management options (so far as they can be currently determined) taking account of the fundamental principles set out in the Policy, the waste hierarchy, and proximity principle. The lead options satisfy the proximity principle, and alternative waste management options, which enable greater application of the waste hierarchy (through volume reduction), have been given due consideration though the detriments of these options have been judged to outweigh the benefits.

As noted in Reference [20], decisions on waste management are influenced by numerous things including policy, regulatory guidance, etc., and that these generally influence decisions in favour of prompt packaging and conditioning (passivation), to immobilise radioactivity and limit waste degradation for reasons of passive safety amongst others including intergenerational equity. The lead options determined from this review align with this generality.

7 BPM AND ALARP SUMMARY ARGUMENTS

7.1 Summary BPM Argument

This document presents a strategic options assessment. The proposed option is considered to represent BPM and supports the requirement to optimise public exposures as:

- it results in minimal generation of further radioactive wastes (secondary wastes are limited to operational and decommissioning wastes associated with existing retrieval and encapsulation processes/equipment, which has arisen/will arise in any case); and
- it minimises the potential for radioactivity to be discharged to the environment (discharges would arise primarily from encapsulation off-gassing, which would be similar in all disposal options assessed; treatment options would result in comparatively significant discharges).

The strategic assessment presented in this document has not addressed how the implementation of the proposed option will be optimised. To clarify how this is being achieved an optimisation summary report will be produced. This will set out how the radiological effects of radioactive discharges on the environment and people have been or will be minimised.

7.2 Summary ALARP Argument

The proposed option is considered to represent ALARP. No additional handling of the waste is proposed (whereas all other options would involve this) and it makes use of the site's established HAW management route which is remotely operated by and large. There would be minimal off-site doses due to discharges compared with treatment options. There are other options which would result in fewer radwaste consignments, and potentially lower public doses due to transports, though these are overall less preferable due to other factors. Long-term risks are managed through prompt waste passivation and applying an underpinned waste management approach.

8 FURTHER WORK

8.1 Further Work Required to Support the Outcome

No further work is proposed to support the outcome of this strategic options assessment. Forward actions may be needed to optimise its implementation, these will be identified upon completion of an optimisation summary report

Whilst not forming a forward action from this review, it is noted that work is ongoing to support the NDA in developing a NSD capability and that this work, along with collaborations with other Scottish waste producers, will hopefully improve how disposal uncertainties are factored into near-term decisions.

9 REVIEW REQUIREMENTS

9.1 Review Requirement (When)

This is to be periodically reviewed every five years, in accordance with company standard S-391, or sooner if prompted by a trigger (see below), until the waste is encapsulated.

Following encapsulation this should only be reviewed if prompted by one of the tiggers.

9.2 Review Requirement (Triggers)

This should be reviewed if:

- LLWR WAC change to enable disposal of the waste as packaged.
- Other alternative management routes become available which challenge the assumptions used in this review.

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APPENDIX A: OPTIONS ASSESSMENT PANEL AND STAKEHOLDER ENGAGEMENT

<u>Options Assessment Panel</u>

The Options Assessment Panel (OAP) included the following people:

- Oliver Smith, Senior Waste Consultant, Waste Strategy & Permissioning
- Elena Alcantara, Baseline Strategy & Integration Manager, Waste Strategy & Permissioning
- Reuben Phillips, Waste Manager, Hunterston A Site
- Graeme Busby, NRE SAWBR HAW Operations, Hunterston A Site
- David Bremner, Radiation Protection & Environment (incl. RSL Adviser), Hunterston A Site
- Tom McLaughlin, Operations Engineer, Hunterston A Site
- Cameron Robertson, Engineering Lead (Waste Programmes), Hunterston A Site
- Richard Delley, HAW Disposability Officer for Hunterston A Site, Waste Strategy & Permissioning
- Michelle Grist, Senior Waste Consultant, Waste Strategy & Permissioning
- Jack Clarke, Assistant Engineer, Waste Strategy & Permissioning

Data and underpinning were provided and/or scrutinised by:

- Joshua Weatherill, Assistant Engineer, Technical Function
- Hannah Bean, Technical Lead, Technical Function
- Bill Westall, Principal Consultant, Technical Function
- Ceri Davies, Principal Waste Consultant, Waste Strategy & Permissioning
- Joseph Stephenson, Senior Waste Consultant, Waste Strategy & Permissioning
- Darryl Smith, Senior Waste Consultant, Waste Strategy & Permissioning
- Eden Nuclear and Environment Ltd
- Andy Sealby, R&D Manager, Sellafield High Active Waste Thermal Treatment Programme
- Christopher Healey, Cost Engineer
- Michelle Grist, Senior Waste Consultant, Waste Strategy & Permissioning

The following stakeholders were also engaged throughout this review:

- Tim Bond, Waste Strategy & Permissioning Manager (principal reviewer of the Management Analysis)
- Mark Blackley, Site Director, Hunterston A Site (Alistair Walker, Acting Site Director, Hunterston A Site engaged prior to Mark's appointment)
- Alan Krailing, Head of Profession, Environment & Waste
- Paul Murray, Waste Programme Director
- Paul Winkle, Chief Operating Officer
- Pam Duerden, EHSS&Q Director
- John Grierson, Deputy Chief Operating Officer

Further review was provided by:

- Andrew Oborne, Waste Programme Chief Engineer
- Patrick Haley, Principal Consultant, Environment & Waste
- Melissa Hughes, Principal Consultant, Waste Strategy & Permissioning

APPENDIX B: OPTIONS ASSUMPTIONS AND DESCRIPTIONS

Option Constraints and Assumptions

The following constraints are identified:

- Prompt processing will take place during the present decommissioning phase (ca. 2020-30)
- Deferred processing will take place during the reactor decommissioning phase (ca. 2070-80)[14].
- For all deferred processing options, all waste will be stored containerised and 'raw' (i.e. not encapsulated) in the ILW Store until the reactor decommissioning phase. The waste that is currently in-bunker will be retrieved and containerised in line with existing practice.
- Magnox Ltd would need to provide a facility for the on-site processing (retrieval, sorting, packaging, etc.) of waste:
    - The sorting of in-bunker waste, and loading into 200l drums, can be performed in the SAWB with new equipment installed above bunker; waste would be hoisted from the bunker to the sorting area in buckets.
    - The emptying of $3m^3$ boxes for sorting and loading into 200l drums cannot be performed in an existing facility; a new building will be required.
- Wastes packaged for at-depth disposal will be packaged in line with prevailing site HAW management strategies, i.e. encapsulation in $3m^3$ stainless steel boxes. Waste can be encapsulated in the present decommissioning phase using SILWE.
- Magnox Ltd would need to provide a treatment facility for the dissolution of magnox as there is no impetus (UK demand) for others to provide such a facility.
- Others will provide treatment facilities for the gasification of graphite and vitrification of magnox. These technologies are not currently available (at a commercial scale).
- Others will provide disposal facilities:
    - The existing LLWR facility can be used for at-surface disposal. The waste would be encapsulated at this facility.
    - There is currently no at-depth disposal facility. The waste would need to be encapsulated on-site before consignment to an at-depth disposal facility.
- The option of long-term storage is not considered as a primary strategy, it only applies where no other options are viewed to be feasible.
- Cross-site transportation can be achieved with existing or planned capabilities.
- Off-site transportation can be achieved with existing or planned capabilities.

The following assumptions apply to the assessment of the options:

Assumption	Reasoning
It is feasible to sort and segregate the waste into its constituent materials to enable their separate management.	It is feasible in principle but unproven. There is mixed experience with FED sorting at other sites. It proved possible to sort and divert a large portion of FED from Bradwell to LLWR. It was not proven possible for FED at Hinkley Point A, which is being managed as ILW and has significant challenges even sorting to IP-2 transport requirements. The strategy for managing FED from Oldbury and Sizewell A is being reviewed in part due to learning from Hinkley Point A. For the FED from Bunker 1 it would not be possible to segregate materials without cross-contamination, especially given the presence of pond sludge and graphite particulate waste, and the ability to effectively segregate small volume, high-activity MAC would also need to be tested.

[14] It is anticipated that the dates for this phase might change, something which is considered in Section 4.4.

Dissolution technology is proven and can be applied during the current decommissioning phase.	The technology exists and has been used at Bradwell and Dungeness A. The ability to implement it within the current decommissioning phase may be unrealistic, however, if only from a schedule perspective.
Third party treatment facilities that are not currently available will become available after the present decommissioning phase but before the reactor decommissioning phase.	This is uncertain though appears possible given the treatment facilities considered in the assessment: vitrification is already being developed as part of a thermal treatment programme managed at Sellafield; a gasification facility, if the case for it is established, would be needed before Magnox reactor decommissioning.
Disposal requires the waste to be encapsulated.	This is true of the current LLW Repository WAC and is more generally true of disposal concepts such as the GDF if waste is packaged in thin-walled containers such as the 3m^3 box. A recent expert view provided by NWS supports this assumption (see Section 6.3)
Waste can be encapsulated in the reactor decommissioning phase using the same facility as that used to encapsulate reactor waste.	Plans for the reactor decommissioning phase are not greatly developed, though it is highly likely that an encapsulated waste package strategy will be used. In theory the encapsulation plant could be designed to accommodate the bunkers waste packages. The requirement to encapsulate the bunkers waste packages during this phase may place an unmanageable burden on the site programme, however, and this would need further evaluation should an option be chosen which proposes this.
An at-depth disposal facility will not become available until after the reactor decommissioning phase.	Scotland’s HAW Policy Implementation Strategy [2] suggests that such a facility will not be developed until after 2070, although there is the opportunity to do so sooner. The reactor decommissioning phase is currently scheduled for 2070-80 and so it seems probable that an at-depth facility would not be established until after this period and storage should be planned for.
The baseline waste packages are suitable for at-depth disposal in their current configuration (when encapsulated).	Assurance of this is provide using the LoC process and feasibility studies have been conducted to consider the suitability of the bunkers waste packages for near-surface disposal. These were based on the GRA and indicated suitability for at-depth disposal (see Appendix G).
Waste remaining following processing or treatment is not suitable for near-surface disposal.	Waste packages comprising waste remaining following processing (segregation) or treatment have been estimated to be at least two orders of magnitude greater in total package activity than the baseline waste packages. This effect is caused because the non-graphite and non-magnox waste materials typically have a greater specific activity than graphite or magnox, and treatment is assumed to concentrate activity. Feasibility studies have not been conducted to consider whether waste remaining following processing or treatment would be suitable for near-surface disposal. However, based on a crude scaling of results from the GRA assessments (summarised in Appendix G) this assumption seems appropriate. This would need further evaluation if any option is chosen which would result in such waste packages being generated, to derive more accurate package inventory estimates and evaluate the contribution of specific radionuclides to doses arising from human intrusion scenarios.
Waste sent off-site for treatment or at-surface disposal will first be packaged into 200l drums.	This is consistent with existing practice, e.g. consignment of FED drums to the LLW Repository from Bradwell or drummed waste for incineration. It might be possible to use the 3m^3 box for importing to facilities in the future, as this could be factored into their design (if there is enough of an impetus to do so), however this isn’t consistent with current practice and relies on the SWTC. The SWTC is being developed for transport of waste for treatment as well as storage or

	disposal, so this could be a significant opportunity to pursue should an off-site treatment option be desirable.
Where on-site storage is required before consignment, the ILW Store can be modified to accept waste stored in 200l drums in stillages and the environment is appropriate for this. Four 200l drums per stillage are assumed using a design similar to that in Reference [21]	This is based on existing designs, though the existing stillage design could potentially be improved upon to accommodate more than four 200l drums.
Transports will use existing equipment or equipment provided by others; no new equipment needs developing by Magnox Ltd.: • Drummed graphite and magnox can be transported in FHISOs. • Drummed Bunker 1 mixed waste can be transported in Novapak transport packages. • All waste in 3m^3 boxes, including treatment by-products, can be transported in the Standard Waste Transport Container (SWTC) (which is assumed to be available in time for use).	The only transport solution envisaged for 3m^3 boxes is the SWTC. The SWTC is required to support the GDF, which is planned to become available before the reactor decommissioning phase at Hunterston A, so is expected to be available in time for use though the UK capacity is unknown and there could be high demand. Mixed waste from Bunker 1 will contain high-activity MAC which is likely to prevent it from being transported within IP-2 transport packages. It is judged that the existing, Type B Novapak transport package could feasibly be relicensed to transport such waste. The feasibility of transporting drummed graphite or magnox in FHISOs would need further investigation if such an option is chosen.
Emptied 3m^3 boxes, which are not intended for re-use, would require management via the LLWR framework. These are assumed to be recycled.	Recycling would be the likely outcome from BPM assessment, though this would need to be properly assessed and supported by further characterisation.
HAW remaining following treatment would need to be returned to Hunterston A.	This may be conservative, as Scotland's HAW Policy [6] does note that if such waste would not add materially to that needing disposal in the country of destination then it can remain there. However, this would need to be tested. The common assumption seems to be that such waste will need to be returned to Scotland.
HAW by-products from any treatment option will be packaged in 3m^3 boxes. Where further processing, e.g. encapsulation, is required this will be performed at Hunterston A. By-products from dissolution and gasification require encapsulation and packaging in 3m^3 boxes at the Hunterston A site. By-products from vitrification can go straight into storage.	The packaging requirements for such wastes are currently unknown, however these assumptions enable comparison with other options. Vitrified waste is a recognised wasteform suitable for disposal and so no further conditioning is assumed.

Current policy and regulatory standards will apply at the time of implementation of any identified strategy.	Future changes cannot be anticipated.

Options Descriptions

The assessed options for managing graphite and magnox involve variations of:

- Timing of processing: none, prompt or deferred
- Encapsulation for disposal: at-surface or at-depth
- Treatment: dissolution, gasification or vitrification

Option Group	Bunkers 2-5 (Graphite)	Bunker 1 (Magnox)	Waste remaining after processing or treatment
Baseline – no sorting	G1. Encapsulate then store for at-depth disposal	M1. Encapsulate then store for at-depth disposal	n/a
Prompt Processing	n/a	M2. Sort and decay store then encapsulate for at surface disposal M3. Sort and treat by dissolution M4. Re-package and store then treat by vitrification	Encapsulate, if necessary, then place into long-term storage
Deferred Processing	G2. Store then sort and treat by gasification	M5. Store then sort and encapsulate for at surface disposal M6. Store then re-package and treat by vitrification	Encapsulate, if necessary, then place into long-term storage

A breakdown of steps involved with each option is included towards the end of this appendix. A basic description of each of these processing, disposal and treatment variations is given below.

Timing of Processing

<u>No Sorting</u>

The containerised waste is encapsulated with no further sorting.

<u>Prompt Processing</u>

The waste is processed during the current decommissioning phase, prior to the site's entry into its quiescent phase. This requires any waste currently remaining in-bunker to be retrieved. For waste already containerised in $3m^3$ boxes this requires boxes to be emptied of their contents.

<u>Deferred Processing</u>

The waste is processed during the reactor decommissioning phase, with all waste stored in $3m^3$ boxes in the ILW Store until this phase, when all boxes would be emptied of their contents. This requires any waste currently in-bunker to be retrieved and containerised in the current decommissioning phase.

Impact of Technology Availability on Graphite Management

Although graphite treatment is proven at a small scale, commercial scale treatment options for the volume of graphite from the bunkers are not currently available. The demand for graphite treatment across the nuclear decommissioning industry will be significantly greater than that from Hunterston A alone and, therefore, it is assumed that such treatment options would be developed off-site, and that storage of the retrieved Hunterston A graphite would be required until such an option is available. The question then arises as to whether it is better to empty the $3m^3$ containers and promptly process the waste, while the site is currently mobilised, or to defer processing until the route is available.

Prompt processing would involve sorting the waste and loading the segregated graphite into containers suitable for storage and later export for off-site treatment. The container choice is likely to be between the $3m^3$ box and 200l drum: the former would enable storage within the ILW Store but has no current transport solution, whereas there would not be space within the ILW Store for the latter though it can make use of existing transport solutions and such drums are typically preferred for importing to treatment facilities.

Given that there is not space in the ILW Store to accommodate graphite in 200l drums and there is doubt as to whether sorting the waste for storage in $3m^3$ boxes is worthwhile, given uncertainty over treatment facility WAC and a reliance on the SWTC, the option of prompt processing is viewed to be sub-optimal when compared to the deferred processing option. It is therefore eliminated from further assessment.

Note: as the volume of magnox is significantly less than that of graphite, there is sufficient space to store it at Hunterston store in 200 l drums pending the availability of a treatment option, and therefore both prompt and deferred processing options are assessed.

Near Surface Disposal

The Implementation Strategy for Scotland’s HAW Policy [2] envisages that a near-surface disposal facility (or facilities) will be constructed in Phase 3 of the policy’s implementation, after 2070, and points to the guidance on requirements for authorisation of such facilities (the GRA) [11].

<u>At-Depth Disposal</u>

At-depth disposal is a form of near-surface disposal, where disposal vaults / caverns are constructed several tens of metres below the surface and accessed through a drift [22].

There is no at-depth disposal option available to the UK at present, though it is being pursued by NDA as an alternative, for some waste, to deep geological disposal [23] in addition to forming a key component of Scotland’s HAW Policy. The indicative suitability of the bunkers waste for at-depth disposal has been assessed using the GRA and existing studies [24] and reported on in Reference [10]. This work indicated that the waste packages arising from each bunker are likely to be disposable based on calculating the resulting doses from bounding human intrusion scenarios at various decay periods into the future, where all scenarios resulted in doses below the GRA guidance levels within the assumed period of institutional control for the disposal facility.

For at-depth disposal options, it is assumed that:

- Waste packaging will use the prevailing packaging concept at site, i.e. encapsulation within thin-walled stainless steel containers.
- Encapsulation is required prior to disposal (see Section 6.3.2 for a commentary on this) and this happens at the Hunterston A site.
- Interim storage is required prior to disposal in any scenario, for which the existing ILW Store will be used. Should the interim storage phase extend beyond the lifetime of the ILW Store then a replacement store will be constructed. This is the basis of the LTP, with replacement stores planned to achieve up to 300 years of on-site storage.
- Waste packages will be transported for disposal within the NWS SWTC.

At-Surface Disposal

At-surface disposal is another form of near-surface disposal, where the disposal facility is on or below the surface where the protective covering is of the order of a few metres thick. Waste containers are placed in constructed vaults and when full the vaults are backfilled [22].

The LLW Repository, operated by LLWR Ltd, is one such facility and is used for the basis of assessment in this review. The suitability of the bunkers waste for at-surface disposal has been assessed using the current LLWR WAC (v5.0) and reported on in Reference [12].

For at-surface disposal options, it is assumed that:

- Magnox intended for at-surface disposal, either with or without a decay storage period, would be packaged in 200l drums and transported to a third-party facility for super-compaction, decay storage (if applicable) and consignment for disposal. This process follows that described in Reference [25]. The third-party facility is assumed to be Tradebe’s Winfrith site, as this is where the existing capability has been established, though a site located closer to the Hunterston A site could be sought if pursuing this option.
- Encapsulation is required prior to disposal (see the Management Analysis for a commentary on this) and this happens at the disposal site (LLWR).

Treatment

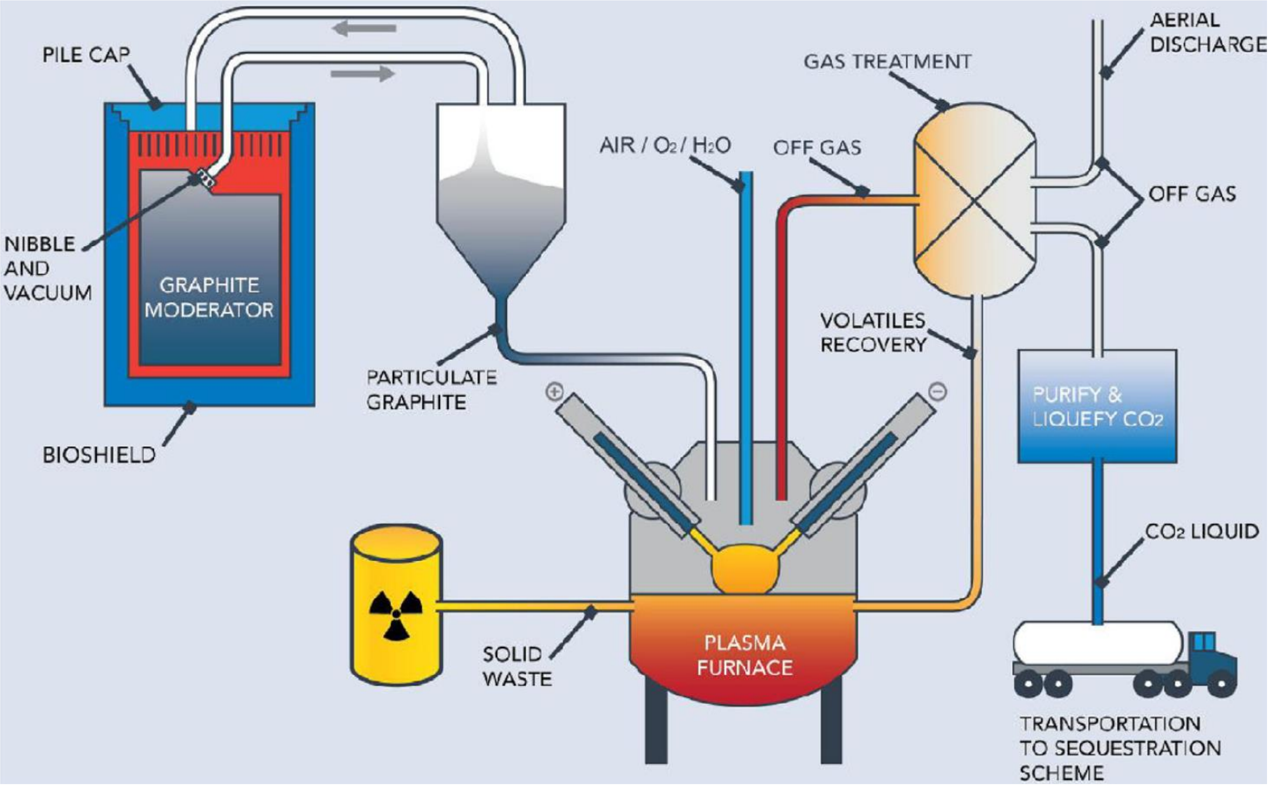
Treatment options for managing the various waste materials have been investigated, as summarised below. With the view that other treatment options, to those listed below, may also become available in future, this review has considered a specific ‘future’ treatment option for both graphite and magnox which can serve as proxies for considering the benefits and detriments of future options in general.

It is assumed that any HAW by-products will be loaded into 3m^3 boxes and returned to the Hunterston A site for processing (if required) followed by long-term storage.

Graphite - Gasification

There has been lots of research conducted into treatment options for graphite and several means of decontamination are theoretically possible [26]. Options for recycling or reuse could exist, e.g. ‘diamond batteries’, though are currently subject to great uncertainty. Gasification has been used for basis of assessment in this review as it has momentum in the industry and may be the most likely option to materialise.

Gasification involves the conversion of carbonaceous materials, such as graphite, into carbon monoxide and hydrogen by reacting the materials at high temperatures with a controlled amount of oxygen or steam, and then converting the gases to carbon dioxide and water (steam). The overall chemical reaction involves the oxidation of carbon by oxygen to form carbon dioxide.



Significant volume reductions are possible from this process, as evidenced through trials [27], though it is not clear what could be expected on a commercial scale. Secondary wastes are expected in the form of residues containing non-volatile radionuclides, the radioactivity having been concentrated. Volatile radionuclides would require management; several options exist such as gaseous discharge to atmosphere, (carbon) capture, or the formation of stable solids.

For this assessment, it is assumed that gasification results in a residue equivalent to 5% of the original volume of graphite (a reasonable guess made from trial data indicating that a significant amount of the graphite could be oxidised by this process [27] but with little data concerning its other by-products) and that this residue contains radioactivity in a concentrated form which renders it unsuitable for near-surface disposal.

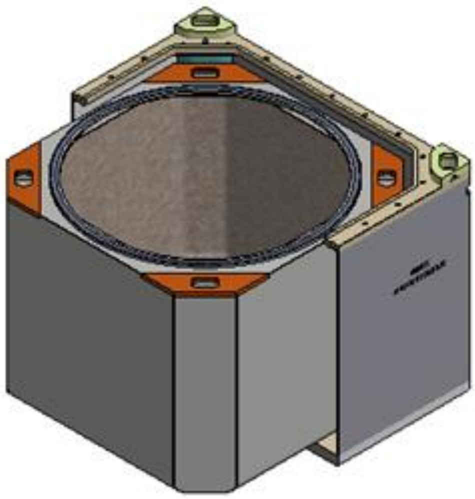
Magnox - Dissolution

Dissolution has been applied at Dungeness A and Bradwell, and the technologies applied at either site could be replicated at Hunterston A. The process involves dissolving magnox in acid. Non-soluble items will remain following the process, and by-products will be generated typically in the form of sludge, ion exchange material and filter materials. For this assessment it is assumed that dissolution results in a volume of secondary wastes totalling 5% of the original volume of magnox following encapsulation (i.e. equivalent $3m^3$ box numbers are reduced by 20:1), based on secondary waste arisings from the Bradwell plant. The majority of radioactivity would be retained in these secondary wastes though a significant amount, in relation to the site's annual limit, would be discharged to environment (aqueous).

Magnox - Vitrification

This treatment technology would convert the waste, with the addition of silica-based material, into a stable glass product through the process of vitrification. It is possible that the magnox could be managed this way using a thermal treatment capability being developed at Sellafield. Further work would be required to establish the feasibility of this route along with processing constraints, should the option appear attractive. The resulting product would be suited to disposal, in general, though the process would concentrate the radioactivity of the waste and potentially prevent it from being disposable in the near-surface environment.

The plant is understood to accept waste in 200l drums and, for magnox, would most likely involve a plasma lost crucible process similar to that being trialled for drums of plutonium contaminated material (PCM). The waste would be loaded into a sacrificial container (crucible) and vitrified using a plasma torch. The crucible and wasteform could then be loaded into a 3m^3 box [28] .



ISO VIEW - LOST CRUCIBLE REFRACTORY IN 3m3 BOX

For this assessment it is assumed that these waste packages would be transported to Hunterston A but require no further processing prior to entering long-term storage.

A significant advantage of this process is that it requires little sorting and segregation. For this assessment it is assumed that the degree of in-bunker sorting currently performed at Hunterston A would be sufficient, minimising requirements for additional equipment in the SAWB, though a 200l export capability will be needed. However, if transporting ‘all’ bunkers waste in 200l drums it is unlikely that FHISOs would be sufficient. For this assessment the Type B Novapak is assumed.

The volume reduction of the bunkers waste could be quite significant. Combined with the need for glass-forming additives and the lost crucible, the process is expected to result in a maximum of 50 200l drums of waste being processed into a 3m^3 box [29], and this upper estimate is used for the basis of assessment in this review. This is likely to be very optimistic (as a blend of materials would be needed for vitrification the amount of magnox within each box would be limited; if the waste from Bunker 1 cannot be blended with waste from elsewhere, e.g. due to policy complications, there could also arise a need for a large amount of ‘clean’ feedstock materials). Should this option evaluate favourably/marginally this assumption will need revisiting.

This technology may become available in the 2020s though uncertainty with this date and what the ‘order book’ would look like suggests that, given the plan for Hunterston A to enter C&M in 2030, some storage at site could be required prior to consignment. Storage in stillages in the ILW Store is assumed with consignment to Sellafield in the 2030s.

<u>Other materials</u>

No treatment routes have been identified as viable, due to activity (WAC) issues and/or proportionality (waste volume) issues. For example, it was not viewed to be credible to pursue the decontamination of metallic materials for recycling. There is the opportunity for some materials to be managed via the above routes, in particular using vitrification, though only where this would be the strategy for the dominant waste material (graphite or magnox).

Processing Steps for Management Options for Bunkers 2 – 5

The following table outlines the steps assumed within each management option. Appendix B provides an explanation of why there is no prompt processing option being assessed.

G1. Encapsulate then store for at-depth disposal	G2. Store then sort and treat by gasification
Manage all waste • Store in ILW Store (short-term only) • Cross-site transport to SILWE • Encapsulate • Cross-site transport to ILW Store • *Store until at depth disposal facility is available* • Transport to NSD facility • Dispose	**Storage** • *Store in ILW Store until reactor decommissioning phase* **Waste retrieval and processing** • Design, build and commission box emptying & sorting facility • Cross-site transport to retrieval & sorting facility • Retrieve from $3m^3$ boxes and sort graphite from non-graphite waste **Manage graphite** • Package into 200l drums • Load into FHISOs • Transport to treatment facility • Treat by gasification • Package residual HAW (treatment by-products) into $3m^3$ boxes • Transport to site • Encapsulate • Cross-site transport to ILW Store • *Long-term storage* • Transport to final management facility • Final management **Manage non-graphite waste** • Package into $3m^3$ boxes • Cross-site transport to encapsulation plant • Encapsulate • Cross-site transport to ILW Store • *Long-term storage* • Transport to final management facility • Final management **Manage contaminated $3m^3$ boxes** • Size reduce • Package into HHISOs • Transport for recycling • Recycle

(storage phases are shown in italics for ease of identification)

Processing Steps for Management Options for Bunker 1

In-Bunker Waste

The following table outlines the steps assumed within each management option, **for the in-bunker waste only**.

M1. Encapsulate then store for at-depth disposal	M2. Sort and decay store then encapsulate for at surface disposal (LLWR)	M3. Sort and treat by dissolution	M4. Re-package and store then treat by vitrification	M5. Store then sort and encapsulate for at surface disposal (LLWR)	M6. Store then re-package and treat by vitrification
Waste retrieval • Retrieve remaining in-bunker waste • Cross-site transport to ILW Store • Store in ILW Store (short-term only) **Manage all waste** • Cross-site transport to SILWE • Encapsulate • Cross-site transport to ILW Store • *Store until at depth disposal facility is available* • Transport to at depth NSD facility • Dispose	**Waste retrieval and processing** • Store in bunker (short-term only, remaining waste) • Design, build and commission sorting & drum loading facility • Retrieve from bunker and sort magnox from non-magnox waste **Manage magnox** • Package magnox into 200l drums • Load 200l drums into FHISOs • Transport FHISOs to third party facility • Super-compact drums into pucks • Decay store pucks • Load into HHISOs • Transport to LLWR • Dispose **Manage non-magnox waste** • Package into new $3m^3$ boxes • Cross-site transport to SILWE • Encapsulate • Cross-site *Store* • Transport to ILW Store • *Long-term storage* • Transport • Final management	**Waste retrieval and processing** • Store in bunker (short-term only, remaining waste) • Design, build and commission sorting & drum loading facility • Design, build and commission dissolution and abatement facility • Design, build and commission $3m^3$ container packaging facility[15] • Retrieve from bunker and sort magnox from non-magnox waste **Manage magnox** • Load into 200l drums • Treat by dissolution • Package residual HAW (treatment by-products) into $3m^3$ boxes/drums • Cross-site transport to SILWE/WILWREP • Encapsulate • Cross-site transport to ILW Store • *Long-term storage* • Transport • Final management **Manage non-magnox waste** • Package into $3m^3$ boxes • Cross-site transport to SILWE • Encapsulate • Cross-site transport to ILW Store • *Long-term storage* • Transport • Final management	**Waste retrieval and processing** • Store in bunker (short-term only, remaining waste) • Design, build and commission 200l drum loading facility • Modify ILW Store to accept 200l drums in stillages • Design and manufacture 200l drum stillages • Retrieve waste from bunker • Package waste into 200l drums • Load into stillages • Cross-site transport to ILW Store • *Store until treatment route is available* **Manage all waste** • Load into Novapak • Transport to treatment facility • Treat by vitrification • Package residual HAW (treatment by-products) into $3m^3$ boxes • Transport to site • *Long-term storage* • Transport • Final management	**Waste retrieval and storage** • Retrieve and containerise remaining in-bunker waste in $3m^3$ boxes • Cross-site transport to ILW Store • *Store in ILW Store until reactor decommissioning phase* **Waste retrieval and processing** • Design, build and commission $3m^3$ box emptying & sorting facility • Cross-site transport to emptying & sorting facility • Retrieve from $3m^3$ boxes and sort magnox from non-magnox waste **Manage magnox** • Package into 200l drums • Load 200l drums into FHISOs • Transport FHISOs to third party facility • Super-compact drums into pucks • Load into HHISOs • Transport to LLWR • Dispose **Manage non-magnox waste** • Package into new $3m^3$ boxes • Cross-site transport to encapsulation facility • Encapsulate • Cross-site transport to ILW Store • *Long-term storage* • Transport • Final management **Manage contaminated $3m^3$ boxes** • Size reduce. • Package into HHISOs. • Transport for LLW management • Recycle	**Waste retrieval and storage** • Retrieve and containerise remaining in-bunker waste in $3m^3$ boxes • Cross-site transport to ILW Store • *Store in ILW Store until reactor decommissioning phase* **Waste retrieval and processing** • Design, build and commission $3m^3$ box emptying facility • Cross-site transport to box emptying facility • Retrieve from $3m^3$ boxes **Manage all waste** • Package into 200l drums • Load into Novapak • Transport to treatment facility • Treat by vitrification • Package residual HAW (treatment by-products) into $3m^3$ boxes • Transport to site • *Long-term storage* • Transport • Final management **Manage contaminated $3m^3$ boxes** • Size reduce. • Package into HHISOs. • Transport for LLW management • Recycle

(storage phases are shown in italics for ease of identification)

[15] Assumed for this assessment that the existing containerisation facility which is part of the Bunker Retrievals plant is no longer available or unsuitable, but an opportunity would exist to reuse this.

Containerised Waste

M1. Encapsulate then store for at-depth disposal	M2. Sort and decay store then encapsulate for at surface disposal (LLWR)	M3. Sort and treat by dissolution	M4. Re-package and store then treat by vitrification	M5. Store then sort and encapsulate for at surface disposal (LLWR)	M6. Store then re-package and treat by vitrification
Manage all waste • Store in ILW Store (short-term only) • Cross-site transport to SILWE • Encapsulate • Cross-site transport to ILW Store • *Store until at depth disposal facility is available* • Transport to at depth NSD facility • Dispose	**Waste retrieval and processing** • Design, build and commission $3m^3$ box emptying and sorting facility • Cross-site transport to box emptying facility • Retrieve from $3m^3$ boxes and sort magnox from non-magnox waste **Manage magnox** • Package magnox into 200l drums • Load 200l drums into FHISOs • Transport FHISOs to third party facility • Super-compact drums into pucks • Decay store pucks • Load into HHISOs • Transport to LLWR • Dispose **Manage non-magnox waste** • Inspect and recertify used $3m^3$ boxes • Package into reused $3m^3$ boxes • Cross-site transport to SILWE • Encapsulate • Cross-site transport to ILW Store • *Long-term storage* • Transport • Final management **Manage contaminated $3m^3$ boxes** • Size reduce. • Package into HHISOs. • Transport for LLW management • Recycle	**Waste retrieval and processing** • Design, build and commission $3m^3$ box emptying and sorting facility with 200l drum loading capability • Cross-site transport to box emptying facility • Retrieve from $3m^3$ boxes and sort • Design, build and commission dissolution and abatement facility • Design, build and commission $3m^3$ container packaging facility • Retrieve from bunker and sort magnox from non-magnox waste **Manage magnox** • Load into 200l drums • Dissolve • Inspect and recertify used $3m^3$ boxes • Package residual HAW (treatment by-products) into reused $3m^3$ boxes • Cross-site transport to SILWE/WILWREP • Encapsulate • Cross-site transport to ILW Store • *Long-term storage* • Transport • Final management **Manage non-magnox waste** • Inspect and recertify used $3m^3$ boxes • Package into reused $3m^3$ boxes • Cross-site transport to SILWE • Encapsulate • Cross-site transport to ILW Store • *Long-term storage* • Transport • Final management **Manage contaminated $3m^3$ boxes** • Size reduce. • Package into HHISOs. • Transport for LLW management • Recycle	**Waste retrieval and processing** • Design, build and commission $3m^3$ box emptying facility with 200l drum loading and export capability • Modify ILW Store to accept 200l drums in stillages • Design and manufacture 200l drum stillages • Retrieve waste from $3m^3$ boxes • Package waste into 200l drums • Load into stillages • Cross-site transport to ILW Store • *Store until treatment route is available* **Manage all waste** • Load into suitable transport container (e.g. Novapak) • Transport to treatment facility • Treat by vitrification • Package residual HAW (treatment by-products) into $3m^3$ boxes • Transport to site • *Long-term storage* • Transport • Final management **Manage contaminated $3m^3$ boxes** • Size reduce. • Package into HHISOs. • Transport for recycling • Recycle	**Storage** • *Store in ILW Store until reactor decommissioning phase* **Waste retrieval and processing** • Design, build and commission $3m^3$ box emptying & sorting facility • Cross-site transport to emptying & sorting facility • Retrieve from $3m^3$ boxes and sort magnox from non-magnox waste **Manage magnox** • Package into 200l drums • Load 200l drums into FHISOs • Transport FHISOs to third party facility • Super-compact drums into pucks • Load into HHISOs • Transport to LLWR • Dispose **Manage non-magnox waste** • Package according to prevailing site HAW strategy[16] • Cross-site transport to encapsulation facility • Encapsulate • Cross-site transport to ILW Store • *Long-term storage* • Transport • Final management **Manage contaminated $3m^3$ boxes** • Size reduce. • Package into HHISOs. • Transport for recycling • Recycle	**Storage** • *Store in ILW Store until reactor decommissioning phase* **Waste retrieval and processing** • Retrieve and containerise remaining in-bunker waste in $3m^3$ boxes • Cross-site transport to ILW Store • *Store in ILW Store (until reactor decommissioning phase)* **Manage all waste** • Design, build and commission $3m^3$ box emptying facility with 200l drum loading and export capability • Cross-site transport to box emptying facility • Retrieve from $3m^3$ boxes • Package into 200l drums • Load into suitable transport container (e.g. Novapak) • Transport to treatment facility • Treat by thermal treatment • Package residual HAW (treatment by-products) into $3m^3$ boxes • Transport to site • *Long-term storage* • Transport • Final management **Manage contaminated $3m^3$ boxes** ○ Size reduce. ○ Package into HHISOs. ○ Transport for recycling ○ Recycle

(storage phases are shown in italics for ease of identification)

[16] Encapsulation in reused $3m^3$ packages using existing site plant currently assumed

APPENDIX C: SELECTION OF ATTRIBUTES

Safety Attributes

Attribute (Safety)	Description	Included / Excluded
S1: Worker Dose	As appropriate, the individual and / or collective planned worker dose due to: o the operations required by the option; o radiation shine from nearby plant or facilities not involved in the option; o off-site transport of radioactive wastes or materials (including during loading/unloading, monitoring and transit); and/or o any other worker exposure routes as may be applicable.	Included
S2: Public Dose: Site Discharges and Shine	The dose received by members of the public under normal (non-fault) conditions associated with: o permitted discharges to air, sea, river, or any other surface water body; and/or o direct shine from site facilities.	Included though doses due to discharges are accounted for in assessment of E4
S3: Public Dose: Site Land Condition	The dose received by members of the public associated with the on-site disposal of solid radioactive wastes and/or from radioactively contaminated ground, including: o doses from non-disruptive, expected source-pathway-receptor linkages, e.g. consumption of water from any groundwater extractions that are impacted; o doses arising from human intrusion events (after the cessation of regulatory controls), including short-term exposure during the undertaking of the intrusive works and long-term exposure from the use of any excavated materials; o doses following disruption by natural processes such as coastal erosion.	Excluded – all disposals are assumed to be off-site
S4: Public Dose: Transport	The dose received by members of the public under normal (non-fault) conditions associated with direct shine from vehicles on public roads transporting radioactive wastes or materials.	Included
S5: Conventional Risk to Workers: Immediate Impacts	The non-radiological risks to workers associated with: o construction & demolition works; o maintenance works; o working at height or underwater, or with heavy lifting operations etc.; o proximity to processes involving high temperatures & high pressures; o working with hazardous chemicals, materials or wastes (e.g. strong acids, toxic chemicals or highly flammable chemicals) which may have immediate and significant non-radiological health consequences in the event of an accident or spillage; o off-site transport (related to off-site vehicle-km travelled); and o other hazardous tasks as may be applicable.	Included
S6: Conventional Risk to Workers: Delayed Impacts	The risks due to working with hazardous chemicals, materials or wastes (e.g. asbestos) which may have significant non-radiological health consequences in the future.	Excluded – this attribute is not relevant to this study
S7: Conventional Risk to the Public: Site Land Condition	The non-radiological harm (or potential harm) to members of the public associated with the on-site disposal of solid wastes and/or from contaminated ground. See S3 for potential pathways / processes by which harm could be initiated.	Excluded – all disposals are assumed to be off-site
S8: Conventional Risk to the Public: Traffic Accidents	The (collective) risk to members of the public from road traffic accidents (related to off-site vehicle-km travelled).	Included
S9. Reliance on Active Systems and/or Prompt Human Intervention	The degree of reliance on active (energised) systems and / or prompt human intervention to maintain safety.	Excluded – passive safety assumed to be possible for storage periods
S10: Time to Significant Hazard Reduction	The time before the risk associated with high hazard wastes or plant etc. is significantly reduced or eliminated.	Included
S11: Novelty / Lack of Prior Use	The conventional and/or radiological risks of implementing an option that is novel (if not adequately covered by other attributes above).	Included

Environment, Waste and Sustainability Attributes

Attribute (Environment etc.)	Description	Included / Excluded
E1. Volume of Radioactive Waste for Disposal	The volume of solid VLLW, LLW and/or ILW to be disposed of off-site. The volume of waste for off-site disposal can be used as a surrogate for physical impacts on or near off-site facilities (e.g. impact on the physical remaining capacity at the facility concerned, or disturbance at off-site facilities).	Included
E2. Activity of Radioactive Waste for Disposal	The activity of radioactive waste to be disposed of off-site. This attribute can be used as a surrogate for the radiological impacts on people and the environment near off site facilities.	Included
E3. Volume of Hazardous Waste for Disposal	The volume / type of hazardous waste to be disposed off-site.	Excluded – not relevant to this study.
E4. Radiological Impacts on the Environment: Discharges	The radiological environmental impacts of radioactive gaseous and/or aqueous discharges *via* permitted routes.	Included
E5: Radiological Impacts on the Environment: Site Land Condition	The radiological environmental impacts associated with the dispersal of radioactivity from on-site disposals of solid radioactive wastes and/or from radioactively contaminated ground. Dispersal may be, for example, *via* groundwater or engineered drainage features to surface waters.	Excluded – all disposals are assumed to be off-site and no radiological impacts are expected from interim / long-term storage
E6. Non-Radiological Impacts on the Environment: Discharges	The non-radiological environmental impacts of gaseous and/or aqueous discharges *via* permitted routes. Matters to consider could include nitrous oxides or other pollutants released to air, and nitrates, metals or organics discharged to surface waters, depending on the matter being assessed and the options.	Included
E7: Non-Radiological Impacts on the Environment: Site Land Condition	The non-radiological environmental impacts associated with the dispersal of contaminants from on-site disposals of solid wastes and/or from contaminated ground. Dispersal may be, for example, *via* groundwater or engineered drainage features to surface waters. Changes to pH levels in the water environment (including groundwater) should be among the considerations if relevant.	Included
E8. Materials	The use or loss of materials including: o new materials (concrete, steel etc.) which, because of how they are used, are unrecoverable (cannot be recycled); and/or o potentially recyclable materials already present or in use that are disposed of.	Included
E9. Disturbances	The disturbance (noise; visual; vibration) to people and the environment (birds etc.) including from construction & demolition type activities and from vehicle movement intensity / duration.	Included
E10. Energy Use	Energy use associated with “industrial” processes.	Included
E11. Waste-miles	A measure of the volume of waste and the distances it travels between its point of origin and its management location(s).	Included
E12. Loss of Amenity Value	This attribute reflects the extent to which an option results in a reduction in the amenity value (public enjoyment) of a location, historical building, viewpoint, natural feature (e.g. beach) etc.	Excluded- not considered to be relevant to this study

Technical Attributes

Attribute (Technical)	Description	Included / Excluded
T1. Development Risk	This attribute reflects the risk that the technology within an option will not be available on the timescales required, if at all.	Included
T2. Risk to Technical Cases	The vulnerability of the options to changes in data, assumptions or required standards in respect of: o the Nuclear Safety Case; o the Environmental Safety Case; o the (off site) Transport Case; and/or o the Disposability Case.	Included
T3. Deployment Difficulty	This attribute reflects how difficult the option is to install, operate, maintain and decommission.	Included
T4. Competition for Use of Shared Assets	The potential for competition for use of other site assets including facilities, land and space within buildings.	Included
T5. Risk of Failure to Meet Project Technical Objectives	The confidence (or lack of) in the option to deliver what is required, i.e. to deliver what would be the project technical objectives when implementing the options.	Included
T6. Long-Term Risk of Unplanned Intervention	The long-term risk that unplanned remedial action will be required to maintain safety, environmental or other forms of compliance.	Included
T7. Impact of Loss of Corporate Records / Memory	The consequence of loss of records / loss of corporate memory.	Included

Socio-Economic Attributes

Attribute (Socio-Economic)	Description	Included / Excluded
SE1. Cost	Total lifecycle costs of each option including (as relevant) development & design, construction, commissioning, operating, decommissioning, and waste management costs.	Included.
SE2. Impacts on Local Infrastructure	The potential for the option to impact on the operation of off-site, non-nuclear infrastructure.	Excluded – not relevant to this project
SE3. Future Burden	Future works required until the waste, facility or land concerned ceases to require any such further works.	Included
SE4. Duration of Restricted Land Use	The period of time over which there would or may be restrictions on land use, when alternative land uses may otherwise have been sought.	Excluded – not relevant to this project

APPENDIX D: ASSESSMENT DATA

The following data have been used for this assessment and originate from a variety of sources, which are quoted where relevant, and estimates (see project file for cost breakdown).

Waste volume and container loadings

Waste Portion	Volume	$3m^3$ box equivalent	200l drum equivalent	FHISO equivalent	HHISO equivalent (compacted)
Bunker 1 in-bunker and retrieved waste (total)	595 m^3 [30]	210 (ref RWI)	n/a	n/a	n/a
Bunker 1 in-bunker waste (total)	284 m^3 (calculated[17])	100 (assumed[18])	1418	n/a	n/a
Bunker 1 in-bunker waste (magnox)	268 m^3 (calculated)	n/a	1343 (calculated[19])	20 (calculated[20])	10 (calculated[21])
Bunker 1 in-bunker waste (non-magnox)	16 m^3 (calculated)	6 (calculated)	n/a	n/a	n/a
Bunkers 2-5 waste (total)	1659 m^3 [30]	890 (ref RWI)	n/a	n/a	n/a
Bunkers 2-5 (graphite)	1496 m^3 [30]	n/a	7479 (calculated[19])	107 (calculated[20])	n/a
Bunkers 2-5 (non-graphite)	164 m^3 [30]	88 (calculated)	n/a	n/a	n/a

Option parameters

Option	Available from	Volume reduction	Distance from site
At-depth disposal	After 2080	n/a	20 miles ('near-site')
At-surface disposal (LLWR)	Now	n/a	180 miles (LLWR)
Super-compaction	Now	4:1	475 miles (Winfrith)
Gasification	Before 2070	20:1	175 miles (Sellafield)
Dissolution	Now + 5 years	20:1	On-site
Vitrification	After 2030	3:1[22]	175 miles (Sellafield)
Metal recycling	Now	n/a	180 miles

[17] Figures proportioned from total volume, 100/210

[18] SAWB retrieval project roughly at 110 boxes containerised at May 2021

[19] This loading is based on a 100% fill and acknowledged to be highly optimistic

[20] 70 drums per FHISO

[21] 140 compacted drums per HHISO

[22] Although the waste volume reduction is much greater than this, the lost crucible process appears to result in an approximately 3:1 reduction in $3m^3$ box numbers (based on optimistic projections).

Option-specific container estimates

Management Options for Bunkers 2-5

G1. Encapsulate then store for at-depth disposal	G2. Store then sort and treat by gasification
Manage all waste 1659 m^3 890 3m^3 boxes	Manage graphite 1496 m^3 waste 7479 200l drums 107 FHISOs 44 3m^3 boxes for residual HAW
	Manage non-graphite waste 164 m^3 waste 88 3m^3 boxes
	Manage contaminated 3m^3 boxes 40 HHISOs[23]

Management Options for Bunker 1 – in-bunker waste only

M1. Encapsulate then store for at-depth disposal	M2. Sort and decay store then encapsulate for at surface disposal (LLWR)	M3. Sort and treat by dissolution	M4. Re-package and store then treat by vitrification	M5. Store then sort and encapsulate for at surface disposal (LLWR)	M6. Store then re-package and treat by vitrification
Manage all waste 284 m^3 100 3m^3 boxes	Manage magnox 268 m^3 waste 1343 200l drums 20 FHISOs 10 HHISOs	Manage magnox 268 m^3 waste 1343 200l drums 5 3m^3 boxes for residual HAW	Manage all waste 284 m^3 waste 1418 200l drums 178 Novapaks[24] 29 3m^3 boxes for residual HAW	Manage magnox 268 m^3 waste 1343 200l drums 20 FHISOs 10 HHISOs	Manage all waste 284 m^3 waste 1418 200l drums 178 Novapaks[24] 29 3m^3 boxes for residual HAW
	Manage non-magnox waste 16 m^3 waste 6 3m^3 boxes	Manage non-magnox waste 16 m^3 waste 6 3m^3 boxes		Manage non-magnox waste 16 m^3 waste 6 3m^3 boxes	Manage contaminated 3m^3 boxes 5 HHISOs[25]
				Manage contaminated 3m^3 boxes 5 HHISOs[25]	

Management Options for Bunker 1 – in-bunker waste only

Not calculated (see Section 5.3).

[23] 802 empty boxes with assumed loading of 20 size-reduced boxes per HHISO (~40) (this loading appears reasonable, based on a ~32,000kg HHISO load capacity, ~900kg mass of each box, and accounting for furniture within the HHISO).

[24] 8 200l drums per Novapak transport assumed (comprising two Novapak transport packages)

[25] 100 empty boxes with assumed loading of 20 size-reduced boxes per HHISO (5)

Third Party Service Cost Assumptions

Activity	Cost	Per
At-depth disposal	£35,000	$3m^3$ box[26]
At-surface disposal (LLWR)	£85,000	HHISO
Super-compaction and management to disposal (with storage)	£2,188	Drum[27]
Super-compaction and management to disposal (no storage)	£1,250	Drum[27]
Gasification	£735	Drum[28]
Vitrification	£735	Drum[28]
FHISO or HHISO transport	£1,500	transport
SWTC transport	£1,500	transport
Novapak transport	£1,500	transport

Facility Cost and Schedule Assumptions

Facility	Capital cost	Comment
Sorting and 200l loading drum facility	£4.5M	This facility would be in an enclosure within the SAWB. Cost based on Bradwell waste transfer facility.
$3m^3$ box emptying and 200l drum loading facility	£50M	This facility would require a new structure, foundations, etc. Cost based on Berkeley waste retrieval module.
Dissolution and abatement facility	£100M	These facilities would be new. Cost based on Bradwell dissolution and abatement facilities.
Gasification	n/a	Provided by others.
Vitrification	n/a	Provided by others.

Container Costs

Container	Purchase price
$3m^3$ box	£13,946
HHISO	£13,300
200l drum	£51
200l drum stillage	£1,900

[26] Based on GDF disposal costs for 3m3 boxes, from NDA cost calculator v.4.2.

[27] Based on total management fees for drums of magnox from Bradwell (which includes super-compaction, storage, HHISO packaging and transport but not disposal costs).

[28] Based on quote for incineration of magnox (£4.1M for 5,579 drums). Probably optimistic.

Assumptions for Discharge Assessments

Option	Processing/treatment steps for discharge calcs	Happens when	Lasts how long
G1. Encapsulation for interim storage then at-depth disposal	Encapsulation of all waste from B2-5	2024	2.5y
G2. Deferred retrieval and sorting for gasification	Gasification of graphite from B2-5	2070	4y
	Encapsulation of non-graphite waste from B2-5	2075	0.5y
M1. Encapsulation for interim storage then at-depth disposal	Encapsulation of all waste from B1*	2023	0.5y
M2. Prompt retrieval and sorting for decay storage then encapsulation and at-surface disposal (LLWR)	Encapsulation of magnox from B1 (at LLWR)*	2030	0.5y
	Encapsulation of non-magnox waste from B1*	2025	0.1y
M3. Prompt retrieval and sorting for dissolution	Dissolution of magnox from B1*	2028	3y
	Encapsulation of non-magnox waste from B1*	2025	0.1y
M4. Prompt retrieval and sorting for storage then vitrification	Vitrification of all waste from B1*	2040	1y
M5. Deferred retrieval and sorting for encapsulation and at-surface disposal (LLWR)	Encapsulation of magnox from B1 (at LLWR)*	2075	0.5y
	Encapsulation of non-magnox waste from B1*	2075	0.1y
M6. Deferred retrieval and sorting for vitrification	Vitrification of all waste from B1*	2075	1y

* Assessments made for in-bunker portion only (see Section 5.3).

APPENDIX E: ASSESSMENT AGAINST THE SELECTED ATTRIBUTES

The following scheme has been used to assess the options against each of the attributes selected in Appendix C:

- **Red** is allocated where the performance of the option on that issue is significantly worse than at least one other option.
- Amber is allocated where the options is clearly, but not significantly, worse than at least one other option.
- **Green** is allocated in other cases.

Assessment of Management Options for Bunkers 2 – 5

The following table compares the attributes between each management option given the assumed steps shown in Appendix B:

Attribute	G1. Encapsulation for interim storage followed by at-depth disposal	G2. Deferred sorting for treatment by gasification
S1: Worker Dose	Most significant steps for worker dose: • Cross-site transports to SILWE (890 movements) • Cross-site transport to ILW Store (890 movements) • Transport to NSD facility (890 movements) Less significant worker doses associated with remote working operations, assumed to be encapsulation, storage and NSD.	Most significant steps for worker dose: • Cross-site transports to 3m³ box emptying facility (890 movements) • **Manage graphite:** ○ Load 200l drums into FHISOs (7479 drums) ○ Transport to treatment facility (107 movements) ○ Transport of HAW by-products to site (44 movements) ○ Cross-site transport to ILW Store (44 movements) ○ Transport of HAW by-products for final management (44 movements) • **Manage all other bunkers waste:** ○ Cross-site transport to encapsulation plant (88 movements) ○ Cross-site transport to ILW Store (88 movements) ○ Transport for final management (88 movements) • **Manage contaminated 3m³ boxes:** ○ Size reduce (802 boxes) ○ Package into HHISOs (40 HHISOs) ○ Transport size reduced 3m³ boxes for recycling (40 movements) ○ Recycle (802 boxes) Less significant worker doses associated with remote working operations, assumed to be storage, box emptying and waste sorting, thermal treatment, packaging by-products, storage of by-products, and final management.
S2: Public Dose: Site Discharges and Shine *No data or clear rationale for asserting that an option is better or worse than another*	Shine from facilities: • SILWE (890 packages) • ILW Store (890 packages to NSD) Site discharges: • SILWE (negligible) • ILW Store (negligible)	Shine from facilities: • ILW Store (890 packages to reactor decommissioning phase / NSD available) • Encapsulation plant (44 + 88 packages) • ILW Store (44 + 88 packages long-term) • Retrieval & sorting facility • FHISO loading facility Site discharges: • ILW Store (negligible) • Encapsulation plant (negligible) • Retrieval & sorting facility (negligible)
S4: Public Dose: Transport	Summary of rad transports (890 consignments): • 890 transports to NSD facility using heavily shielded SWTC	Summary of rad transports (323 consignments): • 107 transports to treatment facility using FHISOs • 44 transports to site for long-term storage using heavily shielded SWTC • 132 transports for final management using heavily shielded SWTC • 40 HHISO transports
S5: Conventional Risk to Workers: Immediate Impacts	Risks posed by: • Operation of existing facilities • Use of cementitious grout (greatest amount handled with this option)	Risks posed by: • Operation of existing facilities • Construction of 3m³ box emptying and sorting facility • Operation of emptying and sorting facility incl. 3m³ box and 200l / FHISO loading and export • **High temperature process poses greater inherent hazard than encapsulation** • Use of cementitious grout
S8: Conventional Risk to the Public: Traffic Accidents	Total 890 radwaste consignments Additional transports required for importing: • grout for encapsulation of 890 3m³ boxes	Total 323 radwaste consignments Additional transports required for importing: • containers to site (7479 200l drums, 107 FHISOs, 40 HHISOs) • grout for encapsulation of 44+88 3m³ boxes • materials for construction of the 3m³ box emptying and sorting facility • removal of facility decommissioning / demolition wastes
S10: Time to Significant Hazard Reduction *RAG rationale: time to passivation/treatment basis for scoring*	All waste passivated (encapsulated) promptly and disposed following interim storage (ca. 80 years passivated storage).	**Waste not passivated for ca. 50 years:** • All waste stored 'raw' for ca. 50 years. • Graphite treated (thermal) following storage with treatment by-products passivated (encapsulated) promptly and finally managed following long-term storage (up to 300 years passivated storage). • All other bunkers waste passivated (encapsulated) following processing and finally managed following long-term storage (up to 300 years passivated storage).
S11: Novelty / Lack of Prior Use	Proven management route/techniques.	**Very novel, not proven beyond small scale trials.**
E1: Volume of Radioactive Waste for Disposal	**No volume reduction.**	Significant volume reduction.

Attribute	G1. Encapsulation for interim storage followed by at-depth disposal	G2. Deferred sorting for treatment by gasification
E2. Activity of Radioactive Waste for Disposal	Total activity disposed of.	Some reduction in total activity due to discharges from treatment. Activity otherwise disposed of / finally managed in a concentrated form.
E4. Radiological Impacts on the Environment: Discharges	Estimated total dose due to discharges: • 2.8E-01 µSv/y airborne from encapsulation of all waste. See Appendix H.	Estimated total dose due to discharges: • 1.3E+01 µSv/y airborne from gasification of graphite • 1.9E-01 µSv/y airborne from encapsulation of all other bunkers waste See Appendix H.
E6. Non-Radiological Impacts on the Environment: Discharges	Negligible discharges though with cement dust risk.	CO_2 discharges expected but assumed to be minimised through carbon capture. Benefit from reduced use of SILWE, lower cement dust risk.
E7: Non-Radiological Impacts on the Environment: Site Land Condition	No additional impact to site baseline.	Site land condition impacted by probable on-site disposal of 3m^3 box emptying facility foundations.
E8. Materials	Materials needed for: • grout for encapsulation of 890 3m^3 boxes • 890 3m^3 boxes	Materials needed for: • new containers (7479 200l drums) • grout for encapsulation of 88 3m^3 boxes • 88 3m^3 boxes • foundations for 3m^3 box emptying facility • gasification feedstock materials (it is assumed that materials for the construction of the 3m^3 box emptying and sorting facility are recoverable)
E9. Disturbances	No new facilities	New box emptying and sorting facility
E10. Energy Use	No energy intensive processes used	High temperature process, highly energy intensive (incl. graphite crushing)
E11. Waste-miles *Assumptions:* *NSD facility is near-site (20 miles assumed)* *LLWR and recycling facilities are 180 miles away* *Treatment site is 175 miles away* *Final management is near-site (20 miles assumed)*	Waste transports: • 890 transports to NSD facility Total 17,800 waste miles	Waste transports: • 107 transports to treatment facility • 44 transports to site for long-term storage • 132 transports for final management • 40 transports to recycling facility Total 37,020 waste miles
T1. Development Risk	Negligible risk that a disposal facility will never become available – a disposal capability is needed in Scotland.	**Credible risk that graphite treatment technology will never become available**, though there is momentum behind developing the technology (for treating reactor core graphite).
T2. Risk to Technical Cases	Management through to disposal uses well established technologies / practice though WAC for disposal are not yet established and there is a risk that disposal criteria cannot be demonstrated. No known LoC issues.	A safety case for storing non-passivated waste is expected to be possible. Management through to treatment uses well established technologies / practice though WAC for treatment are not yet established. Unknown impact on off-site facility cases. **It is not anticipated that NSD WAC could be met for waste remaining following processing or treatment**, though this would be subject to further work. Technical cases supporting long-term storage are unknown. No known LoC issues.
T3. Deployment Difficulty	Involves relatively simple steps to implement at site.	Involves relatively simple steps to implement at site, though there are a greater number of steps. (off-site difficulty with treatment facility is out of scope of assessment)
T4. Competition for Use of Shared Assets	No conflict envisaged (the site is set up to deliver this option).	**Conflict likely to arise with reactor decommissioning works** due to the need for an area for 3m^3 emptying and sorting facility. Conflict likely to arise with competition for use of encapsulation facility.
T5. Risk of Failure to Meet Project Technical Objectives	The option is likely to meet the technical objectives.	Confidence that the technical objectives would be met is affected due to uncertainty with the management requirements for waste remaining following processing or treatment.
T6. Long-Term Risk of Unplanned Intervention	Minimal risk, encapsulated waste storage is a well underpinned concept.	Some risk with raw storage period though expected to be manageable. Some risks will be presented by the long-term storage phase though this will follow an established (passivated) management concept.
T7. Impact of Loss of Corporate Records / Memory	Although records management is assured via the LoC process there is some risk that this information does not fully support NSD and other information will have been lost.	Some risk that records / memory will be lost during the storage phase but could be generated during sort/seg and treatment. There is a fair risk that the retained information does not fully support final management beyond long-term storage.
SE1. Cost *Cost estimates for capital expenses and third-party services*	Significant capital expenses / fees: • transport fees (890 SWTC transports) • disposal fees (890 3m^3 packages for NSD disposals) **Cost estimate: £32,500,000**	Significant capital expenses: • new containers (7479 200l drums) • 3m^3 box emptying and sorting facility • transport fees (107 FHISO, 40 HHISO transports, 88 + 2x44 SWTC transports) • treatment fees (1,495 m^3 graphite to process) • final management fees (132 3m^3 packages) **Cost estimate: £65,000,000**

Attribute	G1. Encapsulation for interim storage followed by at-depth disposal	G2. Deferred sorting for treatment by gasification
SE3. Future Burden	The waste would largely be managed by the current generation. At-depth disposal would be performed by a future generation (though the waste will have already been packaged and encapsulated).	**The waste would largely be managed by a future generation.** Treatment would be performed by a future generation. Management of waste remaining following processing and treatment would fall to future generations (long-term storage), the requirements of which are unknown.

Assessment of Management Options for Bunker 1 (In-Bunker Waste Only)

The following table compares the attributes between each management option given the assumed steps. The data for this table assumes that 110 boxes have been retrieved, with 100 'boxes worth' of waste remaining in the bunker; the data have been scaled accordingly from the bunker totals. **To clarify: these numbers only account for the in-bunker portion of the waste.**

Attribute	M1. Encapsulation for interim storage followed by at-depth disposal	M2. Prompt retrieval and sorting for decay storage followed by at-surface disposal (LLWR)	M3. Prompt retrieval and sorting for treatment by dissolution	M4. Prompt retrieval and storage for treatment by vitrification when available	M5. Prompt retrieval and deferred sorting for at-surface disposal (LLWR)	M6. Prompt retrieval, containerisation & storage for deferred treatment by vitrification
S1: Worker Dose	Most significant steps for worker dose: • Cross-site transports to ILW Store (100 movements) • Cross-site transports to SILWE (100 movements) • Cross-site transport to ILW Store (100 movements) • Transport to NSD facility (100 movements) Less significant worker doses associated with remote working operations, assumed to be retrieval, containerisation, encapsulation, storage and NSD.	Most significant steps for worker dose: • **Manage magnox**: o Load 200l drums into FHISOs (1343 drums) o Transport FHISOs to third party facility (20 movements) o Super-compact (1343 drums) o Load into HHISOs (1343 pucks) o Transport to LLWR (10 movements) o Encapsulate (10 HHISOs) o Dispose (10 HHISOs) • **Manage all other bunkers waste**: o Cross-site transport to SILWE (6 movements) o Cross-site transport to ILW Store (6 movements) o Transport for final management (6 movements) Less significant worker doses associated with remote working operations, assumed to be retrieval, packaging, 3m^3 box encapsulation, storage and 'final management'.	Most significant steps for worker dose: • **Manage magnox**: o Transfer 200l drums to dissolution plant (1343 drums) o Cross-site transport HAW by-products (in 3m^3 boxes) to SILWE/WILWREP (5 movements) o Cross-site transport to ILW Store (5 movements) o Transport for final management (5 movements) • **Manage all other bunkers waste:** o Cross-site transport to SILWE (6 movements) o Cross-site transport to ILW Store (6 movements) o Transport for final management (6 movements) Less significant worker doses associated with remote working operations, assumed to be retrieval, packaging, dissolution, management of by-products, 3m^3 box encapsulation, storage, and 'final management'.	Most significant steps for worker dose: • Load into stillages (1418 drums) • Cross-site transport to ILW Store (355 movements) • Load 200l drums into Novapaks (1418 drums) • Transport to treatment facility (178 movements) • Transport HAW by-products to site (29 movements) • Transport for final management (29 movements) Less significant worker doses associated with remote working operations, assumed to be retrieval, packaging, thermal treatment, management of by-products, 3m^3 box encapsulation, storage, and 'final management'. N.B. modification of ILW Store assumed not to be invasive, e.g. stillage designed to interface with existing configuration.	Most significant steps for worker dose: • Cross-site transport to ILW Store (100 movements) • Cross-site transport to retrieval & sorting facility (100 movements) • **Manage magnox**: o Load 200l drums into HHISOs (1343 drums) o Transport HHISOs to third party facility (38 movements) o Super-compact (1343 drums) o Load into HHISOs (1343 pucks) o Transport to LLWR (10 movements) o Encapsulate (10 HHISOs) o Dispose (10 HHISOs) • **Manage all other bunkers waste**: o Cross-site transport to SILWE (6 movements) o Cross-site transport to ILW Store (6 movements) o Transport for final management (6 movements) • **Manage contaminated 3m^3 boxes**: o Size reduce (100 boxes) o Package into HHISOs (5 HHISOs) o Transport for recycling (5 movements) o Recycle (5 HHISOs) Less significant worker doses associated with remote working operations, assumed to be retrieval, packaging, 3m^3 box encapsulation, storage, and 'final management'.	Most significant steps for worker dose: • Cross-site transport to ILW Store (100 movements) • Cross-site transport to retrieval & sorting facility (100 movements) • **Manage waste**: o Load 200l drums into Novapaks (1418 drums) o Transport to treatment facility (178 movements) o Transport HAW by-products to site (29 movements) o Transport for final management (29 movements) • **Manage contaminated 3m^3 boxes**: o Size reduce (100 boxes) o Package into HHISOs (5 HHISOs) o Transport for recycling (5 movements) o Recycle (5 HHISOs) Less significant worker doses associated with remote working operations, assumed to be retrieval, packaging, thermal treatment, management of by-products, 3m^3 box encapsulation, storage, and 'final management'. N.B. modification of ILW Store assumed not to be invasive, e.g. stillage designed to interface with existing configuration.
S2: Public Dose: Site Discharges and Shine *Other than for dissolution (which would certainly increase site discharges), no data or clear rationale for asserting that an option is better or worse than another* *Note: Not considering discharges or shine from off-site facilities*	Shine from facilities: • SAWB • ILW Store (100 packages) • SILWE (100 packages) Site discharges: • ILW Store (negligible) • SILWE (minimal)	Shine from facilities: • SAWB • 200l drum/FHISO facility • ILW Store (6 packages) • SILWE (6 packages) Site discharges: • SILWE (negligible) • ILW Store (negligible)	Shine from facilities: • SAWB • Dissolution facility • Packaging facility • SILWE/WILWREP (11 packages) • ILW Store (11 packages) Site discharges: • Dissolution (see Appendix H) • SILWE (negligible) • ILW Store (negligible)	Shine from facilities: • SAWB • 200l drum/Novapak facility • ILW Store (29 packages) Site discharges: • ILW Store (negligible)	Shine from facilities: • SAWB • 200l drum/FHISO/LLW facility • SILWE (6 packages) • ILW Store (6 packages) Site discharges: • SILWE (negligible) • ILW Store (negligible)	Shine from facilities: • SAWB • 200l drum/Novapak/LLW facility • ILW Store (29 packages) Site discharges: • ILW Store (negligible)

Attribute	M1. Encapsulation for interim storage followed by at-depth disposal	M2. Prompt retrieval and sorting for decay storage followed by at-surface disposal (LLWR)	M3. Prompt retrieval and sorting for treatment by dissolution	M4. Prompt retrieval and storage for treatment by vitrification when available	M5. Prompt retrieval and deferred sorting for at-surface disposal (LLWR)	M6. Prompt retrieval, containerisation & storage for deferred treatment by vitrification
S4: Public Dose: Transport	Summary of rad transports (100 consignments): • 100 transports to NSD facility using heavily shielded SWTC	Summary of rad transports (36 consignments): • 20 transports to compaction facility using FHISOs • 10 transports to LLWR in HHISOs • 6 transports for final management using heavily shielded SWTC	Summary of rad transports (16 consignments): • 6 transports for final management using heavily shielded SWTC • 5 transports for final management using heavily shielded SWTC	Summary of rad transports (236 consignments): • 178 transports to treatment facility using Novapaks • 29 transports to site for long-term storage using heavily shielded SWTC • 29 transports for final management using heavily shielded SWTC	Summary of rad transports (59 consignments): • 20 transports to compaction facility using FHISOs • 10 transports to LLWR in HHISOs • 5 HHISO transports for recycling • 6 transports for final management using heavily shielded SWTC	Summary of rad transports (241 consignments): • 178 transports to treatment facility using HHISOs • 29 transports to site for long-term storage using heavily shielded SWTC • 5 HHISO transports for recycling • 29 transports for final management using heavily shielded SWTC
S5: Conventional Risk to Workers: Immediate Impacts *RAG rationale: inherent high hazard activities penalised*	Risks posed by: • Operation of existing facilities • Use of cementitious grout (greatest amount handled with this option)	Risks posed by: • Operation of existing facilities • Construction of sorting facility • Operation of sorting facility incl. 200l loading and export • Use of cementitious grout	Risks posed by: • Operation of existing facilities • Construction of sorting facility • Construction of dissolution and abatement facilities • Construction of packaging facility • Operation of above facilities where low concentration acid is assumed (no significantly inherent hazard increase above encapsulation). • Use of cementitious grout	Risks posed by: • Operation of existing facilities • Construction of 200l / Novapak loading facility • Operation of 200l / Novapak loading and export • **High temperature process poses greater inherent hazard than encapsulation.**	Risks posed by: • Operation of existing facilities • Construction of 3m3 box emptying and 200l drum export facility • Operation of box emptying, packaging and export facility • Contaminated box management • Use of cementitious grout	Risks posed by: • Operation of existing facilities • Construction of 3m3 box emptying and 200l drum / Novapak facility • Operation of box emptying, packaging and export facility • **High temperature process poses greater inherent hazard than encapsulation.** • Contaminated box management • Use of cementitious grout

S8: Conventional Risk to the Public: Traffic Accidents
RAG rationale: dissolution penalised for transports for facility construction / demolition, all other options viewed as comparable
Note: Transports for construction / import of materials to off-site facilities not accounted for
	Total 100 radwaste consignments
	Additional transports required for importing:
	• containers to site (100 $3m^3$ boxes)
	• grout for encapsulation of 100 $3m^3$ boxes
		Total 36 radwaste consignments
		Additional transports required for importing:
		• containers to site (1343 200l drums, 20 FHISOs and 6 $3m^3$ boxes)
		• grout for encapsulation of 6 $3m^3$ boxes
		• materials for construction of the sorting facility
		• removal of facility decommissioning / demolition wastes
			Total 16 radwaste consignments
			Additional transports required for importing:
			• containers to site (1343 200l drums, 20 FHISOs and 11 $3m^3$ boxes)
			• grout for encapsulation of 11 $3m^3$ boxes
			• materials for construction of three facilities:
			  ○ sorting facility
			  ○ dissolution and abatement facility
			  ○ HAW packaging facility
			• removal of facility decommissioning / demolition wastes
				Total 236 radwaste consignments
				Additional transports required for importing:
				• containers to site (1418 200l drums, 178 Novapak deliveries)
				• new stillages to site (355 stillages)
				• materials for construction of the sorting facility
				• removal of facility decommissioning / demolition wastes
					Total 59 radwaste consignments
					Additional transports required for importing:
					• containers to site (1343 200l drums, 20 FHISOs, 5 HHISOs and 6 $3m^3$ boxes)
					• grout for encapsulation of 6 $3m^3$ boxes
					• materials for construction of the $3m^3$ box emptying and sorting facility
					• removal of facility decommissioning / demolition wastes
						Total 241 radwaste consignments
						Additional transports required for importing:
						• containers to site (1418 200l drums, 178 Novapak deliveries, 5 HHISOs)
						• materials for construction of the $3m^3$ box emptying and sorting facility
						• removal of facility decommissioning / demolition wastes

S10: Time to Significant Hazard Reduction *RAG rationale: time to passivation/treatment basis for scoring*	All waste passivated (encapsulated) promptly and disposed following interim storage (ca. 80 years passivated storage).	Magnox passivated (encapsulated) and disposed following decay storage (ca. 20 years raw storage). All other waste passivated (encapsulated) promptly and finally managed following long-term storage (up to 300 years passivated storage).	Magnox treated (dissolution) promptly. Dissolution by-products passivated (encapsulated) promptly and finally managed following long-term storage (up to 300 years passivated storage). All other waste passivated (encapsulated) promptly and finally managed following long-term storage (up to 300 years passivated storage).	Magnox treated (vitrified) following storage period (ca. 10 years raw storage). Treatment by-products passivated (vitrified) promptly and finally managed following long-term storage (up to 300 years passivated storage).	Magnox passivated (encapsulated) and disposed during reactor decommissioning phase (ca. 50 years raw storage) All other waste passivated (encapsulated) promptly and finally managed following long-term storage (up to 300 years passivated storage).	Magnox treated (vitrified) following storage period (ca. 50 years raw storage). Treatment by-products passivated (vitrified) promptly and finally managed following long-term storage (up to 300 years passivated storage).
S11: Novelty / Lack of Prior Use	Proven management route/techniques.	Proven management route/techniques.	Proven management route/techniques.	Based on existing technology but the TRL for this process is relatively low	Proven management route/techniques.	Based on existing technology but the TRL for this process is relatively low
E1: Volume of Radioactive Waste for Disposal	No volume reduction	Compacted drums	Significant volume reduction.	Volume reduction comparable to compaction	Compacted drums	Volume reduction comparable to compaction

Attribute	M1. Encapsulation for interim storage followed by at-depth disposal	M2. Prompt retrieval and sorting for decay storage followed by at-surface disposal (LLWR)	M3. Prompt retrieval and sorting for treatment by dissolution	M4. Prompt retrieval and storage for treatment by vitrification when available	M5. Prompt retrieval and deferred sorting for at-surface disposal (LLWR)	M6. Prompt retrieval, containerisation & storage for deferred treatment by vitrification
E2. Activity of Radioactive Waste for Disposal	Total activity disposed of	Total activity disposed of / finally managed.	Some reduction in total activity due to discharges from treatment. Activity otherwise finally managed in a concentrated form.	Some reduction in total activity due to discharges from treatment. Activity otherwise finally managed in a concentrated form.	Total activity disposed of / finally managed.	Some reduction in total activity due to discharges from treatment. Activity otherwise finally managed in a concentrated form.
E4. Radiological Impacts on the Environment: Discharges	Estimated total dose due to discharges: • 2.6E-03 µSv/y airborne from encapsulation of all waste See Appendix H.	Estimated total dose due to discharges: • 6.9E-04 µSv/y airborne from encapsulation of magnox • 1.9E-03 µSv/y airborne from encapsulation of all other waste See Appendix H.	Estimated total dose due to discharges: • 7.5E-01 µSv/y airborne from dissolution of magnox • 1.5E+00 µSv/y liquid from dissolution of magnox • 5.8E-04 µSv/y airborne from encapsulation of all other waste See Appendix H.	Estimated total dose due to discharges: • 8.5E-01 µSv/y airborne from vitrification of all waste See Appendix H.	Estimated total dose due to discharges: • 6.1E-04 µSv/y airborne from encapsulation of magnox • 1.8E-03 µSv/y airborne from encapsulation of all other waste See Appendix H.	Estimated total dose due to discharges: • 4.7E-01 µSv/y airborne from vitrification of all waste See Appendix H.
E6. Non-Radiological Impacts on the Environment: Discharges *None deemed significantly worse as not data available to quantify*	Negligible discharges.	Negligible discharges.	Non-radioactive aqueous and gaseous discharges expected.	Non-radioactive gaseous discharges expected.	Negligible discharges.	Non-radioactive gaseous discharges expected.
E7: Non-Radiological Impacts on the Environment: Site Land Condition	No additional impact to site baseline.	No additional impact to site baseline.	Site land condition impacted by probable on-site disposal of new facility foundations.	No additional impact to site baseline.	Site land condition impacted by probable on-site disposal of $3m^3$ box emptying facility foundations.	Site land condition impacted by probable on-site disposal of $3m^3$ box emptying facility foundations.
E8. Materials *RAG rationale: The various container/ grout/ facility material demands are similar (no clearly worse option)*	Materials needed for: • new containers (100 $3m^3$ boxes) • grout for encapsulation of 100 $3m^3$ boxes	Materials needed for: • new containers (1343 200l drums, 10 HHISOs and 6 $3m^3$ boxes) • grout for encapsulation of 6 $3m^3$ boxes and 10 HHISOs (it is assumed that materials for the construction of the sorting facility are recoverable though some waste will be generated from this facility/process)	Materials needed for: • new containers (1343 200l drums and 11 $3m^3$ boxes) • grout for encapsulation of 11 $3m^3$ boxes (it is assumed that materials for the construction of the sorting, dissolution and abatement, and HAW packaging facilities are recoverable though some waste will be generated from these facilities/processes)	Materials needed for: • new containers (1418 200l drums and 29 $3m^3$ boxes) • vitrification crucibles and feedstock (sand etc) (it is assumed that materials for the stillages and construction of the sorting facility are recoverable though some waste will be generated from this facility/process)	Materials needed for: • new containers (1343 200l drums, 10 HHISOs and 6 $3m^3$ boxes) • grout for encapsulation of 6 $3m^3$ boxes and 10 HHISOs (it is assumed that materials for the construction of the $3m^3$ box emptying and sorting facility are recoverable though some waste will be generated from this facility/process)	Materials needed for: • new containers (1418 200l drums and 29 $3m^3$ boxes) • vitrification crucibles and feedstock (sand etc) (it is assumed that materials for the construction of the $3m^3$ box emptying and sorting facility are recoverable though some waste will be generated from this facility/process)
E9. Disturbances	No new facilities	New sorting facility	New dissolution, abatement, sorting, packaging facilities	New sorting facility	New box emptying and sorting facility	New box emptying and sorting facility
E10. Energy Use	No energy intensive processes used	No energy intensive processes used	Dissolution is an active process with an associated energy requirement though not highly intensive High demand for energy during construction	High temperature process, highly energy intensive	No energy intensive processes used	High temperature process, highly energy intensive
E11. Waste-miles *Assumptions:* *NSD facility is near-site (20 miles assumed)* *LLWR is 180 miles away*	Waste transports: • 100 transports to NSD facility Total 2000 waste miles	Waste transports: • 20 transports to compaction site using FHISOs • 10 transports to LLWR from compaction site in HHISOs • 6 transports for final management using heavily shielded SWTC	Waste transports: • 6 transports for final management using heavily shielded SWTC • 5 transports for final management using heavily shielded SWTC Total 220 waste miles	Waste transports: • 178 transports to treatment facility using Novapaks • 29 transports to site for long-term storage using heavily shielded SWTC	Waste transports: • 20 transports to compaction facility using FHISOs • 10 transports to LLWR in HHISOs • 5 HHISO transports for recycling • 6 transports for final management using heavily shielded SWTC	Waste transports: • 178 transports to treatment facility using Novapaks • 29 transports to site for long-term storage using heavily shielded SWTC • 5 HHISO transports for recycling

Attribute	M1. Encapsulation for interim storage followed by at-depth disposal	M2. Prompt retrieval and sorting for decay storage followed by at-surface disposal (LLWR)	M3. Prompt retrieval and sorting for treatment by dissolution	M4. Prompt retrieval and storage for treatment by vitrification when available	M5. Prompt retrieval and deferred sorting for at-surface disposal (LLWR)	M6. Prompt retrieval, containerisation & storage for deferred treatment by vitrification
Third-party compaction site is 475 miles away (340 miles from LLWR) *Thermal treatment site is 175 miles away* *Final management is near-site (20 miles assumed)*		Total 13,020 waste miles		• 29 transports for final management using heavily shielded SWTC Total 36,3805 waste miles	Total 13,920 waste miles	• 29 transports for final management using heavily shielded SWTC Total 37,705 waste miles
T1. Development Risk	Negligible risk that an at-depth disposal facility will never become available – a disposal capability is needed in Scotland.	An at-surface disposal facility already exists.	Dissolution is a proven technology.	Credible risk that the treatment technology will not become available.	An at-surface disposal facility already exists.	Credible risk that the treatment technology will not become available.
T2. Risk to Technical Cases *RAG rationale: For at-surface disposal options the LLWR disposal risks are additional to NSD risks (and so this performs worse than the baseline which 'just' has NSD risks). Long-term storage uncertainty is also penalised.*	Management through to disposal uses well established technologies / practice though WAC for disposal are not yet established and there is a risk that disposal criteria cannot be demonstrated. No known LoC issues.	A safety case for storing non-passivated magnox is expected to be possible. It is probable that LAW disposal criteria cannot be demonstrated for all (theoretically eligible) waste due to contaminants, e.g. pond sludge, fuel fragments / discrete items. It is not anticipated that at-depth disposal WAC could be met for waste remaining following processing, though this would be subject to further work. Technical cases supporting long-term storage are unknown. No known LoC issues.	This option uses established technologies / practice though it presents greater challenges for the site safety and environmental safety case. It is not anticipated that at-depth disposal WAC could be met for dissolution by-products, though this would be subject to further work. Technical cases supporting long-term storage are unknown. No known LoC issues.	A safety case for storing non-passivated magnox is expected to be possible. Management through to treatment uses well established technologies / practice though WAC for treatment are not yet established. Unknown impact on off-site facility cases. It is not anticipated that at-depth disposal WAC could be met for treatment by-products, though this would be subject to further work. Technical cases supporting long-term storage are unknown. No known LoC issues.	A safety case for storing non-passivated waste is expected to be possible. It is probable that LAW disposal criteria cannot be demonstrated for all (theoretically eligible) waste due to contaminants, e.g. pond sludge, fuel fragments / discrete items. It is not anticipated that at-depth disposal WAC could be met for waste remaining following processing, though this would be subject to further work. Technical cases supporting long-term storage are unknown. No known LoC issues.	A safety case for storing non-passivated waste is expected to be possible. Management through to treatment uses well established technologies / practice though WAC for treatment are not yet established. Unknown impact on off-site facility cases. It is not anticipated that at-depth disposal WAC could be met for treatment by-products, though this would be subject to further work. Technical cases supporting long-term storage are unknown. No known LoC issues.
T3. Deployment Difficulty	Involves relatively simple steps to implement.	Involves relatively simple steps to implement.	Dissolution and abatement/treatment is a relatively complex process (based on Bradwell experience).	Involves relatively simple steps to implement. (development difficulty with the treatment plant is outside of Magnox scope)	Involves relatively simple steps to implement. Requires 3m^3 box emptying facility.	Involves relatively simple steps to implement. Requires 3m^3 box emptying facility. (development difficulty with the treatment plant is outside of Magnox scope)
T4. Competition for Use of Shared Assets On-site only	No conflict envisaged (the site is set up to deliver this option).	Conflict could arise due to the need for a sorting facility and use of LLW route on-site.	Conflict likely to arise due to infrastructure requirements to enable the dissolution process. There is also a considerable risk of delaying the site's entry to C&M.	Conflict could arise due to the need for a 200l drum/Novapak facility. ILW Store capacity not threatened though increase in imports/exports will increase strain on site schedule.	Conflict likely to arise with reactor decommissioning works due to the need for an area for 3m^3 emptying and LLW route. Conflict likely to arise with competition for use of encapsulation facility.	Conflict likely to arise with reactor decommissioning works due to the need for an area for 3m^3 emptying and 200l/Novapak facility.
T5. Risk of Failure to Meet Project Technical Objectives *RAG rationale: long-term storage uncertainty is penalised in particular.*	The option is likely to meet the technical objectives.	The option is likely to meet the technical objectives.	Confidence that the technical objectives would be met is affected due to uncertainty with the management requirements for treatment by-products.	Confidence that the technical objectives would be met is affected due to uncertainty with the management requirements for treatment by-products.	The option is likely to meet the technical objectives.	Confidence that the technical objectives would be met is affected due to uncertainty with the management requirements for treatment by-products.
T6. Long-Term Risk of Unplanned Intervention	Minimal risk, encapsulated waste storage is a well underpinned concept.	Some risk with raw storage period though expected to be manageable. Some risks will be presented by the long-term storage phase though this	Minimal risk, waste will be promptly treated. Some risks will be presented by the long-term storage phase though	Some risk with raw storage period though expected to be manageable. Some risks will be presented by the long-term storage phase though this	Some risk with raw storage period though expected to be manageable. Some risks will be presented by the long-term storage phase though this	Some risk with raw storage period though expected to be manageable. Some risks will be presented by the long-term storage phase though this

Attribute	M1. Encapsulation for interim storage followed by at-depth disposal	M2. Prompt retrieval and sorting for decay storage followed by at-surface disposal (LLWR)	M3. Prompt retrieval and sorting for treatment by dissolution	M4. Prompt retrieval and storage for treatment by vitrification when available	M5. Prompt retrieval and deferred sorting for at-surface disposal (LLWR)	M6. Prompt retrieval, containerisation & storage for deferred treatment by vitrification
		will follow an established (passivated) management concept.	this will follow an established (passivated) management concept.	will follow an established (passivated) management concept.	will follow an established (passivated) management concept.	will follow an established (passivated) management concept.
T7. Impact of Loss of Corporate Records / Memory	Although records management is assured via the LoC process there is a risk that this information does not fully support NSD and other information will have been lost.	Some risk that the retained information does not fully support at-surface disposal, though it will be sought during sorting/drumming. There is a risk that the retained information for the waste remaining following processing does not fully support their final management beyond long-term storage.	Negligible risk of loss of records / memory through to dissolution. There is a risk that the retained information for the HAW by-products does not fully support their final management beyond long-term storage.	Some risk that records / memory will be lost during the storage phase. There is a risk that the retained information for the HAW by-products does not fully support their final management beyond long-term storage.	A risk that the retained information does not fully support at-surface disposal, though it will be sought during sorting/drumming. There is a risk that the retained information for the waste remaining following processing does not fully support their final management beyond long-term storage.	Some risk that records / memory will be lost during the storage phase. There is a risk that the retained information for the HAW by-products does not fully support their final management beyond long-term storage.
SE1. Cost *Cost estimates for capital expenses and third-party services*	Significant capital expenses / fees: • new containers (100 3m³ boxes) • transport fees (100 SWTC transports) • disposal fees (100 3m³ packages for NSD disposals) **Cost estimate: £5,000,000**	Significant capital expenses / fees: • sorting facility, SAWB roof • new containers (1343 200l drums, 10 HHISOs and 6 3m³ boxes) • transport fees (20 FHISO and 10 HHISO transports, 6 SWTC transports) • compaction / handling fees (1343 drums) • disposal fees (10 HHISOs for at-surface disposal) • final management fees (6 3m³ packages) **Cost estimate: £8,800,000**	Significant capital expenses / fees: • new containers (1343 200l drums and 11 3m³ boxes) • construction of three facilities: ○ sorting facility, SAWB roof ○ dissolution and abatement facility ○ HAW packaging facility • transport fees (11 SWTC transports) • final management fees (11 3m³ packages) **Cost estimate: £105,000,000**	Significant capital expenses / fees: • new containers (1418 200l drums and 6 3m³ boxes) • new stillages (355 stillages) • 200l drum/Novapak facility, SAWB roof • transport fees (178 Novapak transports, 58 SWTC transports) • Final management fees (29 3m³ packages) **Cost estimate: £8,000,000**	Significant capital expenses / fees: • 3m³ box emptying and sorting facility • new containers (1343 200l drums, 10 HHISOs and 6 3m³ boxes) • transport fees (20 FHISO and 15 HHISO transports, 6 SWTC transports) • compaction / handling fees (1343 drums) • disposal fees (10 HHISOs for at-surface disposal) • final management fees (6 3m³ packages) **Cost estimate: £55,000,000**	Significant capital expenses: • new containers (1418 200l drums and 6 3m³ boxes) • 3m³ box emptying and sorting facility • transport fees (178 Novapak transports, 5 HHISO transports, 58 SWTC transports) • final management fees (29 3m³ packages) **Cost estimate: £55,000,000**
SE3. Future Burden *RAG rationale: deferred packaging, treatment, encapsulation penalised. Long-term management penalised.*	The waste would largely be managed by the current generation. NSD disposal would be performed by a future generation (though the waste will have already been packaged and encapsulated).	The waste would largely be managed by the current generation. At-surface disposal may be performed by a future generation and, if so, there would be an increased burden (compared to NSD disposal) due to the deferred encapsulation. Management of the non-magnox waste would fall to future generations (long-term storage), the requirements of which are unknown.	The waste would largely be managed by the current generation. Management of the dissolution by-products would fall to future generations (long-term storage), the requirements of which are unknown. Management of the non-magnox waste would fall to future generations (long-term storage), the requirements of which are unknown.	The waste would largely be managed by the current generation. Treatment would be performed by the current generation. Management of the treatment by-products would fall to future generations (long-term storage), the requirements of which are unknown.	The waste would largely be managed by a future generation. Packaging, encapsulation and at-surface disposal would be performed by a future generation. Management of the non-magnox waste would fall to future generations (long-term storage), the requirements of which are unknown.	The waste would largely be managed by a future generation. Treatment would be performed by a future generation. Management of the treatment by-products would fall to future generations (long-term storage), the requirements of which are unknown.

APPENDIX F: LAW DIVERSION FEASIBILITY STUDY

To assess whether it would be feasible to pursue LAW management of the bunkers waste packages or waste materials calculations were performed considering basic activity constraints of the current LLW Repository WAC. These are reported in Reference [12].

Approach Taken

This assessment used the bunkers waste inventories [9] decayed to set times (2040, 2120, 2220 and 2320) and considering two questions – whether the waste packages could be suitable for LAW management (and, if so, when), or whether any of the individual waste materials could be suitable for LAW management (and, if so, when). These questions were answered primarily with reference to specific activity levels with some commentary on other challenges, for example the acceptability of the waste package form or individual radionuclide constraints.

Results

The results from Reference [12] are shown below. The green shading denotes an activity < 12 GBq/te and a red shading where > 12GBq/te. For the waste materials/items an orange shading is also used to indicate where an activity could fall < 12GBq/te after encapsulation (see Interpretation section for a commentary on this).

Average 3m^3 box waste package activity (when encapsulated) – mixed waste (GBq/te)

Waste package from	2040	2120	2220	2320
Bunker 1	33.8	15.7	8.0	4.5
Bunker 2	352.1	196.5	108.4	64.2
Bunker 3	205.8	98.3	57.9	37.8
Bunker 4	165.0	51.6	33.4	24.5
Bunker 5	228.0	89.0	52.0	33.6

Weighted average activity per waste material/item (GBq/te)

Waste material	2040	2120	2220	2320
Magnox	9.5	2.9	1.7	1.2
Graphite	62.0	21.1	19.1	18.2
Fuel support members	925.4	381.6	206.6	119.7
Zirconium D-bars	444.6	155.2	95.1	66.0
Other MAC items	54971.1	31741.4	16327.9	8588.8
Thermocouples	241731.1	139277.5	71477.3	37440.1
Sludge	71.3	23.8	16.4	14.1

Interpretation

These results have considered specific activities against the basic 12GBq/te activity criterion. From this it is indicated that the magnox could be managed as LAW but for all other waste materials or waste packages the results need to be viewed with some caution. LLW Repository disposal has formed the basis of these considerations.

Waste packages

Waste packages from Bunker 1 could potentially be eligible for LLW Repository disposal sometime next century (estimated ca. 2170) based on specific activity and presuming such a facility still exists (which it is not planned to be). If this facility had similar WAC to the current one it could prove challenging to gain acceptance due to the waste package format (3m^3 stainless steel boxes) and due to limits on discrete items. Changes to the LLW Repository environmental safety case (ESC) and, resultantly, the WAC could present an opportunity for earlier disposal (if the WAC become less restrictive, which may not be the case). In general, the potential to dispose of Bunker 1 waste packages to the LLW Repository looks highly unlikely, due principally to the timeframe needed for radioactive decay but also WAC-related challenges.

Waste materials/items

These results arise from consideration of waste which have been segregated into discrete materials/items, e.g. magnox, fuel support members, etc. A common caution to apply to these results, therefore, concerns the practicalities of segregation and the effect that contamination, e.g. from sludge or fuel particles, could have on the specific activity of any consignment intended for the LLW Repository.

The magnox can be seen to have the greatest potential to meet the disposal WAC. These results indicate that disposal in 2040 is possible (and that the magnox would, in its raw form, be suitable in ca. 2035). Given a dilution factor from encapsulation disposal ‘today’ may be possible, though this review has considered a decay storage period in part to account for activity variation throughout the magnox population as well as specific activity increases from other waste items / contamination – this is consistent with Reference [25] where the requirement for decay storage is in part driven by high dose items that are difficult to segregate. Additionally, experience with Bradwell FED shows that a storage period of some duration is likely to be required to manage hydrogen generation rates for transport. In general, however, it is viewed as credible to dispose of magnox at the LLW Repository in the near-term and under the current WAC though the ability to do this for all of the magnox will be limited due to sorting and segregation / WAC demonstration challenges.

The credibility of disposing of any other waste materials/items, however, has not been demonstrated from this exercise. In most cases this is simply due to specific activities being (well) in excess of 12GBq/te. For graphite and sludge there appears to be the potential for these specific activities to be brought below 12GBq/te once the dilution effect of encapsulation is accounted for. However, sludge is effectively present within the bunkers waste as a contaminant and cannot be readily segregated. Graphite is, at face value, possible to dispose of in an encapsulated form given ca. 100 years of decay storage. The key challenge to disposing of the graphite is its C-14 content which would take up a significant portion of the capacity afforded within the LLW Repository’s current ESC. It is possible that ESC revisions would lead to increased capacity for C-14 and, potentially, risk-based disposals. However, it is not currently permitted to dispose of this graphite at the LLW Repository and the time until its specific activity (when encapsulated) would fall below 12GBq/te also puts it at the extremes of credibility regardless of the C-14 issue, which is significant in itself.

APPENDIX G: AT-DEPTH DISPOSAL FEASIBILITY STUDY

To assess whether it would be feasible to dispose of the bunkers waste packages, Eden Nuclear and Environment Ltd (‘Eden’) was contracted by Magnox Ltd to determine whether a hypothetical at depth disposal facility, containing the bunkers waste packages, would comply with the environmental regulators’ Guidance on Requirements for Authorisation for Near-Surface disposal facilities on land for solid radioactive wastes (the ‘GRA’).

This appendix summarises the assessment reported in Reference [10] which is based on the waste package inventories used for this strategic options review. A separate assessment has also been performed to consider the LoC inventories and to investigate the effect of differing quantities of fuel particles/fragments on the outcome, this is reported in Reference [31].

Approach Taken

As reported in Reference [10], no standardised approach exists for conducting such assessments and, as such, Eden has developed an approach based on existing regulations, guidance and previous studies (precedent) from which analogies can be drawn.

Magnox has provided Eden with waste package inventories [9], tasking Eden to determine, for a variety of cases, the time in the future at which doses from human intrusion scenarios[29] would fall beneath the dose guidance levels of the GRA. These calculations have been performed for several scenarios, considering intrusion into:

- waste packages from Bunker 1[30];
- waste packages from Bunker 2;
- waste packages from Bunker 3;
- waste packages from Bunker 4;
- waste packages from Bunker 5;
- waste packages from Bunkers 1 to 5 (five-high stack);
- waste packages from Bunkers 2 to 5 (four-high stack)
- highest dose waste packages stacked five-high; and
- waste packages from Bunkers 1 to 5 (seven-high stack[31]).

To assess these cases, the inventories have been decayed to set assessment times (50, 100, 150, 200, 300, 400, 600, 800, and 1,000 years from now). The doses arising from intrusion have been calculated for each of these times to determine when these doses fall below the GRA dose guidance levels.

The waste packages are assumed to be disposed of in a silo-type facility, which will be sited greater than 30m below ground level. Eden has chosen a facility concept similar to the disposal silo concept being considered as part of NDA-led work on near-surface disposal opportunities. Different stacking configurations have been considered. Figure 3 shows the packages from Bunkers 1 to 5 stacked five-high, where each layer is comprised of waste packages from a different bunker.

[29] Human intrusion scenarios are considered to be bounding for the purposes of this assessment.

[30] An additional case including a 1kg fuel fragment was also considered though the results of this have been omitted from this review to align with its scope. Please refer to Reference [10] for these results.

[31] A seven-high stack is the maximum design withstand for the $3m^3$ box.

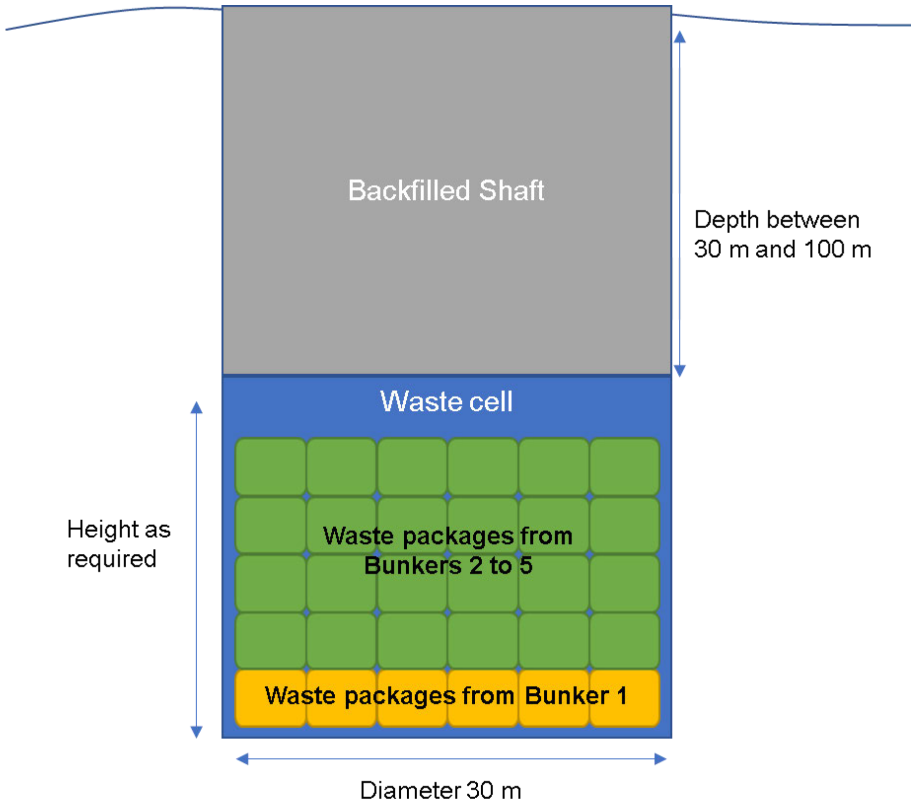


Figure 3: Assumed Disposal Configuration (five-high)

Doses arising from human intrusion are considered for the following scenarios[32] and exposed groups, which were defined by the Health Protection Agency (now Public Health England[33]) as part of a near-surface disposal study commissioned by SEPA [24]:

- Borehole drilling
  - Geotechnical worker handling cores on-site
  - Resident (Adult, Child, Infant) living on contaminated land and consuming fruit and vegetables grown on contaminated land
  - Consumer of contaminated drinking water (Adult, Child, Infant)
- Tunnelling
  - Tunnel worker
  - Spoil truck driver
- Controlled intrusion
  - Controlled intrusion worker clearing the area and studying excavated material

Eden has collated and applied exposure pathway parameters from previous studies, and applied several assumptions to determine the doses received by each exposed group in each scenario. A third-party, Quintessa Ltd ('Quintessa'), has conducted a peer review of this approach to confirm that it has applied the correct regulations and guidance, draws on appropriate studies and uses appropriate assumptions.

[32] Other scenarios have been excluded from consideration for the bunkers waste, as they are either not applicable or not bounding, as noted in Reference [10].

[33] Or potentially the National Institute for Health Protection by the time of this note's issue.

Results

Whilst the calculated intrusion doses do not provide a definitive answer regarding disposability, they do provide a measure of feasibility and confidence should at depth disposal be pursued.

The time relates to the period of institutional control necessary for the disposal facility post-closure – such controls are assumed to prevent human intrusion – which is assumed to last for up to 300 years.

The results from these calculations (reported in Reference [10]) are shown below. For each table the assessment results are shown at different times of intrusions. The dose for workers is calculated for a single intrusion event, the dose for residents and drinking water consumers represents the dose in one year. The green shading denotes a dose < 3 mSv, orange shading a dose between 3 mSv and 20 mSv and red shading denotes a dose above 20 mSv.

As a rule of thumb interpretation, disposal feasibility can be viewed to have been indicated if no doses exceed the dose guidance levels at 300 years. This is true for all scenarios considered except one.

Doses from intrusion into a package from Bunker 1

Scenario	Total annual dose (Sv y-1) after decay time (y)				
	50	100	200	300	1000
Borehole - Geotechnical Worker	1.48E-03	1.25E-03	1.07E-03	9.74E-04	6.40E-04
Borehole - Resident (Adult)	2.25E-04	7.70E-05	1.69E-05	1.06E-05	7.27E-06
Borehole - Resident (Child)	3.17E-04	1.04E-04	1.85E-05	9.91E-06	6.73E-06
Borehole - Resident (Infant)	1.74E-04	5.94E-05	1.28E-05	7.94E-06	5.73E-06
Borehole - Water (Adult)	1.30E-01	4.02E-02	4.12E-03	6.46E-04	1.89E-04
Borehole - Water (Child)	1.21E-01	3.74E-02	3.73E-03	5.42E-04	1.44E-04
Borehole - Water (Infant)	1.24E-01	3.83E-02	3.94E-03	6.60E-04	2.15E-04
Tunnel Worker	9.17E-03	4.28E-03	2.11E-03	1.75E-03	1.15E-03
Spoil Truck Driver	4.19E-03	1.58E-03	4.80E-04	3.43E-04	2.22E-04
Controlled Intrusion	1.78E-03	5.78E-04	8.10E-05	2.95E-05	1.70E-05

Doses from intrusion into a package from Bunker 2

Scenario	Total annual dose (Sv y-1) after decay time (y)				
	50	100	200	300	1000
Borehole - Geotechnical Worker	4.16E-06	3.46E-06	2.99E-06	2.77E-06	2.67E-06
Borehole - Resident (Adult)	2.20E-06	1.94E-06	1.72E-06	1.62E-06	1.49E-06
Borehole - Resident (Child)	3.09E-06	2.71E-06	2.41E-06	2.26E-06	2.10E-06
Borehole - Resident (Infant)	2.58E-06	2.25E-06	1.96E-06	1.82E-06	1.67E-06

Borehole - Water (Adult)	8.68E-04	4.79E-04	3.63E-04	3.15E-04	2.44E-04
Borehole - Water (Child)	7.73E-04	4.37E-04	3.16E-04	2.66E-04	2.01E-04
Borehole - Water (Infant)	1.29E-03	7.24E-04	4.80E-04	3.73E-04	2.49E-04
Tunnel Worker	2.57E-04	2.13E-04	1.74E-04	1.53E-04	1.28E-04
Spoil Truck Driver	1.33E-04	1.10E-04	9.04E-05	7.99E-05	6.68E-05
Controlled Intrusion	6.07E-05	5.02E-05	4.11E-05	3.63E-05	3.03E-05

Doses from intrusion into a package from Bunker 3

Scenario	Total annual dose (Sv y-1) after decay time (y)				
	50	100	200	300	1000
Borehole - Geotechnical Worker	6.35E-06	4.47E-06	3.84E-06	3.57E-06	3.34E-06
Borehole - Resident (Adult)	2.82E-06	2.32E-06	2.07E-06	1.95E-06	1.82E-06
Borehole - Resident (Child)	3.98E-06	3.27E-06	2.92E-06	2.76E-06	2.60E-06
Borehole - Resident (Infant)	3.22E-06	2.63E-06	2.33E-06	2.19E-06	2.04E-06
Borehole - Water (Adult)	1.06E-03	4.37E-04	3.31E-04	3.01E-04	2.48E-04
Borehole - Water (Child)	8.76E-04	3.76E-04	2.80E-04	2.50E-04	2.05E-04
Borehole - Water (Infant)	1.35E-03	5.64E-04	3.95E-04	3.34E-04	2.57E-04
Tunnel Worker	3.46E-04	2.61E-04	2.16E-04	1.95E-04	1.68E-04
Spoil Truck Driver	1.83E-04	1.37E-04	1.14E-04	1.03E-04	8.85E-05
Controlled Intrusion	8.35E-05	6.25E-05	5.18E-05	4.67E-05	4.02E-05

Doses from intrusion into a package from Bunker 4

Scenario	Total annual dose (Sv y-1) after decay time (y)				
	50	100	200	300	1000
Borehole - Geotechnical Worker	7.93E-06	5.32E-06	4.63E-06	4.29E-06	3.90E-06
Borehole - Resident (Adult)	2.86E-06	2.21E-06	1.99E-06	1.90E-06	1.80E-06
Borehole - Resident (Child)	4.02E-06	3.10E-06	2.80E-06	2.67E-06	2.57E-06
Borehole - Resident (Infant)	3.18E-06	2.43E-06	2.19E-06	2.08E-06	1.98E-06
Borehole - Water (Adult)	1.44E-03	4.23E-04	3.23E-04	3.05E-04	2.62E-04
Borehole - Water (Child)	1.18E-03	3.58E-04	2.68E-04	2.50E-04	2.17E-04

Borehole - Water (Infant)	1.79E-03	5.08E-04	3.60E-04	3.26E-04	2.73E-04
Tunnel Worker	3.23E-04	2.14E-04	1.78E-04	1.60E-04	1.39E-04
Spoil Truck Driver	1.71E-04	1.11E-04	9.24E-05	8.30E-05	7.23E-05
Controlled Intrusion	7.78E-05	5.05E-05	4.18E-05	3.75E-05	3.26E-05

Doses from intrusion into a package from Bunker 5

Scenario	Total annual dose (Sv y-1) after decay time (y)				
	50	100	200	300	1000
Borehole - Geotechnical Worker	7.92E-06	5.48E-06	4.72E-06	4.34E-06	3.89E-06
Borehole - Resident (Adult)	2.61E-06	2.04E-06	1.88E-06	1.82E-06	1.77E-06
Borehole - Resident (Child)	3.66E-06	2.86E-06	2.64E-06	2.57E-06	2.53E-06
Borehole - Resident (Infant)	2.90E-06	2.25E-06	2.06E-06	1.99E-06	1.95E-06
Borehole - Water (Adult)	1.57E-03	4.43E-04	3.22E-04	2.97E-04	2.51E-04
Borehole - Water (Child)	1.30E-03	3.83E-04	2.72E-04	2.46E-04	2.09E-04
Borehole - Water (Infant)	2.01E-03	5.74E-04	3.79E-04	3.28E-04	2.64E-04
Tunnel Worker	2.83E-04	1.90E-04	1.63E-04	1.52E-04	1.40E-04
Spoil Truck Driver	1.47E-04	9.73E-05	8.41E-05	7.84E-05	7.29E-05
Controlled Intrusion	6.70E-05	4.39E-05	3.80E-05	3.54E-05	3.29E-05

Doses from intrusion into packages from Bunkers 1 to 5

Scenario	Total annual dose (Sv y-1) after decay time (y)				
	50	100	200	300	1000
Borehole - Geotechnical Worker	1.51E-03	1.27E-03	1.09E-03	9.89E-04	6.54E-04
Borehole - Resident (Adult)	2.16E-04	7.88E-05	2.31E-05	1.70E-05	1.35E-05
Borehole - Resident (Child)	3.04E-04	1.07E-04	2.77E-05	1.93E-05	1.60E-05
Borehole - Resident (Infant)	1.73E-04	6.44E-05	2.03E-05	1.54E-05	1.29E-05
Borehole - Water (Adult)	2.44E-02	7.62E-03	1.02E-03	3.65E-04	2.40E-04
Borehole - Water (Child)	2.27E-02	7.06E-03	9.05E-04	3.05E-04	1.96E-04
Borehole - Water (Infant)	2.37E-02	7.38E-03	1.04E-03	3.97E-04	2.52E-04
Tunnel Worker	2.03E-03	9.89E-04	5.30E-04	4.48E-04	3.22E-04

Spoil Truck Driver	9.57E-04	4.01E-04	1.66E-04	1.31E-04	1.00E-04
Controlled Intrusion	4.13E-04	1.57E-04	5.06E-05	3.70E-05	3.05E-05

Dose from intrusion into packages from Bunkers 2 to 5

Scenario	**Total annual dose (Sv y-1) after decay time (y)**				
	50	100	200	300	1000
Borehole - Geotechnical Worker	2.64E-05	1.87E-05	1.62E-05	1.50E-05	1.38E-05
Borehole - Resident (Adult)	1.05E-05	8.50E-06	7.66E-06	7.28E-06	6.88E-06
Borehole - Resident (Child)	1.47E-05	1.19E-05	1.08E-05	1.03E-05	9.80E-06
Borehole - Resident (Infant)	1.19E-05	9.56E-06	8.54E-06	8.07E-06	7.65E-06
Borehole - Water (Adult)	1.23E-03	4.46E-04	3.35E-04	3.04E-04	2.51E-04
Borehole - Water (Child)	1.03E-03	3.88E-04	2.84E-04	2.53E-04	2.08E-04
Borehole - Water (Infant)	1.61E-03	5.93E-04	4.03E-04	3.40E-04	2.61E-04
Tunnel Worker	3.02E-04	2.19E-04	1.83E-04	1.65E-04	1.44E-04
Spoil Truck Driver	1.59E-04	1.14E-04	9.52E-05	8.60E-05	7.51E-05
Controlled Intrusion	7.22E-05	5.18E-05	4.32E-05	3.90E-05	3.40E-05

Doses from intrusion into a five-high stack of packages from Bunker 1

Scenario	**Total annual dose (Sv y-1) after decay time (y)**				
	50	100	200	300	1000
Borehole - Geotechnical Worker	7.40E-03	6.27E-03	5.36E-03	4.87E-03	3.20E-03
Borehole - Resident (Adult)	1.13E-03	3.85E-04	8.47E-05	5.31E-05	3.64E-05
Borehole - Resident (Child)	1.58E-03	5.21E-04	9.26E-05	4.95E-05	3.36E-05
Borehole - Resident (Infant)	8.72E-04	2.97E-04	6.39E-05	3.97E-05	2.87E-05
Borehole - Water (Adult)	1.30E-01	4.02E-02	4.12E-03	6.46E-04	1.89E-04
Borehole - Water (Child)	1.21E-01	3.74E-02	3.73E-03	5.42E-04	1.44E-04
Borehole - Water (Infant)	1.24E-01	3.83E-02	3.94E-03	6.60E-04	2.15E-04
Tunnel Worker	9.17E-03	4.28E-03	2.11E-03	1.75E-03	1.15E-03
Spoil Truck Driver	4.19E-03	1.58E-03	4.80E-04	3.43E-04	2.22E-04
Controlled Intrusion	1.78E-03	5.78E-04	8.10E-05	2.95E-05	1.70E-05

The table below contains the assessment results at key times for intrusion into a seven-high stack with one waste package from each of Bunkers 1, 2 and 5, and two waste packages from Bunkers 3 and 4. Two waste packages from Bunkers 3 and 4 have been included in this stack because these two bunkers have the highest dose waste packages from Bunkers 2, 3 and 4, and Bunkers 2, 3 and 4 contain more waste packages than Bunkers 1 and 5.

Doses from intrusion into a seven-high stack of waste packages

Scenario	Total annual dose (Sv y-1) after decay time (y)				
	50	100	200	300	1000
Borehole - Geotechnical Worker	1.52E-03	1.28E-03	1.10E-03	9.97E-04	6.61E-04
Borehole - Resident (Adult)	2.21E-04	8.29E-05	2.71E-05	2.08E-05	1.71E-05
Borehole - Resident (Child)	3.10E-04	1.13E-04	3.34E-05	2.47E-05	2.11E-05
Borehole - Resident (Infant)	1.78E-04	6.92E-05	2.47E-05	1.96E-05	1.69E-05
Borehole - Water (Adult)	1.77E-02	5.53E-03	8.16E-04	3.47E-04	2.44E-04
Borehole - Water (Child)	1.64E-02	5.11E-03	7.22E-04	2.89E-04	2.00E-04
Borehole - Water (Infant)	1.72E-02	5.39E-03	8.47E-04	3.77E-04	2.56E-04
Tunnel Worker	1.54E-03	7.73E-04	4.33E-04	3.69E-04	2.73E-04
Spoil Truck Driver	7.33E-04	3.22E-04	1.47E-04	1.20E-04	9.45E-05
Controlled Intrusion	3.18E-04	1.28E-04	4.95E-05	3.85E-05	3.22E-05

Interpretation

These results provide some measure of confidence that it would be possible to dispose of the bunkers waste packages in an at depth facility. They support the assumption used in this review that the bunkers wastes could be disposed of.

These results also illustrate some sensitivity to how the packages are emplaced within the facility. Further sensitivities include the assumptions used for these calculations as well as waste inventory uncertainties. In lieu of at-depth disposal WAC the LoC process has been used to guide waste package manufacture which extends to the packaging specification and adequacy of supporting information such as characterisation.

Reference [31] summarises a similar assessment performed using the LoC inventories. This also supports the assumption that the bunkers wastes could be disposed of although some scenarios require longer for doses to fall below the guidance levels.

APPENDIX H: ASSESSMENT OF DOSES DUE TO DISCHARGES

This appendix summarises the results of the discharge assessment reported in Reference [32] which is based on the Environment Agency's Initial Radiological Assessment Methodology [33], waste package inventories used for this strategic options review [9] and the assumptions shown in Appendix D.

This assessment applies the same release fractions as reported in the Hunterston A site SILWE discharge assessment [34] which was updated in 2023 to incorporate more empirical data from encapsulation of FED at Trawsfynydd.

In summary (adapted from Reference [32]):

- Doses due to discharges have been estimated for the encapsulation and/or treatment processes used in each option considered in this strategic options assessment. Doses have been calculated for all Bunkers 2-5 waste and the waste remaining in Bunker 1.
- The dominant nuclide in determining dose in all options is C-14.
- Doses due to discharges are manageable in all scenarios and abatement assumptions have been factored into the assessment where abatement is viewed as likely to be required or BPM. Note, however, it is not in the remit of this assessment to determine BPM, these assumptions have been made to support a strategic options assessment only.
- Gasification exceeds the threshold for requiring abatement. Greater abatement than has been assumed for the assessment may, in reality, be likely to enable other waste to be processed at the plant during the year.
- Vitrification does not exceed the threshold for requiring abatement, however abatement is likely to be BPM and has been factored into the assessment.
- Dissolution does not exceed the threshold for further abatement. However, it was noted that almost the entirety of the dose is due to the discharge of C-14 which was not affected by the abatement technology used at Bradwell and therefore this style of abatement is unlikely to be BPM.
- In line with the findings of Reference [34], further gaseous discharge abatement is not required or viewed to be BPM for encapsulation-based options using SILWE.

The estimated doses due to discharges are shown overleaf, these doses have been determined following abatement where applied (see Ref [32]). N.B. Doses prior to abatement are shown in Reference [32] but omitted here for simplicity.

The sum of total doses for each process in each option give the following total dose in μSv/y for each option (as reported in the main body of this report):

G1	G2	M1	M2	M3	M4	M5	M6
2.8E-01	1.3E+01	2.6E-03	2.6E-03	2.3E+00	8.5E-01	2.4E-03	4.7E-01

Doses from processes within each option (with abatement, where applied (see Ref [32]))

Option	Processing/treatment steps for discharge calcs	Happens when	Lasts how long	Airborne (Local Habitants and Terrestrial Wildlife			Liquid Discharge (Fisherman & Estuary Wildlife)		
				Total Dose µSv/y	Food Dose µSv/y	Wildlife Total Dose Rate (µGy/h)	Total Dose µSv/y	Food Dose µSv/y	Wildflife Total Dose Rate (µGy/h)
G1. Encapsulation for interim storage then at-depth disposal	Encapsulation of all waste from B2-5	2024	2.5y	2.8E-01	1.3E-01	1.5E-03			
G2. Deferred retrieval and sorting for gasification	Gasification of graphite from B2-5	2070	4y	1.3E+01	9.3E+00	3.5E-02			
	Encapsulation of all other waste from B2-5	2075	0.5y	1.9E-01	8.2E-02	1.0E-03			
M1. Encapsulation for interim storage then at-depth disposal	Encapsulation of all waste from B1*	2023	0.5y	2.6E-03	1.2E-03	1.4E-05			
M2. Prompt retrieval and sorting for decay storage then encapsulation and at-surface disposal (LLWR)	Encapsulation of magnox from B1 (at LLWR)*	2030	0.5y	6.9E-04	3.2E-04	3.7E-06			
	Encapsulation of all other waste from B1*	2025	0.1y	1.9E-03	9.1E-04	1.0E-05			
M3. Prompt retrieval and sorting for dissolution	Dissolution of all magnox from B1*	2028	3y	7.5E-01	3.4E-01	4.1E-03	1.5E+00	1.5E+00	5.7E-04
	Encapsulation of all other waste from B1*	2025	0.1y	5.8E-04	2.8E-04	3.1E-06			
M4. Prompt retrieval and sorting for storage then vitrification	Vitrification of all waste from B1*	2040	1y	8.5E-01	3.2E-01	4.8E-03			
M5. Deferred retrieval and sorting for encapsulation and at-surface disposal (LLWR)	Encapsulation of magnox from B1 (at LLWR)*	2075	0.5y	6.1E-04	2.9E-04	3.2E-06			
	Encapsulation of all other waste from B1*	2075	0.1y	1.8E-03	8.9E-04	9.7E-06			
M6. Deferred retrieval and sorting for vitrification	Vitrification of all waste from B1*	2075	1y	4.7E-01	2.2E-01	2.6E-03			

* In bunker portion only

APPENDIX I: FURTHER SENSITIVITY ANALYSIS

The following sections provide a further sensitivity analysis supporting the lead options (G1 and M1) with reference to alternative options as identified below.

Option Group	Bunkers 2-5 (Graphite)	Bunker 1 (Magnox)	Waste remaining after processing or treatment
Baseline – no sorting	G1. Encapsulate then store for at-depth disposal	M1. Encapsulate then store for at-depth disposal	n/a
Prompt Processing	n/a	M2. Sort and decay store then encapsulate for at surface disposal M3. Sort and treat by dissolution M4. Re-package and store then treat by vitrification	Encapsulate, if necessary, then place into long-term storage
Deferred Processing	G2. Store then sort and treat by gasification	M5. Store then sort and encapsulate for at surface disposal M6. Store then re-package and treat by vitrification	Encapsulate, if necessary, then place into long-term storage

Work planning

It is expected (pending Government approval) that the reactor decommissioning phase will be brought forwards for the Hunterston A site. This has no bearing on the lead options.

It would reduce the likelihood that treatment options are available by the reactor decommissioning phase (for gasification in particular). For deferred sorting options the time at risk due to 'raw' storage would be reduced and time to passivation could be shortened, though the detriment with 3m^3 box emptying etc. remain. If this change removes the C&M period for site then this could help reduce the competition for site assets, particularly for the dissolution option (though this would not compensate for its other detriments).

It has been decided that the Magnox Ltd scope will be expanded to include decommissioning and waste management of the Hunterston B site, in which case there are potentially other times at which the wider site would be mobilised meaning that there could be further options for when to defer retrieval and sorting to. However, the detriments associated with the deferred sorting options are largely independent of time, relating more to the scope.

At-depth disposal

Encapsulation can be performed at the disposal facility

As captured within the options assessment, encapsulation is performed at and at-surface disposal facility (based on LLWR) but is assumed not to be performed at an at-depth disposal facility. If this change in assumption was to be agreed soon this could avoid the need for encapsulation at the site (for all options). It would increase 'raw' storage risks for options which would otherwise have encapsulated waste prior to on-site storage, putting them on-par with the deferred sorting options in this respect. It would significantly reduce the scope of work performed at Hunterston A but does not remove the scope, therefore for the prompt encapsulation options it increases the burden placed on future generations. The greatest benefit of this change in assumption could be as a disposal risk mitigation (see Section 6.3).

Disposal facility becomes available before reactor decommissioning phase

This would avoid the need for interim storage beyond the reactor decommissioning phase and would be positive for Option G1/M1 in this regard. Availability of WAC prior to this phase would also be of benefit when developing plans for Options G2, M5 and M6, though the assumption used in this assessment is that wastes remaining following processing or treatment are unsuitable for disposal.

Waste remaining following processing or treatment is disposable

This would benefit Options G2 and M2-6 by providing greater certainty over the end point for waste currently assumed for long-term storage, though the difficulty is in proving this assumption 'today' given the absence of disposal WAC and disposal feasibility studies providing no clear evidence to support a change of assumption. If this could be established then it would also reduce uncertainty with the lead options.

At-surface disposal

Disposal of magnox becomes possible without decay storage

If it was possible to at-surface dispose of the magnox (to LLWR) without decay storage this would have benefits in reducing the storage burden at Hunterston A and forgo the need to manufacture stillages and enable the ILW Store to accommodate 200l drums. It would enable earlier disposal of the magnox, however the management uncertainty for the non-magnox waste would remain. The key difference between the at-surface and at-depth disposal options assessed is the sorting and segregation required to pursue the former, which remains irrespective of when the waste is disposed.

Disposal of graphite becomes possible

It is possible that the LLWR WAC could change in future to enable disposal of graphite. However, as the graphite is already containerised, the significant detriment associated with its retrieval and sorting remains.

Disposal of the waste as packaged becomes possible

It is conceivable that changes to the LLWR WAC could enable disposal of the waste as packaged in 3m^3 boxes. The waste, particularly that from Bunker 1, could comply with the facility's environmental safety case if risk-based disposals became possible. There would be a number of challenges to overcome should this become a possibility, e.g. relating to discrete items criteria, however the lead options do not foreclose this opportunity.

Disposal of magnox is not possible

It may not be possible to send all magnox for at-surface disposal, e.g. due to pond sludge contamination. It may be possible to 'clean' the magnox, though this could require additional infrastructure to that considered in the assessment. More probable is that, were this option to be chosen, it would need to be accepted that the LLWR WAC cannot be demonstrated for a portion of the eligible magnox, and this would need to be routed via the long-term storage route along with the other waste materials in the bunker.

Treatment options

Treatment options do not materialise

This is a credible risk for vitrification and gasification options and this risk favours the lead options.

Treatment processes can import 3m^3 boxes

This has the potential to avoid the need for the box emptying facility, though it depends on the sorting requirements for the facility. Potentially, gasification and vitrification would be quite accommodating with their WAC and so this option has some credibility. If it were the case then the containerised waste could be consigned for processing simply, e.g. in SWTCs. It is still unlikely to be attractive to pursue vitrification for magnox as the benefit from volume reduction is not great. Other detriments with the dissolution option are also viewed to outweigh this benefit. It may be attractive for the gasification option and potentially the by-products could go on for vitrification, resulting in a greatly reduced volume but greatly increased activity wasteform. These options would still result in discharges and other environmental detriment, e.g. due to waste-miles, as well as present socio-economic detriments, however. As noted above, applying BPM, as set out in SEPA guidance [4], presents an imperative to minimise radioactive waste discharged to the environment.

Other options become available

The merit of such options can be considered by using the deferred retrieval options as proxies, e.g. what benefit would such an option need to provide to compensate for the detriment associated with the process of emptying $3m^3$ boxes, etc. No feasible material recovery options have been identified for this review though should these become available then a greater detriment could potentially be tolerated. This is considered further in Section 6.

Transport

Unable to transport waste in FHISOs

This would have no bearing on the lead option. It is unlikely to affect magnox though is credible for graphite, for which it may be necessary to transport in a different configuration; most likely this would be reduced quantity transports at increased cost/detriment.

Loading efficiency of 200l drums is reduced to that assumed

A highly optimistic loading assumption has been used for calculations in this assessment (100%) and, in reality, this would be lower. However, this has no bearing on the lead options; it would increase drum and FHISO numbers, and consequently waste-miles, as well as increasing other detriments such as time and cost for options involving 200l drums.

Long-term storage

This has no bearing on the lead option unless at-depth disposal WAC cannot be demonstrated (a disposal risk, see Section 6).

It has been assumed that waste remaining following processing or treatment is unsuitable for near-surface disposal. The implementation strategy for Scotland's HAW Policy recognises that there will be such wastes, referring to them as "challenging", and that work will be needed to identify management options for them. This assessment assumes that such wastes would require 'long-term storage' whilst options are developed, potentially up to 300 years. Although the Magnox baseline allows for such storage, for wastes that are expected to be disposable there is greater certainty in the end point (and it is assumed that the disposal facility would be available in the relative near-future[34]). The uncertainty associated with long-term storage affects assessment of the attributes, e.g. it is unclear what burden is being placed on future generations.

Regarding waste remaining following treatment only, it may not prove necessary to return such wastes to Scotland for long-term storage, as Clause 2.04.13 of Scotland's HAW Policy [6] infers; the presumption is only that if this adds materially to the waste needing to be disposed of in the country of destination should it be returned to Scotland, and a case could reasonably be made on these grounds. However, Clause 2.04.12 notes that the export of waste from Scotland for treatment would only be permitted where it would result in the recovery of reusable materials or the treatment would make the subsequent storage or disposal of the waste more manageable. The treatment options assessed in this review could be viewed to improve the subsequent management of the waste if resulting in volume reductions, though this argument is weakened if these wastes are unsuitable for near-surface disposal. In any case, the legality of this would need testing to fully establish the feasibility of any HAW management option conducted in another part of the UK. N.B. This is not viewed to affect the at-surface disposal option as this would be a LLW route.

Should it prove feasible, and the treatment by-products not need returning to Scotland, then it removes the uncertainty associated with long-term storage and the associated detriment identified

[34] The NDA is also engaging with Scottish Government about potentially implementing an at-surface disposal solution earlier than indicated in the HAW Policy's implementation strategy.

in the options assessment. This makes the treatment options more attractive but this alone is not enough to overcome the other detriments with such options, which are largely associated with the increases to dose, safety hazards, discharges, costs and burden associated with (enabling) treatment rather than managing by-products.