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National Waste Programme

National Waste Programme

Guidance on decision making for management of wastes close to the LLW and ILW categorisation boundary that could potentially cross the LLW boundary

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Guidance on decision making for management of wastes close to the LLW and ILW categorisation boundary that could potentially cross the LLW boundary

Document Management

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Executive Summary

LLW / ILW cross boundary wastes can be defined as ILW and LLW with a concentration of specific radionuclides that prohibits or significantly challenges its acceptability at existing and planned future disposal facilities for LLW, that could be practicably be managed as LLW (on the basis of radiochemical and physico-chemical properties) through application of some treatment process or decay storage. Management of this waste inventory is complex for waste management practitioners in the UK[1] owing to the inherent characteristics of the waste and the challenge that such waste poses to the radiological capacity of disposal facilities such as the Low Level Waste Repository (LLWR). In addition, there are tensions for waste consignors in that the best option from the waste consignor perspective may not necessarily align with the best option from the perspective of national waste strategy, and that implementation of certain waste management options (such as the management of short-lived ILW by geological disposal) may prove to be sub-optimal.

Despite the challenges posed by this waste type, there has historically been an absence of specific guidance for waste practitioners to assist decision making and waste routing. This guidance document, produced in conjunction with Nuclear Decommissioning Authority (NDA) estate Site Licence Companies (SLCs) and Radioactive Waste Management Directorate (RWMD), is intended to provide waste practitioners with information on the decision making factors specifically relevant to cross-boundary wastes to assist the identification of Best Available Technique (BAT) and / or the development of Business Cases (where investment decisions are required relating to waste management).

A review of a 2009 inventory study [Ref. 1] to identify wastes that are classifiable as cross-boundary waste was undertaken, with reference to and update from the UK Radioactive Waste Inventory (UKRWI) 2010 [Ref. 2], to define an inventory of cross-boundary waste for the UK. This review has identified approximately 156,000m^3 of cross-boundary waste, 54% of which was identified as classifiable as LLW (this has been identified to be an upper bound of the inventory owing to the uncertainties and assumptions in the inventory analysis). This waste is predominantly concrete, mixed waste and metals; and the vast majority (some 93%) is expected to arise from the NDA estate.

Eight key decision making factors have been identified that are relevant to waste management decisions for cross-boundary wastes. These include ease of processing, cost, schedule / timing, LLWR Waste Acceptance Criteria (WAC) / Environmental Safety Case (ESC) compliance, stakeholders, strategic considerations, safety / environmental risks and packaging / transport. The constituent sub factors for each of these generic factor groups have been identified and a framework for identification of cross-boundary waste, factor prioritisation and factor usage has been developed. Supporting sources of information for each factor have been identified and signposting to generic (i.e. non-waste / site / SLC specific) information sources has been provided in this guidance. This has been augmented by development of norms for carbon footprinting and LLW waste management lifecycle costs.

A range of issues and recommendations relevant to cross-boundary waste decision making have been identified. Management of these issues by implementation of the recommendations provides a mechanism to improve and optimise the efficacy of decision making for cross-boundary wastes.

[1] It is noted that policies for the disposal of HAW differ in Scotland and in England / Wales [Ref. 3]. The following guidance can be applied equally in England, Scotland and Wales, but references to geological disposal and the Geological Disposal Facility (GDF) will correspond to long-term near-surface storage when applied to Scotland. In addition, the Dounreay Site Restoration Ltd (DSRL) SLC has its own permitted facility for disposition of LLW; it is intended that this guidance is also applicable to Dounreay but that references to disposal to LLWR will correspond to the Dounreay facility in this case.

Definitions, Acronyms and Abbreviations

Definitions

Term	Definition
Best Available Technique (BAT)	Best Available Techniques (BAT) means the latest stage of development of processes, facilities or methods of operation which indicate the practical suitability of a particular measure for limiting waste arisings and disposal. In determining what constitutes BAT consideration shall be given to: • Comparable processes, facilities or methods which have been tried out successfully • Technological advances and changes in scientific knowledge and understanding • The economic feasibility of such techniques • Time limits for installation in both new and existing plants • The nature and volume of the disposals concerned It follows that BAT will change with time in the light of technological advances, economic and social factors, and changes in scientific understanding.
Higher Activity Waste (HAW)	All High Level Waste (HLW) and ILW, and a small fraction of LLW with a concentration of specific radionuclides that prohibits its disposal at existing and planned future disposal facilities for LLW.
Intermediate Level Waste (ILW)	Wastes exceeding the upper boundaries for classification as LLW, but which do not require heating to be taken into account in the design of storage or disposal facilities.
LLW / ILW Cross-Boundary Waste	LLW / ILW cross boundary wastes can be defined as ILW and LLW with a concentration of specific radionuclides that prohibits or significantly challenges its acceptability at existing and planned future disposal facilities for LLW, that could be practicably be managed as LLW (on the basis of radiochemical and physico-chemical properties) through application of some treatment process or decay storage.
Low Level Waste (LLW)	Wastes having a radioactive content not exceeding 4 GBq per tonne of alpha activity, or 12 GBq per tonne of beta / gamma activity.
Lower Activity Waste (LAW)	Low Level Waste (LLW) only (i.e. the full spectrum of LLW including Very Low Level Waste).

Acronyms and Abbreviations

Term	Definition
ALARA	As Low As Reasonably Achievable
ALARP	As Low As Reasonably Practicable
BAT	Best Available Technique
BPEO	Best Practicable Environmental Option
DSRL	Dounreay Site Restoration Ltd
EA	Environment Agency
ESC	Environmental Safety Case
FED	Fuel Element Debris
GDF	Geological Disposal Facility
HAW	Higher Activity Waste

Term	Definition
HLW	High Level Waste
ILW	Intermediate Level Waste
LAW	Lower Activity Waste
LLW	Low Level Waste
LLWR	Low Level Waste Repository / LLW Repository Ltd.
LoC	Letter of Compliance
NDA	Nuclear Decommissioning Authority
ONR	Office for Nuclear Regulation
RSRL	Research Sites Restoration Ltd.
RWMC	Radioactive Waste Management Case
RWMD	Radioactive Waste Management Directorate
SEPA	Scottish Environmental Protection Agency
TBURD	Technical Baseline and Underpinning Research and Development Requirements
TRL	Technology Readiness Level
WAC	Waste Acceptance Criteria

Contents

Document sections identified by **bold text** are those providing direct guidance for waste consignors. The document sections identified by standard text are those providing supporting or background information.

Figures and Tables

Figures

Tables

1. Introduction

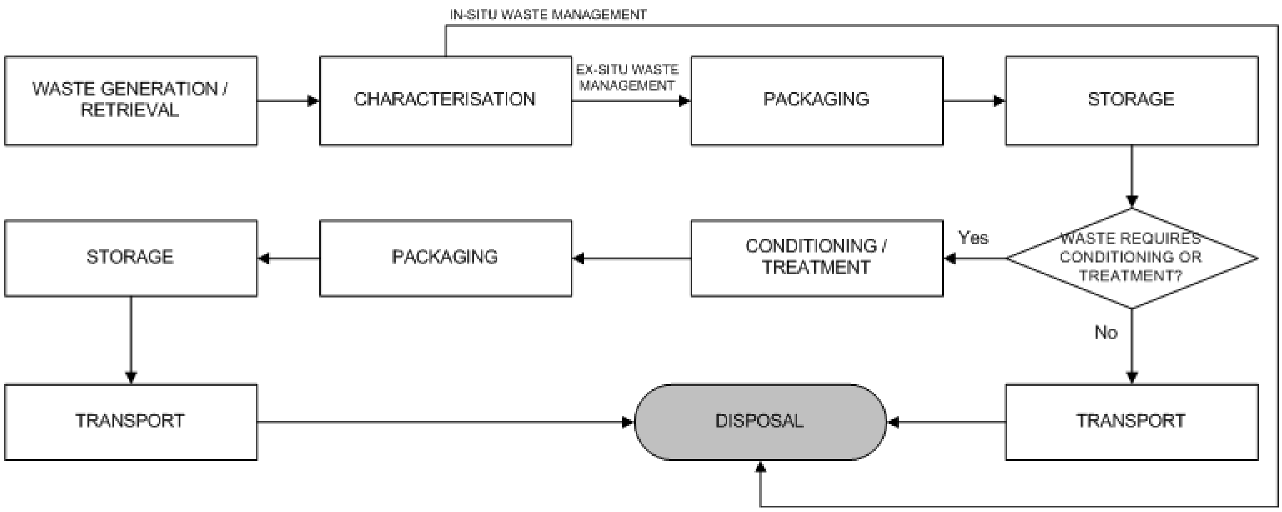
1.1 LLW / ILW Cross-Boundary Wastes

LLW / ILW cross boundary wastes can be defined as ILW and LLW with a concentration of specific radionuclides that prohibits or significantly challenges its acceptability at existing and planned future disposal facilities for LLW that practicably be managed as LLW (on the basis of radiological and physico-chemical properties) through the application of a treatment process or decay storage. These form a category of waste of significant interest within the UK nuclear industry as waste management strategies for it are typically not well defined and are potentially challenging to execute. However, finding the right solution for such wastes can often lead to significant opportunities for hazard reduction, cost reduction and schedule acceleration.

1.2 Waste management decision making

Waste management describes the process by which waste is collected, transported, recovered, conditioned and disposed of [Ref. 4]. It covers all the phases of activity relating to a waste from the point of generation or retrieval to the point of disposal; including characterisation, conditioning / treatment, packaging and transport. It is a key element of commercial nuclear fuel cycle operations and decommissioning. Decision making with respect to waste management refers to the combination of individual decisions made for each of the elements of the waste management lifecycle but is often described in terms of the treatment / conditioning and disposal decisions.

Figure 1 – Waste management project lifecycle



In the UK, formal and robust waste management decision making and optioneering is a regulatory expectation which is part of the requirement for demonstration of BAT (England and Wales) / BPM (Scotland)[2] and ALARP. In addition, for the NDA estate, where investment is required for the execution of a waste management option, optioneering is a mandatory legal requirement via business cases.

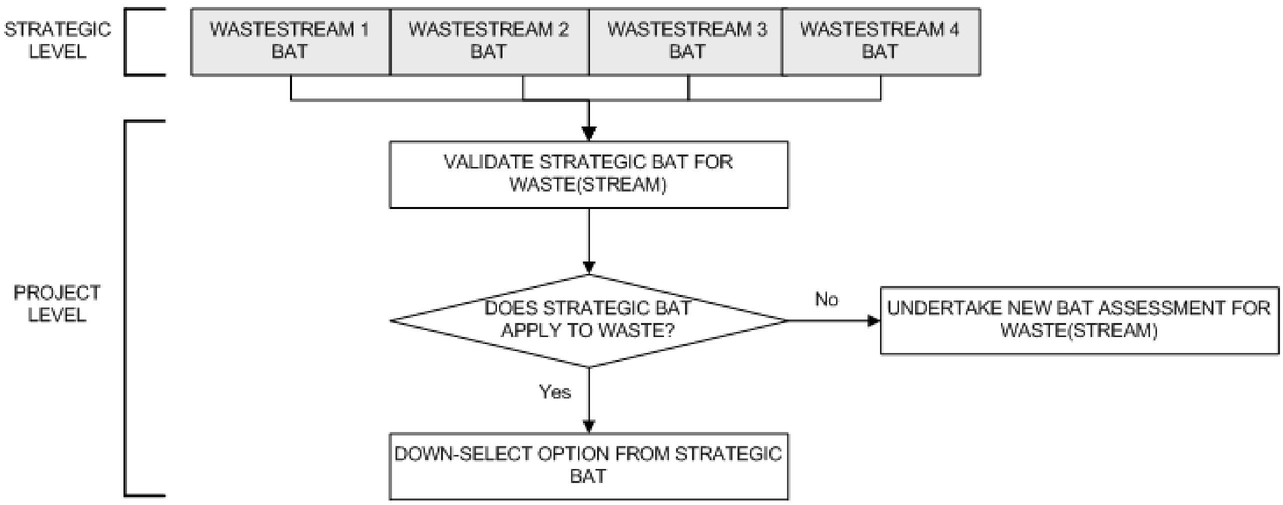
[2] It is recognised that the use of Best Practicable Means (BPM) continues to be required by the Scottish Environmental Protection Agency (SEPA) and the Northern Ireland Environment Agency. The Environment Agency (EA) and SEPA consider the requirement to use BPM as equivalent to the requirement to use BAT and that the obligations on waste producers are the same. As a consequence, this guidance will also be applicable in Scotland [Ref. 5]. The term BAT is predominantly used in this document but this applies to BPM for those waste consignors in Scotland.

1.2.1 *Best Available Technique (BAT)*

Operators with Environmental Permits for the disposal of radioactive waste have a requirement, under the conditions of the Environmental Permitting Regulations (England and Wales) 2010 and their Environmental Permit (Radioactive Substances Act 1993 Amendment (Scotland) Regulations and Radioactive Substances Act 1993 Authorisation in Scotland), to ensure that all exposures to the public are As Low As Reasonably Achievable (ALARA), whilst having regard to factors such as protection of the environment and other social / economic impacts. The application of Best Available Technique (BAT), in England and Wales, is the means that such operators use to demonstrate compliance with this requirement [Ref. 5].[3]

Waste practitioners have been observed to apply BAT in a two phased approach, with the definition of strategic level BAT and project level BAT (what was Best Practicable Environmental Option (BPEO) and Best Practicable Means (BPM) respectively in the previous regulatory regime for England and Wales)[4]. At the strategic level BAT defines the strategic or reference position for waste management for a generic wastestream, identifying a preferred option or options (i.e. defines the "what"). At the project level, BAT applies to a specific waste item, population of wastes or specific wastestream (i.e. defines the "how") and describes in more detail the management arrangements to minimise and optimise the wastestream.

Figure 2 – Relationship between strategic level and project level BAT



1.2.2 *Business Cases*

Business cases are a mandatory part of planning, approval, procurement and delivery of investments within the public sector, and are a requirement on NDA and its contractors (i.e. the NDA estate) [Ref. 5]. For the NDA estate, business cases are produced by waste consignors where there is a need for an investment decision relating to programmes, projects and work activities, or where there is a need for a strategy to progress through the NDA Strategy Management System. Business cases involve different aspects of options identification and options appraisal (particularly within the Economic, Commercial and Financial cases). Methodology for the development of business cases is provided in NDA Guidance for the Production of Business Cases EGG08 [Ref. 6].

[4] This document refers to strategic level BAT and project level BAT. These terms can be read as strategic level BPM and project level BPM respectively for those operating within the Scottish regulatory regime.

1.2.3 *Radioactive Waste Management Cases (RWMC)*

RWMC are a regulatory expectation for the management of HAW. The RWMC intends to provide a demonstration of radioactive waste management across the lifecycle of a wastestream (or wastestreams) and should provide a transparent narrative of the management of that wastestream (or wastestreams) from retrieval to disposal, including the reasoning and justification for the proposed waste management approach. Specific detailed description of the regulatory framework and content of RWMC is provided in the Office for Nuclear Regulation (ONR) / EA / SEPA joint regulatory guidance on radioactive waste management [Ref. 7-8].

1.3 Challenges for LLW / ILW cross-boundary waste decision making

The selection of waste management approaches and strategies for LLW / ILW cross-boundary waste is often challenging for waste practitioners as a consequence of the nature of the waste (often higher dose and consequently more difficult to handle than LLW), the range of waste management options and potentially conflicting strategic priorities. The principal issues and barriers which contribute to making waste decision making challenging for LLW / ILW cross-boundary wastes are outlined in this section.

1.3.1 *Waste / site specific issues and barriers*

There are a number of waste and site specific issues and boundaries which contribute to the challenging nature of waste decision making for cross-boundary wastes. These include:

- The ability, and opportunity, to appropriate characterise the waste. This may be a consequence of the availability of suitable characterisation techniques, the high-dose environments where characterisation may need to take place and the timing / scheduling of waste management operations.
- The mode and levels of contamination of the waste (surface contamination, volumetric contamination, activation, the contamination source, extent / type of contamination).
- The type and geometry of the waste; and the associated ease of decontamination.
- The availability of facilities and infrastructure for retrieval, handling, processing, packaging and transport of waste.

1.3.2 *Generic issues and barriers*

A number of generic issues and barriers which pose challenges to effective decision-making for LLW / ILW cross-boundary wastes have been identified by waste practitioners including:

- A perceived lack of integration, joined-up thinking and communication between LLWR and RWMD with respect to decision making for disposal of such wastes, resulting in an increased burden of work on waste practitioners.
- A perceived absence, in some parts of the nuclear industry, of a centralised knowledge management system relating to BAT assessments and Letter of Compliance (LoC) submissions across the NDA estate (and indeed outwith the NDA estate) limiting information sharing and dissemination, and potentially contributing to duplication of effort.
- A lack of a national strategic perspective on the relative value of LLWR and GDF (e.g. is a unit volume of space or unit amount of radioactivity at LLWR more valuable to UK plc than at GDF?). Waste practitioners have indicated that this would be a key discriminator between waste management options for cross-boundary wastes.
- The limited facilities and infrastructure at SLC sites with the capability to handle such cross-boundary and ILW wastes, impacting on the range of waste management approaches which can feasibly be employed and potentially contributing to implementation of non-optimal solutions.
- Lack of guidance on how to define the waste sentencing volume (i.e. what constitutes an item, population and wastestream), which can have a significant impact on decision making.
- The cultural norm for waste management has been to consider wastestreams (large generic volumes) rather than items or populations for waste classification and decision making. Systems for waste consignors, e.g. for activity assessment, are designed for wastestreams which makes decision making for discrete items or populations of waste more challenging.

1.3.3 Tension with national waste strategies / regulatory requirements

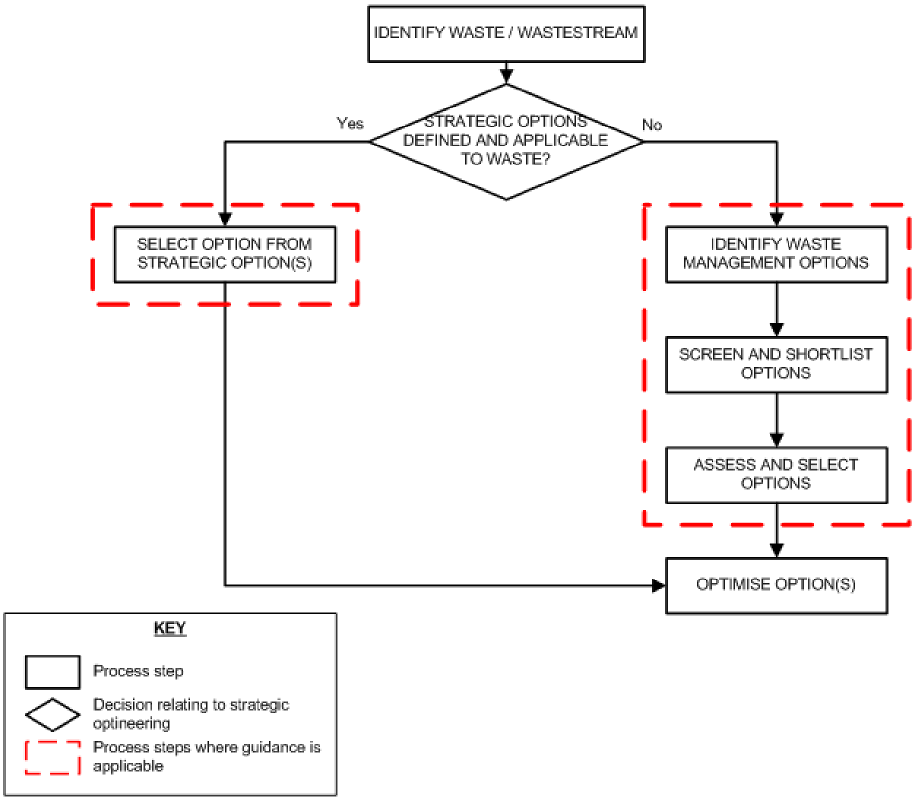
Management of cross-boundary waste is arguably more complex than for other types of waste because it involves a decision between disposal (of raw waste, conditioned / treated waste and / or secondary wastes from treatment of raw waste as applicable) of radioactive waste to LLWR, decay storage and subsequent waste management, or interim storage pending disposal to the Geological Disposal Facility (GDF). The disposal fate of the raw or transformed waste has differing consequences for waste consignors (in terms of cost, schedule, site end state, storage volume available on site etc.) and for UK plc (in terms of the remaining radiological and volumetric capacity at both the LLWR and GDF). The importance of both of these disposal facilities has been identified in national strategic space [Ref. 3, 9] and it is known that there are (or will be, in the case of GDF) limitations on capacity at these facilities. Despite this there is an absence of definitive guidance on the relative value of LLWR versus GDF, and hence where cross-boundary wastes should be dispositioned. In addition to this, waste management practitioners are managing a dynamic tension between national strategy and policy for management of radioactive waste [Ref. 3, 9-10] and certain regulatory requirements (such as site license conditions which require the minimisation of the rate of production and total quantity of radioactive waste accumulation on a site at any time; and Safety Assessment Principles which identify waste avoidance and minimisation as the foremost principles for good waste management [Ref. 10]).

1.4 Purpose of Guidance Document

Given this context, the issue of waste management of LLW / ILW cross-boundary waste is significant within the nuclear industry. Whilst guidance has been developed and published on the management of HAW on nuclear licensed sites [Ref. 7-8, 11-14], historically there has been a lack of guidance on the management of those wastes that, through application of treatment, can cross the boundary between HAW and LAW. This document aims to make a contribution towards closing this gap by providing guidance, based on the practical experience of NDA estate SLCs, on the factors used for waste management decision making for LLW / ILW cross-boundary wastes. It is intended to support waste practitioners in making such decisions by identifying those factors deemed to be the most relevant to LLW / ILW cross-boundary wastes and by providing a structured approach for considering these factors. This is complementary to, and not a separate requirement from, existing decision making / optioneering processes used by Consignors for identification of BAT or production of business cases and is designed to be used in conjunction with those processes. It is intended that this guidance could be used to inform decision making at various stages of the waste management optioneering process (as summarised in Figure 3): including the stage of validation of any existing strategic level optioneering; and / or at preliminary option identification and screening; and / or at the final waste option identification stages.

This guidance does not intend to dictate an approach that must be implemented by Consignors but rather to provide guidance to support and augment existing (or developing) SLC or site procedures and strategies. It should be noted that this guidance does not directly apply to discrete (i.e. non cross-boundary) LLW and ILW, although some of the factors identified may be appropriate to support decision making for these wastes.

Figure 3 – Decision making schematic illustrating applicability of guidance to waste decision making process steps



2. Scope and Objectives

This document is a guidance document on decision making relating to the management of wastes close to the LLW / ILW classification boundary. This guidance document seeks to support waste management optioneering for LLW / ILW cross-boundary waste by describing the specific decision making factors which are key for this particular waste classification.

The objective of this document is to provide guidance and support to practitioners making decisions relating to the waste management of LLW / ILW cross-boundary waste by:

- Describing the key factors involved in decision making relating specifically to LLW / ILW cross-boundary wastes.
- Providing a model to enable the decision making factors to be considered in a structured, relevant and prioritised way by waste management practitioners.
- Identifying how this model can be applied in the context of optioneering for BAT and business cases.
- Providing specific information and links to sources of information that enable application of these decision making factors.

In the context of this guidance document:

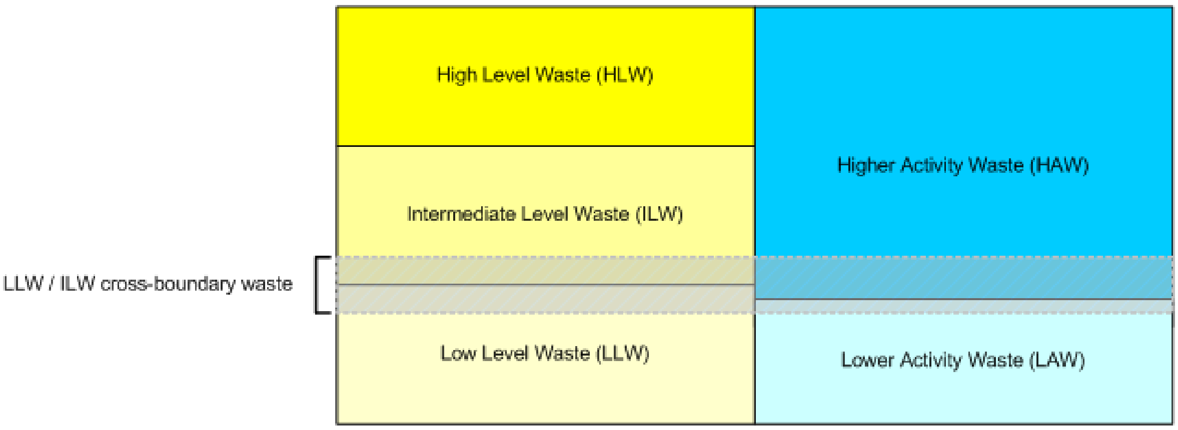
- 'Treatment' refers to any process which can be applied to a waste (stream) that will change its physical, chemical and / or radiochemical characteristics. This includes (but is not limited to) decontamination, thermal processing (e.g. incineration, metal melting, vitrification), encapsulation. Decay storage is referred to as a distinct process as it can be considered to be a passive rather than active process.
- 'Disposal' refers to the authorised emplacement of packages of radioactive waste in a disposal facility without the primary intention of retrieval.
- 'Cross-boundary waste' refers to higher activity waste (HAW) and LLW whose concentration of specific radionuclides and / or physico-chemical characteristics would significantly challenge its disposability at current and future LLW disposal facilities, that practicably be managed as LLW through the application of a treatment process or decay storage.
- 'Waste management practitioner' and 'waste consignor' refers to any individual or group of individuals who have responsibility for making decisions on the management of LLW / ILW cross-boundary waste.
- Waste management refers to the whole process of managing waste from generation / retrieval to disposal.

It is noted that policies for the disposal of HAW differ in Scotland and in England / Wales [Ref. 3]. The following guidance can be applied equally in England, Scotland and Wales, but references to geological disposal and the Geological Disposal Facility (GDF) will correspond to long-term near-surface storage when applied to Scotland. In addition, the DSRL has its own permitted facility for disposition of LLW; it is intended that this guidance is also applicable to Dounreay but that references to disposal to LLWR will correspond to the Dounreay facility in this case.

3. Identifying LLW / ILW cross-boundary wastes

LLW / ILW cross-boundary waste is a non-formal waste classification, which is based on the radioactive properties of the waste. This waste classification incorporates LLW and ILW which is classifiable as higher activity waste (HAW), and some LLW classifiable as lower activity waste (LAW) as illustrated by Figure 4.

Figure 4 – Schematic illustrating positioning of LLW / ILW cross-boundary waste classification in conventional radiological waste classification spectrum



It should be noted that the physico-chemical properties of a waste (or wastestream) are an equally important factor in determining the feasibility of a particular waste management option. For example, a waste may satisfy the radiochemical requirements for disposition to LLWR but may possess physico-chemical properties which preclude this, which may result in the waste requiring disposal in GDF or being classified as an orphan waste. Alternatively, the physico-chemical properties of a waste may preclude management via geological disposal. Thus, the physico-chemical properties of a waste should be considered when establishing whether a waste is a cross-boundary waste.

The test criteria for determining whether a waste is (or is expected to be) a LLW / ILW cross-boundary waste are:

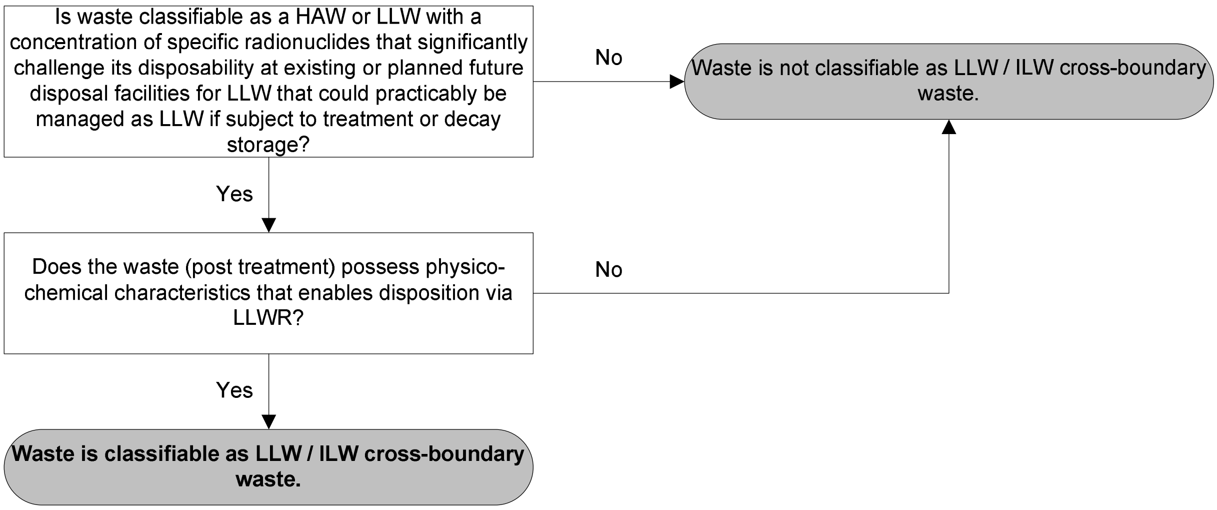
- Is the waste currently classifiable as a HAW or LLW with a concentration of specific radionuclides that significantly challenge its disposability at existing or planned future disposal facilities for LLW that could practicably be managed as LLW through the application of some treatment process or decay storage?
- Does the waste (post treatment) possess physico-chemical characteristics that enables disposition via LLWR?

These test criteria are summarised in Figure 5.

A definition of LLW / ILW cross-boundary waste can be provided based on these test criteria:

LLW / ILW cross-boundary waste comprises of ILW and LLW with a concentration of specific radionuclides that prohibits or significantly challenges its acceptability at existing and planned future disposal facilities for LLW that practicably be managed as LLW (on the basis of radiological and physico-chemical properties) through the application of a treatment process or decay storage.

Figure 5 – Summary of test criteria for determining waste classification as a LLW / ILW cross- boundary waste



4. Inventory of LLW / ILW cross-boundary waste

To provide context to the definition of waste provided in Section 3 and to provide waste practitioners with examples of what constitutes LLW / ILW cross-boundary waste, a review of the UK radioactive waste inventory to identify LLW / ILW cross-boundary waste has been undertaken. This inventory analysis is based on a historical review of cross-boundary wastes undertaken in 2009 [Ref. 1] to support the LLWR 2011 Environmental Safety Case, which identified a range of wastestreams which potentially meet the classification of LLW / ILW cross-boundary waste as provided in Section 3 (i.e. waste whose characteristics do not comply with the current LLWR WAC which would become potentially acceptable on treatment). The findings of this 2009 study have been updated based on a review of the 2010 UKRWI report [Ref. 2] and datasheets. This inventory of LLW / ILW cross-boundary waste is described in terms of volume on the basis of radiological classification of the raw waste, waste type and consignor.

This inventory analysis is provided for indicative purposes only – as identified in Section 4.1 and 4.2 there are a range of assumptions and uncertainties associated with the data and analysis which have overestimated the inventory – so as to provide some context to the issue of LLW / ILW cross-boundary waste for waste practitioners.

4.1 Assumptions

A number of specific assumptions have been used in the generation of this inventory analysis:

- The primary data set is the 2009 Conditioned Waste Disposal Study [Ref. 1] and UKRWI 2010 [Ref. 2]. The specific assumptions used for the generation of these two information sources apply to this inventory analysis. A list of the wastestreams included in the analysis is provided in Appendix 1.
- As setting a quantified definition of LLW / ILW cross boundary waste based on radioactivity is difficult owing to the diversity of potential waste management techniques, the main inventory assumption of the 2009 study [Ref. 1] has been utilised to derive this inventory. Wastestreams included in the analysis are those which are ILW that have already been conditioned for disposal as LLW to LLWR and those which are yet to be conditioned but which have specific activity five times that of the current repository total specific activity acceptance limits [Ref. 1]. It is acknowledged that this may overestimate the inventory of LLW / ILW cross-boundary wastes.
- Two key wastestreams – graphite and contaminated land - have been specifically excluded from consideration in this analysis owing to ongoing national strategy development for these waste types. It is identified that definition of a specific strategic direction will have significant impact on the inventory and as such, until such a position is identified, these wastes have been excluded from the analysis.
- The acceptability of the physico-chemical form of the waste has not been considered.

4.2 Uncertainties

There are a number of specific uncertainties in the data and inventory analysis which have an impact on the inventory reported in Sections 4.3 to 4.5:

- Radiochemical data provided in UKRWI 2010 [Ref. 2] is reported on a wastestream basis and may in some cases, owing to the timescales for waste retrieval / decommissioning / demolition, not be based on robust or comprehensive characterisation data.
- Discrete items or volumes of waste may have different radiochemical characteristics to that declared in the relevant wastestream reported in UKRWI 2010 [Ref. 2]; and this may not be ascertained until characterisation of the waste post retrievals.
- The performance of wastestream radiochemical data against limits in the LLWR WAC for fissile isotopes has not been discretely considered.

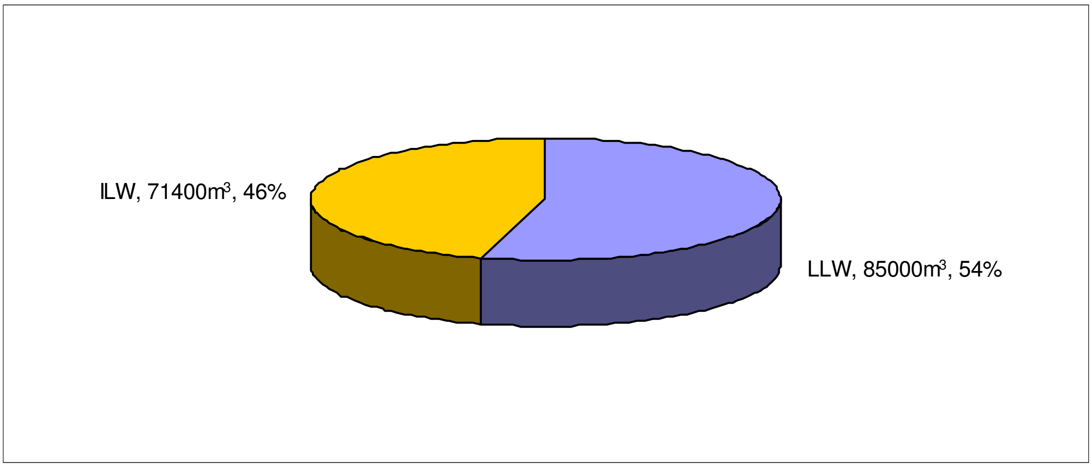
- Uncertainty on radionuclide specific activity as reported in UK RWI 2010 [Ref. 2].
- The national strategic position for management of specific high volume wastestreams such as graphite and contaminated land HAS YET TO BE DEFINED.
- It is acknowledged that there is an inconsistency in the volume of cross-boundary pond furniture waste identified in this and other inventory analyses [Ref. 15]. This is a consequence of the differing assumption sets and the fact that this analysis is based on the labelling / description of wastestreams in UKRWI. Comparison against the analysis in Ref. 15 indicates that the inventory of pond furniture detailed in this analysis is over-estimated.
- The performance of wastestreams against limits for specific radionuclides associated with disposition to LLWR has not been discretely considered, owing to the ongoing review of the LLWR Environmental Safety Case (ESC). Analysis undertaken in Ref. 1 considered the performance of identified cross-boundary wastestreams against 18 key LLWR ESC radionuclides and identified that only approximately 18,800m^3 of waste had a concentration of key radionuclides exceeding 1% of the total future ESC inventory (a nominal level of acceptability selected for the study). This analysis demonstrates that the concentration of specific radionuclides may have significant impact on the acceptability of waste to LLWR (and hence the inventory of cross-boundary waste).
- Inconsistencies in the SLC responses in the inventory analysis used in Ref. 1 (i.e. the use of different inventory calculation methodologies by Consignors in the data submitted to LLWR for analysis).
- Site specific waste decommissioning plans, where different to the intended destinations of waste specified in Ref. 2, have not been considered and factored into the analysis. On this basis, certain volumes of waste may be overestimated (for example, a decommissioning strategy for management of concrete may involve scabbling, reducing the volume of potential LLW / ILW cross-boundary waste).

It is considered that, owing to the combination of these uncertainties, that the inventory detailed in this document is an upper bound of the inventory of cross-boundary waste in the UK.

4.3 Inventory breakdown by radiological classification

The breakdown of the projected LLW / ILW cross-boundary waste inventory for the UK by radiological classification of the raw waste is described by Figure 6.

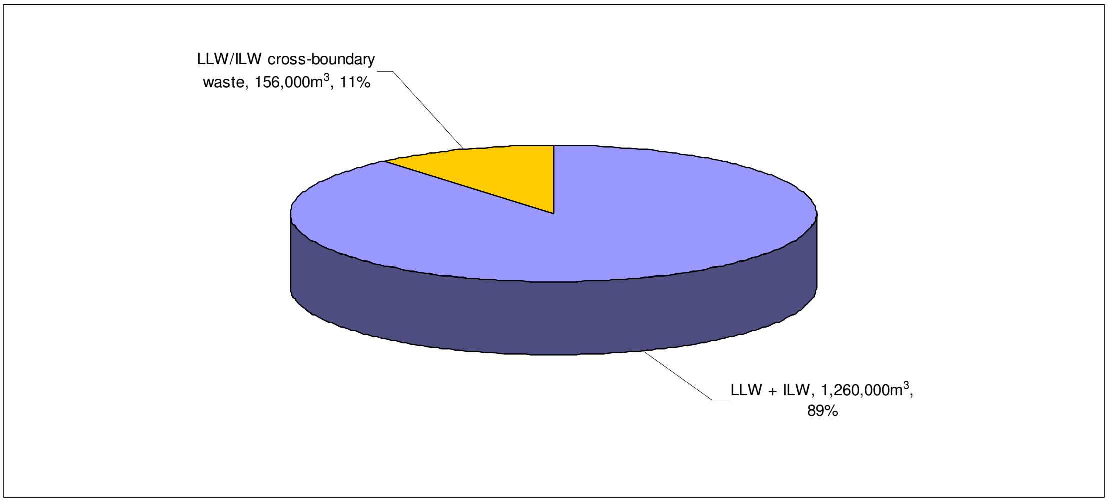
Figure 6 – Breakdown of 2010-2100 projected LLW / ILW cross-boundary waste volume (m3) in the UK by radiological classification



The total volume of waste arisings between 2010 and 2100, on the basis of this inventory review, of LLW / ILW cross-boundary waste is projected to be 156,000m^3. The split of this inventory between LLW and ILW is projected to be approximately equal (54% and 46% respectively).

Figure 7 presents this upper-bound volume of cross-boundary waste in the context of the total national inventory of LLW and ILW (as derived from Ref. 2). This indicates that, at the maximum, the volume of cross-boundary waste is 11% of the total national LLW and ILW inventory generated from 2010 to 2120.

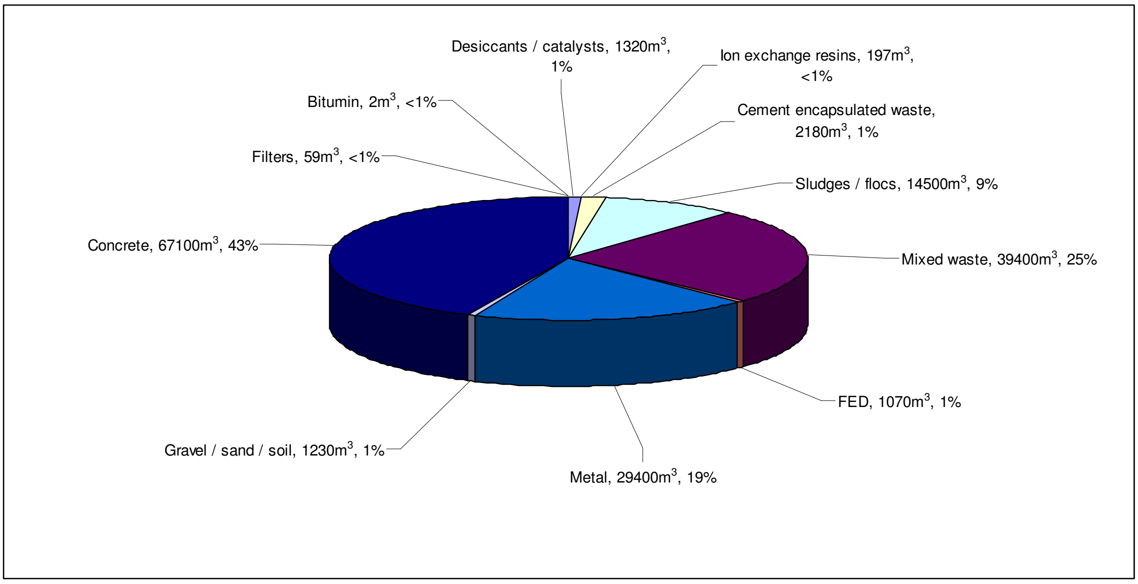
Figure 7 – Projected upper-bound volume (m^3) of LLW / ILW cross-boundary waste in the context of the national UKRWI LLW and ILW inventory 2010-2120



4.4 Inventory breakdown by waste type

The LLW / ILW cross-boundary waste inventory is comprised of a diverse range of waste types, as illustrated by Figure 8.

Figure 8 – Breakdown of 2010-2100 projected LLW / ILW cross-boundary waste volume (m3) in the UK by waste type



The national LLW / ILW cross-boundary waste inventory is dominated by concrete (43% of the inventory by volume), mixed waste (i.e. combinations of metallic, plastic, rubber, cellulosic and ceramic wastes from operations or decommissioning operations which contributes 25% of the volume) and discrete metallic waste (19%, of which 3% is pond furniture). The smallest volumes of waste are attributed to ion exchange resins (<1%), filters (<1%) and bitumen (<1%).

4.5 Inventory breakdown by consignor

LLW / ILW cross-boundary waste will be produced by a range of waste consignors within the UK nuclear industry, both within and outside the NDA estate, as illustrated by Figure 9. It is projected on the basis of this inventory analysis that the vast majority of the LLW / ILW cross-boundary waste will arise from the NDA estate (approximately 93% by volume).

Figure 9 – Breakdown of 2010-2100 projected LLW / ILW cross-boundary waste volume (m3) in the UK by consignor

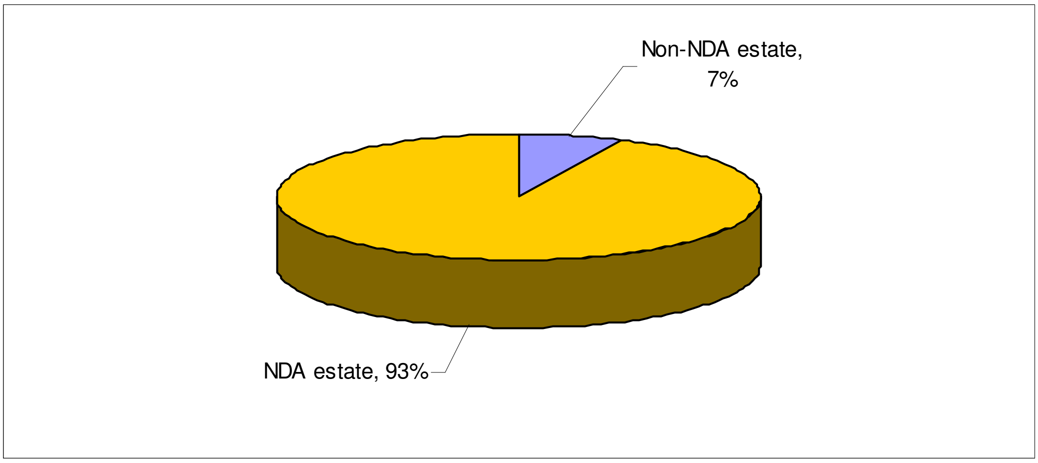
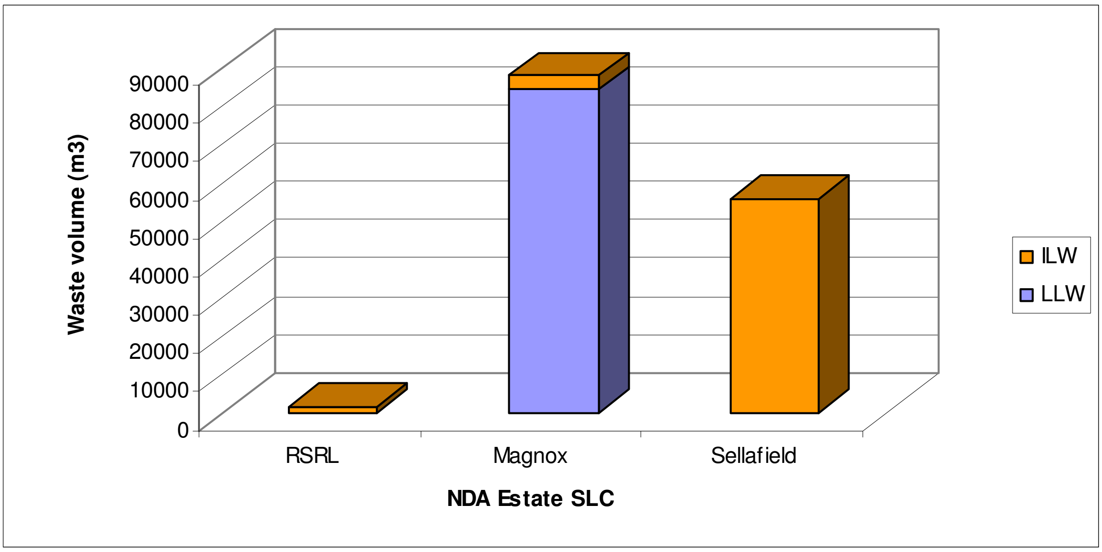


Figure 10 provides an illustration of the inventory breakdown within the NDA estate. It is projected that the largest volume of LLW / ILW cross-boundary waste will be generated by Magnox Ltd. (approximately 60% of the NDA estate inventory of cross boundary waste and 56% of the national inventory). The majority of the Magnox Ltd. cross-boundary waste inventory is comprised of LLW (predominantly consisting of concrete and metal). Sellafield Ltd. possess 38% of the projected inventory (36% of the national inventory), which is entirely classifiable in its raw form as ILW and comprises concrete, mixed waste and sludges / flocs with smaller volumes of metal and pond furniture. Within the NDA estate, RSRL has the smallest volume of cross-boundary waste with 1% of the volume which based on this inventory analysis is wholly comprised of legacy cement-encapsulated wastes. The key contributors to the inventory of waste arising from the non-NDA estate are Ministry of Defence, AWE and EdF.

Figure 10 – Breakdown of 2010-2100 projected LLW / ILW cross-boundary waste volume (m3) in the UK by consignor within the NDA estate



5. Waste disposal approval process

LLWR and RWMD have different procedures for waste acceptance, and these are detailed below to provide some context to waste decision making; and identification of how BAT and business cases fit into this context.

Waste consignors / decision-makers should note that sustained engagement with LLWR and RWMD is a vital component of the waste disposal approval process. Engagement with LLWR and RWMD from the earliest possible phase of the decision making process allows for appropriate sharing of information and should result in more robust and underpinned waste management decisions.

5.1 LLWR Waste Acceptance Procedure

LLWR, as an operational radioactive waste disposal facility, has a formal waste acceptance procedure [Ref. 16] which details how waste must be consigned under the LLWR Waste Services Contract and Waste Acceptance Criteria [Ref. 17-18].

The WAC, owing to the range and diversity of LLW, is generic enough to cover the majority of waste consigned but there are instances when consignors require variations to specific conditions of the WAC for specific waste(streams). LLWR operates a variation process [Ref. 19] that provides waste consignors with a mechanism to request a variation or waiver of a particular condition of the WAC for a particular waste management project. Any request for a variation is assessed by LLWR (with consideration of the implications to the LLWR 2011 Environmental Safety Case (ESC) and the national implications of accepting the waste) and feedback on acceptance or rejection of the variation is provided to the waste consignor.

For especially challenging wastes, review of the Waste Enquiry (plus supporting information) and Waste Variation (where applicable) is undertaken by the LLWR Strategic Waste Management Project Committee [Ref. 20]. This Committee reviews waste management proposals in the following cases:

- Where the waste represents a significant challenge to existing operational practices (e.g. use of non-standard containers, disposal of non-containerised waste or wastes outwith of the WAC).
- Where the project involves waste(stream)s not identified in the National LLW inventory used to underpin the 2011 ESC
- Where the waste represents a significant use of the radiological and / or volumetric capacity of the LLWR site.

The Strategic Waste Management Project Committee is comprised of the LLWR Executive, along with relevant subject matter experts within LLWR, and representation from NDA, RWMD and the EA. The Committee enables LLWR and stakeholders to discuss and thereafter reject or approve (subject to any further technical assessment and / or sanction) proposals for any individual waste management project which meets the specified criteria.

5.2 RWMD Waste Acceptance Procedure

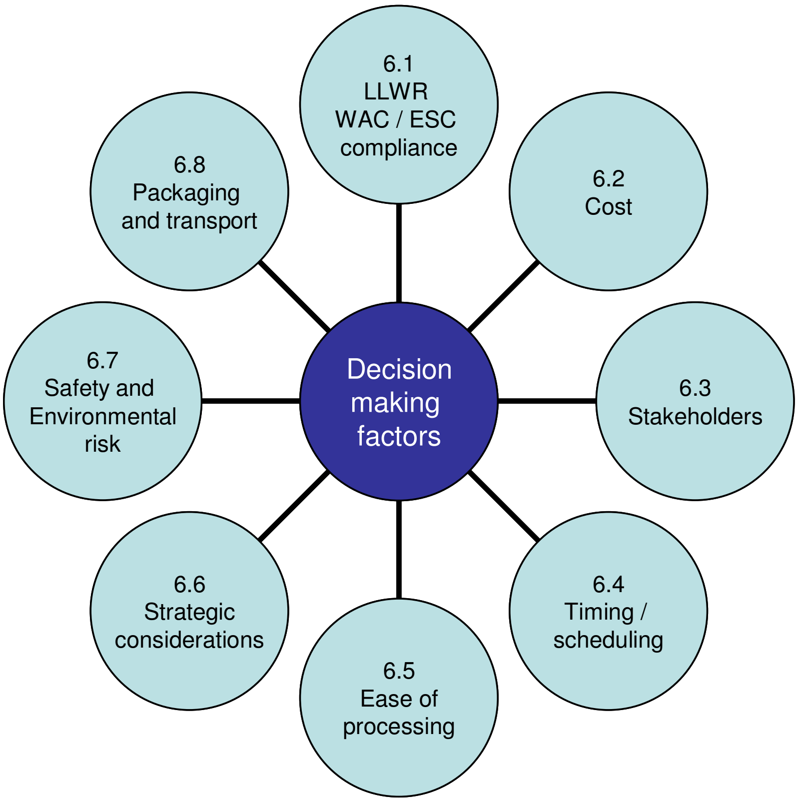
RWMD is responsible for the programme of work that will deliver the geological disposal facility (GDF) for the UK.

Whilst specification, siting, design, permissioning and construction of the GDF are ongoing, RWMD is not in a position to accept waste for disposal. RWMD is delivering a specific remit, however, to assess the disposability of waste packages to allow nuclear sites to progress clean-up and hazard reduction, with packaged waste undergoing managed interim storage at waste consignor sites pending the availability of the GDF [Ref. 21]. Detailed information relating to the RWMD waste acceptance process is available via the NDA website (www.nda.gov.uk, Ref. 21 and Ref. 22).

6. Decision Making Factors

It is acknowledged that decision making with respect to any waste type is driven by consideration of a range of factors. Documents such as the BAT NICoP [Ref. 5] and EGG08 [Ref. 6] provide guidance on which factors may be considered when making decisions about waste management. Given the particularly challenging nature of LLW / ILW cross-boundary wastes (in terms of handling, range of options and consequences of implementing options) it is recognised that a different range of decision making factors, or a specific sub-set of the factors in the BAT NICoP [Ref. 5] and EGG08 [Ref. 6], are more relevant to decision making for this waste type. A range of high-level decision making factors pertinent to LLW / ILW cross-boundary waste management decision making have been identified in conjunction with NDA estate SLCs and are summarised in Figure 11.

Figure 11 – Summary of key decision making factors for LLW / ILW cross-boundary wastes



Detailed definition of each of the decision factors identified in Figure 11 is provided in the introduction to Sections 6.1 to 6.8.

It has been identified that the mix of these decision making factors for consideration varies depending on the phase of the decision making process (for example, certain factors are more useful for identifying options than for differentiating between different options). The applicability of the decision making factors to the different phases of the waste management decision making process are mapped in Table 1. However, it should be noted that all of the factors should be initially assessed for their relevance to the specific phase of decision making and that Table 1 is for guidance purposes only.

Table 1 – Matrix illustrating applicability of decision making factors to phases of waste management decision making process (✓ means factor is applicable, ×/✓ means factor may or may not be applicable)

	Phase of decision making process			
Factor	**Validation of strategic BAT**	**Identification of potential options**	**Option screening / short-listing**	**Option assessment (differentiation between options)**
Ease of processing	✓	✓	✓	✓
Strategic considerations	✓	✓	✓	✓
Cost	✓	×/✓	✓	✓
Stakeholders	✓	✓	✓	✓
LLWR WAC / ESC compliance	✓	✓	✓	✓
Timing / scheduling	✓	✓	✓	✓
Safety / environmental risk	×/✓	×/✓	✓	✓
Packaging and transport	✓	✓	✓	✓

Each of these high-level factor groups are comprised of a range of specific sub-factors which enable analysis of different waste management options. Sections 6.1 to 6.8 provide a summary of the sub-factors for each of the individual factor groups. These summaries for each factor group consist of a definition of the high-level factor, a list of the sub-factors (expressed as a question set), reference to the phase of the decision making process (as described in Figure 3) to which that question is specifically relevant and a list of the information sources which could be used to resolve that question / sub-factor. The listing of information sources is not exhaustive and many of these information sources are specific to the waste, plant or SLC and so are locally available, but there are also a number of more generic information sources referenced (further information about these information sources is available in Appendix 2).

Prioritisation of the factors and sub-factors, as described in Step 5 in Table 2, should be undertaken on a case-by-case basis. Factor / sub-factor prioritisation has been identified to be driven by local issues and constraints – such as waste(stream) type, project schedules, corporate priorities and regulatory requirements – which are unique to the waste(stream) in question.

6.1 Sub-factors for Compliance with LLWR Waste Acceptance Criteria / Environmental Safety Case

This factor group specifically relates to the acceptability of the wastestream for disposal at LLWR in terms of performance against the WAC and Environmental Safety Case (ESC). This may apply to the raw waste, conditioned waste and any relevant secondary wastes arising from waste treatment. It should be noted that the requirements of the ESC will be communicated to waste consignors via the WAC for LLWR, and this should be the primary source of information for waste consignors.

Description of sub-factor	Information sources[5]
What physically, chemically and radiologically can be disposed of to LLWR (what are the constraints / requirements of the LLWR WAC)? What are the processes / options for wastes that do not comply with the WAC for disposal to LLWR? Does the waste(stream) in question meet the requirements of the WAC?	• *LLWR Disposal Waste Acceptance Criteria [Ref. 18]* • *LLWR Environmental Safety Case [Ref. 23]* • BAT Assessments for similar wastes (acceptable to LLWR) • *LLWR Services Waste Acceptance Criteria [Ref. 24-26]* • *RWMD Waste package specification and guidance documents [Ref. 27]* • Characterisation data (physical, chemical and radiochemical) • Waste Enquiry (via LLWR) [Ref. 28] • Dialogue with LLWR • Dialogue with RWMD
Does the waste(stream) meet the intent of the ESC?	• *LLWR Disposal Waste Acceptance Criteria [Ref. 18]* • *LLWR Environmental Safety Case [Ref. 23]* • Characterisation data (physical, chemical and radiochemical) • Waste Enquiry (via LLWR) [Ref. 28] • Dialogue with LLWR • BAT Assessments for similar wastes (acceptable to LLWR)

[5] Information sources denoted in *italics* are generic information sources and further information is available in Appendix 1.

6.2 Sub-factors for cost

This factor specifically relates to the cost of implementing an option, both in terms of full lifecycle cost for implementation of a given option and the more practical affordability of a given option within site / programme / project specific funding constraints.

Decision Factor Question	Information Sources
What is the full lifecycle cost for implementing a specific option?	• *LLWR cost norm model (EGG01 Supplemental [Ref. 29], LLWR Service Pricing [Ref. 30], Appendix 4)* • *LLW metal decontamination study [Ref. 31]* • *EARWG Waste Minimisation database [Ref. 32]* • GDF cost norm model[6] • *Guidance material on the transport of radioactive waste [Ref. 33]* • *Packaging specifications for higher activity waste [Ref. 27]* • Lifetime Plan data • Characterisation, treatment, packaging and transport cost information from supply chain. • Characterisation, treatment, packaging and transport cost information from LLWR (via Waste Enquiry).

[6] Refer to Appendix 5 for further information relating to the GDF cost norm model

Decision Factor Question	Information Sources
What is the short-term cost for implementation of a specific option?	• *LLWR cost norm model (EGG01 Supplemental [Ref.29], LLWR Service Pricing [Ref. 30], Appendix 4)* • *LLW metal decontamination study [Ref. 31]* • *EARWG Waste Minimisation database [Ref. 32]* • GDF cost norm model[6] • Lifetime Plan data • Characterisation, treatment, packaging and transport cost information from supply chain • Characterisation, treatment, packaging and transport cost information from LLWR (via Waste Enquiry)
What is the cost of interim storage of waste on-site?	• Lifetime Plan data
What is the uncertainty in the full lifecycle and short-term costs?	• *LLWR cost norm model (EGG01 Supplemental [Ref. 29], LLWR Service Pricing [Ref. 30], Appendix 4)* • *LLW metal decontamination study [Ref. 31]* • *EARWG Waste Minimisation database [Ref. 32]* • GDF cost norm model[6] • *Guidance material on the transport of radioactive waste [Ref. 33]* • *Packaging specifications for higher activity waste [Ref. 27]* • Lifetime Plan data • Characterisation, treatment, packaging and transport cost information from supply chain. • Characterisation, treatment, packaging and transport cost information from LLWR (via Waste Enquiry).

6.3 Sub-factors for stakeholders

This factor involves identifying the expectations of key stakeholders and measuring the performance of options against these. This is undertaken by establishing which stakeholders relevant to the specific waste management project, their expectations and what would be acceptable in terms of the waste management solution and outcomes; then making an assessment of whether the waste management solution and outcomes will be acceptable to the stakeholders.

Decision Factor Question	Information Sources
Which stakeholders are relevant to the waste management project? What are the expectations of the stakeholders relevant to the project? What is going to be acceptable to the stakeholders? Does the option meet the expectations of the key stakeholders?	• Stakeholder maps (for project, programme, plant or SLC) • Dialogue with LLWR • Dialogue with RWMD • Dialogue with regulators / NDA • Stakeholder engagement / dialogue with stakeholders • Output from local site stakeholder group meetings • BAT assessment for similar wastes • Site Environmental Permit • *Guidance material on the transport of radioactive waste [Ref. 33]* • *Joint regulatory guidance on HAW management [Ref. 7-8, 11-14]* • *Transport Regulations* • Waste management option descriptions

6.4 Sub-factors for Timing / Scheduling

The compatibility of a particular waste management option with the project / programme schedule is a key decision making factor. This question set provides prompts to explore the schedule sensitivity of the project / programme and provides a means to assess whether a particular waste management decision or option will impact upon this in an unacceptable manner.

Decision Factor Question	Information Sources
When does a decision on waste management strategy need to be taken for a specific waste(stream)? When does the waste management solution need to be implemented for the specific waste(stream) and when does it need to be completed by? What other conflicting or complementary activities, which may impact on implementation of a waste management solution, are planned for this key time period and what are their interdependencies?	• Project / programme schedule • Dialogue with LLWR and / or RWMD to determine duration of waste acceptance process • Schedules for other project / programmes for same time period for particular site / SLC / other sites • Lifetime Plan • Integrated Waste Strategy
What are the dependencies relating to management of this waste [e.g. disposal facilities, waste effluent treatment infrastructure, cranes, packages etc.]?	• Project / programme schedule • Schedules for other project / programmes for same time period for particular site / SLC / other sites • Dialogue with LLW Repository Ltd. • Dialogue with RWMD • *Guidance material on the transport of radioactive waste [Ref. 33]* • *Joint regulatory guidance on HAW management [Ref. 7-8, 11-14]* • *RWMD Waste package specification and guidance documents [Ref. 27]* • *UK Radioactive Waste Inventory [Ref. 2]* • *EARWG Waste Minimisation Database [Ref. 32]*

Decision Factor Question	Information Sources
Is management of this waste dependent on something (e.g. asset, infrastructure) that may not be available within the required schedule?	• Project / programme schedule • Schedules for other project / programmes for same time period for particular site / SLC / other sites • Dialogue with LLWR • Dialogue with RWMD • Other relevant experience of similar projects (learning from experience) • *LLW Strategic Review [Ref. 34]*
Does delay to the project significantly change the physical, chemical and / or radiochemical characteristics of the waste? What implications does this have? For example – significant project delay may result in the decay of short-lived radionuclides, changing the radiological classification of the waste and thus the management approach.	• Characterisation data • Projected characterisation data (adjusted for impact of time) • Project / programme schedule
Does implementation of any specific waste management option enable accelerated decommissioning and waste retrievals?	• Project / programme schedule • Schedules for other project / programmes for same time period for particular site / SLC / other sites • Dialogue with LLWR • Dialogue with RWMD • Dialogue with regulators • Other relevant experience of similar projects (learning from experience)

6.5 Sub-factors for ease of processing

This sub-factor set relates to the operational aspects of implementing waste management options. This is a wide ranging question set incorporating consideration of availability of technology, the feasibility of options for particular wastestreams, the flexibility of the technology, technical maturity and the availability of the necessary resources (people and/or infrastructure).

It should be noted that treatment / processing of waste may be required to render a particular waste (or wastestream) acceptable for disposal at either LLWR or GDF. The sub-factors detailed in this section should be considered in this context.

Decision Factor Question	Information Sources
Is further segregation practicable? • How homogeneous is the waste? • Is further segregation of the waste feasible? • How is the waste containerised? Does this facilitate segregation of the waste? • What are the lifecycle consequences of segregation? • Does further segregation provide any additional benefit?	• Characterisation data • Technology assessments for segregation / size reduction methods • Infrastructure assessments • Dialogue with LLWR • Dialogue with RWMD • *LLWR WAC [Ref. 18, 24-26]* • *RWMD Waste package specification and guidance documents [Ref. 27]* • *LLWR Pond Furniture Strategic Guidance [Ref. 15]* • *Joint regulatory guidance on HAW management [Ref. 7-8, 11-14]*
What are the type and volumes of secondary wastes that would be generated if the waste is treated? How will these be managed?	• Characterisation data • Waste treatment process description / flowsheet(s) • Technology assessments for segregation / size reduction methods • Infrastructure assessments • Dialogue with LLWR • Dialogue with RWMD • *LLWR WAC [Ref. 18, 24-26]* • *RWMD Waste package specification and guidance documents [Ref. 27]* • *LLWR Pond Furniture Strategic Guidance [Ref. 15]* • *Joint regulatory guidance on HAW management [Ref. 7-8, 11-14]*

Decision Factor Question	Information Sources
What are the available treatment options?	• Technical Baseline and Underpinning Research Document(s) (TBURD) • Waste Enquiry (via LLWR) [Ref. 28] • Literature search • BAT Assessment for similar wastes • *LoC for similar wastes (information available via Ref. 35-36)* • Characterisation data • Dialogue with supply chain • *Joint regulatory guidance on HAW management [Ref. 7-8, 11-14]* • *LLWR Strategic BPEO [Ref. 37-40]* • *LLWR Strategic Review [Ref. 34]* • *LLWR Waste Acceptance Criteria [Ref. 18, 24-26]* • *LLWR Pond Furniture Strategic Guidance [Ref. 15]* • *US DOE Energy Citations Database [Ref. 41]*
What is the volume of raw waste vs. the volume of processed waste for each treatment option? Can the volume of waste for disposal be practicably minimised?	• TBURD • Waste Enquiry (via LLWR) [Ref. 28] • Literature search • BAT Assessment for similar wastes • *LoC for similar wastes (information available via Ref. 35-36)* • Characterisation data • Dialogue with supply chain
Are sufficient SQEP personnel (within parent organisation, LLWR / RWMD, regulators and supply chain) available to implement the option?	• Resource assessments • SQEP / Training records (site / supply chain personnel) • Dialogue with LLWR / RWMD, regulators and supply chain (as appropriate)

Decision Factor Question	Information Sources
Do we have sufficient and appropriate technology available to manage the waste? What is the status of the technology?	• TBURD • Waste Enquiry (via LLWR) [Ref. 28] • Literature search • BAT Assessment for similar wastes • Characterisation data • Dialogue with supply chain • Technology Readiness Levels • *LLWR Pond Furniture Strategic Guidance [Ref. 15]*
Do we have sufficient and appropriate infrastructure to manage the waste?	• TBURD • Waste Enquiry (via LLWR) [Ref. 28] • Literature search • BAT Assessment for similar wastes • Dialogue with supply chain • Dialogue with LLWR / RWMD and supply chain (as appropriate)
What are the physical constraints at the workface? Is management of the waste by a specific technique(s) feasible despite these physical constraints?	• Visual evidence from technical drawings, photographs etc. • Dialogue with plant operators and Safety personnel • Technology descriptions
Can the necessary resources (people / technology / infrastructure) be made available within the required timescale?	• Plant / programme schedule • Resource assessments • Technology assessments • Infrastructure assessments • Dialogue with LLWR, RWMD, NDA, regulators and supply chain (as appropriate)
Is the waste inventory appropriately defined? Can the waste inventory be appropriately defined within the required timescale? What are the uncertainties in characterisation and activity assessment, and do these materially impact confidence in the waste classification?	• Characterisation data • Plant / programme schedule • Dialogue with characterisation providers (site, LLWR or supply chain)

Decision Factor Question	Information Sources
What have other consignors done? Does another consignor possess a similar waste with a LoC or has another consignor had a similar waste accepted to LLWR?	• Dialogue with LLWR • Dialogue with RWMD • *LoC for similar wastes [Ref. 35-36]* • TBURD • Forums such as Nuclear Waste Research Forum (NWRF) • BAT Assessment for similar wastes • Literature search
Is co-disposal feasible (can the primary waste(stream) be managed with other waste(streams))? Can sufficient additional suitable waste be accessed from site / other sites to enable this?	• Dialogue with LLWR • Dialogue with RWMD • Dialogue with regulators • *LLWR WAC [Ref. 18, 24-26]* • *RWMD Waste package specification and guidance documents [Ref. 27]* • Waste Enquiry (via LLWR) [Ref. 28] • *UK Radioactive Waste Inventory [Ref. 2]* • *Joint regulatory guidance on HAW management [Ref. 7-8, 11-14]*

6.6 Sub-factors for strategic considerations

Assessment of the wider strategic issues surrounding waste management of a LLW / ILW cross-boundary wastestream may be necessary, particularly (although not exclusively) when waste optioneering is being undertaken for a large volume wastestream and / or where the wastestream is expected to be generated at some point in the future. Issues such as compatibility of the waste management solution against site end state or interim end state, the availability and compatibility of waste against final LoC etc. are key strategic aspects that require assessment.

It should be noted that treatment / processing of waste may be required to render a particular waste (or wastestream) acceptable for disposal at both LLWR and GDF. The sub-factors detailed in this section should be considered in this context.

Decision Factor Question	Information Sources
What is the desired end-state for the plant / site? Does the waste management option comply with this end state? For example – if site end state is de-licensing within a specific period of time, decay storage which would take a longer period of time than the end state time scale would not comply.	• Site end-state definitions • BAT Assessment for similar wastes • Characterisation data • Waste treatment process description / flowsheet(s) • Lifetime Plan
Does the proposed end-state preclude any options? For example – if the site end state is de-licensing, there may be restrictions on the on-site disposal of waste.	• Site end-state definitions • BAT Assessment for similar wastes • Characterisation data • Waste treatment process description / flowsheet(s)
What is the key inventory information needed to define the critical path for the waste management project? What is the level of uncertainty on the inventory data? Is sufficient inventory data of sufficient precision available or going to be available within an appropriate timescale?	• Characterisation data • Wastestream inventory descriptions • Characterisation / inventory requirements for waste route
Was the waste produced in accordance with a final LoC?	• Relevant / applicable LoC • Dialogue with RWMD • *RWMD Waste package specification and guidance documents [Ref. 27]*

Decision Factor Question	Information Sources
Is the waste compatible with the GDF disposal concept?	• Relevant / applicable LoC • Dialogue with RWMD • *RWMD Waste packaging requirements and guidance [Ref. 27]* • *LoC for similar wastes [Ref. 35-36]*
Within a national perspective, what are the options for managing the waste?	• Dialogue with LLWR • Dialogue with RWMD • *LLWR Strategic Review [Ref. 34]* • *LoC for similar wastes [Ref. 35-36]*
Does LLWR have enough capacity to accept the waste without prejudicing future disposals (in terms of volume and activity)?	• Dialogue with LLWR • *LLWR Disposal Waste Acceptance Criteria [Ref. 18]* • *LLWR Environmental Safety Case [Ref. 19]* • BAT Assessments for similar wastes (acceptable to LLWR) • *LLWR Strategic Review [Ref. 34]* • *UK Radioactive Waste Inventory [Ref. 2]*

6.7 Sub-factors for safety and environmental risks

This is a wide ranging factor encompassing dose management and ALARP, environmental discharges (radiological and non-radiological) in terms of risk of operator / public exposure and the risk of environmental detriment, conventional health and safety issues, and security. This question set involves identifying the key safety and environment risks (for operators, public, plant and general environment) for all stages of the lifecycle of waste management and the tolerability that the plant / organisation has to each risk; analysing whether the tolerability thresholds are breached by any specific waste management option; identifying any benefits that any specific option may bring and whether these balance the risks; and identifying whether any options perform significantly better than others in terms of minimising risk. The key aspect in terms of risk is whether any specific waste management option lowers safety and environmental risk to tolerable levels within practicable means.

Decision Factor Question	Information Sources
Can a safety case or modification to a safety case be made for a specific waste management methodology?	• Characterisation data • Safety Case (existing) • Liaison with Safety case advisors (site / plant) • Dose assessments • Waste treatment process description / flowsheet(s) • Environmental impact assessments for options / technologies • Dialogue with regulators
What are the key safety and environmental risks for each stage in the waste management lifecycle for the specific item / wastestream for each option? Can the safety and environmental risks be reduced to ALARP for a particular waste management option?	• Plant / Organisation Risk Registers • Characterisation data • Waste management option description / flowsheets • Dose assessments • Environmental Impact Assessments • Site Environmental Permit • *EARWG Waste Minimisation Database [Ref. 32]*
What are the potential security risks and implications for specific waste management options? Can any identified security risks and implications be appropriately managed for specific waste management options?	• Waste management option description / flowsheets • Security requirements • Dialogue with regulators

Decision Factor Question	Information Sources
Does any specific option(s) clearly perform better than others in terms of minimising the safety risk to operators, the public, plant and the environment?	• Risk analysis output
What is the lifecycle carbon footprint for a specific option?	• *Carbon footprint norms [Appendix 3]*
What is the rate of hazard reduction for the different waste management options? Which waste management option performs best in terms of hazard reduction?	• Characterisation data • Waste management option description / flowsheets • Dose assessments • Environmental Impact Assessments
For which of the waste management options does the resultant wasteform comply with the concept of passive safety?	• Characterisation data • Waste management option description / flowsheets • Dose assessments • *Joint regulatory guidance on HAW management [Ref. 7-8, 11-14]*

6.8 Sub-factors for Packaging and Transport

This factor requires consideration of the packaging and transport requirements for the implementation of specific waste management options, identifying whether wasteforms produced by treatment / processing can be transported as necessary for disposition under the Transport Regulations and whether there is sufficient infrastructure available to enable the packaging / transport of the waste. This factor also considers the impacts of specific choices of transport methodology.

Decision Making Factor	Information Sources
What packaging and transport routes are required throughout the waste management lifecycle to manage the waste? How feasible are these packaging and transport options? Are these packaging / transport choices compatible with the treatment / disposal site for that specific option?	• Transport and Logistics Enquiry (via LLWR) • Literature search • BAT Assessment for similar wastes • Characterisation data • *LoC for similar wastes (information available via Ref. 35-36)* • *LLWR Disposal Waste Acceptance Criteria [Ref. 18]* • Dialogue with supply chain • Dialogue with LLWR • Dialogue with RWMD • Dialogue with regulators • Transport Regulations • *RWMD Waste package specification and guidance documents [Ref. 27]* • *Guidance material on the transport of radioactive waste [Ref. 33]*
What is the total number of transport trips, number of miles and mode of transport for each waste management option? Which transport system has least environmental impact?	• Waste enquiry (via LLWR) [Ref. 28] • Waste option descriptions / flowsheets • Transport regulations • *Guidance material on the transport of radioactive material [Ref. 33]* • Characterisation data (quantity surveys) • *Carbon footprint norms [Appendix 3]*

7. LLW / ILW cross-boundary waste management decision making model

7.1 Process model for decision-making

As has been described previously, waste management decision making pertaining to LLW / ILW cross-boundary wastes is complex owing to the variability in waste disposal options and the differing consequences for the waste consignor and the UK nuclear sector in the choice of waste management strategy. To support waste consignors with decision making relating to LLW / ILW cross-boundary wastes, this guidance has been developed, in conjunction with NDA estate SLCs, to provide a decision making framework. The individual factors which should be considered when undertaking decision making are considered in detail in Section 6. A process model for undertaking waste management decisions - to enable identification, prioritisation and analysis of the decision making factors – has been developed, and is summarised in Figure 12 and further elucidated in Table 2. It should be noted that this, or any waste decision making process relating to LLW or ILW, should not be undertaken without early and sustained dialogue with LLWR and / or RWMD (as appropriate). Effective sustained engagement with LLWR and RWMD is a vital element to robust, underpinned and successful decision making for LLW / ILW cross-boundary wastes.

Figure 12– Flowchart for decision making process for cross-boundary wastes

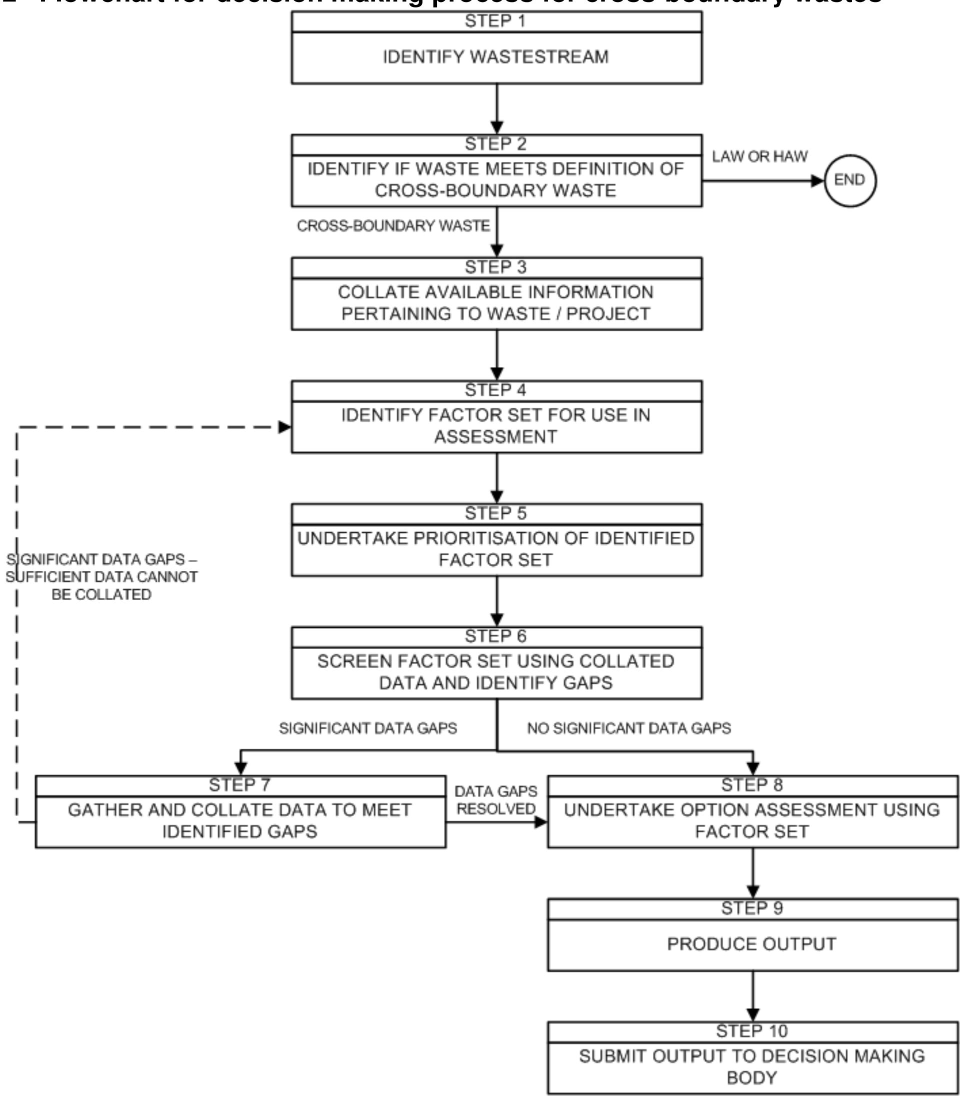


Table 2 – Summary of cross-boundary waste management decision making model

Step 1 – Identify wastestream
Identify the waste sentencing volume (item or population) or wastestream of interest and gather / assess relevant information pertaining to the waste. This information may include (but is not limited to) characterisation data, wastestream characterisation documents, history / provenance information, quantity survey, LoC assessments for similar wastes etc.
Step 2 – Identify if waste meets definition of cross-boundary waste
Assess the waste against the test criteria for classification as cross-boundary waste. Dialogue with LLWR and / or RWMD should be commenced at this stage and sustained throughout the process. The test criteria are: • Is the waste currently classifiable as a HAW or LLW with a concentration of specific radionuclides that significantly challenge its disposability at existing or planned future disposal facilities for LLW that could practicably be managed as LLW through the application of treatment process or decay storage? • Does the waste (post treatment) possess physico-chemical characteristics that enables disposition via LLWR? The waste is classifiable as cross-boundary waste if these test criteria are met. A simplistic methodology for classification is to compare the characteristics of the waste in its raw state and state post treatment / conditioning with the WAC for LLWR [Ref. 18]. If the waste has been classified as cross-boundary waste, it should be identified whether there is benefit in following this process. Criteria for identifying the benefit in the implementation of this process include (but are not limited to): • Where there is no existing or applicable BAT assessment or Business Case • Where it is considered that there would be challenge to decision making by LLWR, RWMD or the regulators • Where a variation to the WAC for LLWR is required • Where it is considered that disposal of the waste may have a significant impact on the radiological capacity of LLWR The process continues from step 3 for wastes classifiable as cross-boundary waste and where the waste consignor has identified a benefit in using this model / guidance. For those wastes not classifiable as cross-boundary waste, the process ends and this guidance is not directly relevant (although it should be noted that aspects of the factors and factor question sets outlined in Section 6 are likely to be applicable to non-cross boundary wastes and this document may provide useful information to support decision making for such wastes). The normal site BAT process, business case process or Waste Enquiry / LoC process would apply.

Step 3 – Collate available information pertaining to waste / project
Gather and collate all readily available relevant information pertaining to the waste(stream) and project. This information may include (but is not limited to): project schedules, project funding, stakeholder maps, risk registers, Lifetime Plan, BAT / BPEO / BPM assessments (for this waste and other similar wastes), RWMD LoC (for this waste and other similar wastes), dose assessments, environmental impact assessments, waste management option descriptions and flowsheets, waste acceptance criteria etc. Specific constraints and assumptions relating to the management of the waste(stream) should also be identified at this stage.
Step 4 – Identify factor set for use in assessment
Review the factor sets provided in Section 6 in the context of the specific waste(stream) and project environment, and identify which factors and questions are relevant. This may encompass all factors / questions, a portion of the factors / questions or a fraction of the questions within a specific factor.
Step 5 – Undertake prioritisation of identified factor set
Review the selected factor set identified in Step 4 and rank the factors in terms of priority based on the project requirements (but with cognisance of site / corporate priorities, regulatory requirements and national strategy). Repeat this prioritisation step for the questions for each of the selected factors.
Step 6 – Screen factor set using collated data and identify gaps
Undertake screening of the selected and prioritised factor set identified in Step 5 using the information collated in Step 3. Identify any factors or individual questions within the selected factor set for which there is insufficient or inadequate information to enable resolution of the factor / question set. If no gaps in the information are identified, the process continues from Step 8. Where information gaps are identified, assess the significance of these. If the significance of the information gaps is deemed to be low, i.e. factor / question set can still be analysed from the information gathered so far, continue the process from Step 8. Where the information gap is significant but it is deemed that collection of information to fill the gap is practicable, the process continues from Step 7. Otherwise, that specific factor or questions should be omitted from assessment and the process reverts back to step 4 to enable renewed analysis of the applicability of the factors / question set.
Step 7 – Gather and collate data to meet identified gaps
For the information gaps identified during assessment in step 6, gather and collate any additional data pertaining to the waste(stream) and project.
Step 8 – Undertake options assessment
Undertake waste management options assessment, using the factor set identified, as per local procedures, BAT NICoP [Ref. 5] or EGG08 [Ref. 6] as required.

Step 9 – Produce output
Develop and produce the required output for the waste management options assessment as per local procedures, BAT NICoP [Ref. 5] or EGG08 [Ref. 6] as required.
Step 10 – Submit output to decision making body
Submit the output to any relevant decision making body and any key stakeholders as required to progress the management of the waste(stream) as per local procedures, BAT NICoP [Ref. 5] or EGG08 [Ref. 6] as required.

7.2 Benefits of using the decision making model

This decision making model provides a methodology for identifying, prioritising and resolving key decision making factors for the management of LLW / ILW cross-boundary wastes. The decision making factors described in Section 6 are those identified to have specific relevance for such cross-boundary wastes.

Whilst the use of this model is not mandatory for waste acceptance at LLWR or GDF, it does provide benefits for waste consignors faced with selecting a waste management option for cross-boundary wastes. The use of this model by waste consignors allows for the selection of appropriate waste management option (or options) for a cross-boundary waste, based on a reasoned and underpinned evaluation of the challenges and benefits. The model also enables waste consignors to readily identify wastes that are not immediately disposable at either LLWR or GDF, where some treatment step is required to enable disposal; and a mechanism for evaluating the relative merits of the potential different treatment options.

In addition, the use of this model represents a step forward in the consideration and adoption of the “disposal by safety case” concept, which is particularly pertinent to cross-boundary wastes. Current waste management arrangements are based on radiological classifications of waste based on Government policy. The disposal by safety case concept, which is currently not common practice in the UK, enables waste management to be optioneered on the basis of the implications of disposal safety case, rather than by categorisation, enabling consideration of a wider range of waste management options and thus enabling the optimised use of national disposal capacity for radioactive waste.

8. Conclusions

This guidance document identifies the decision making factors which, based on the practical experiences of SLCs within the NDA estate, have particular relevance for waste management decisions pertaining to LLW / ILW cross-boundary wastes. This document provides waste practitioners with a toolkit of information, and a structured framework for use / analysis of the information, to support and guide waste management decision making for such wastes.

The key conclusions for this guidance document are:

- A definition of LLW / ILW cross-boundary waste has been established as: ILW and LLW with a concentration of specific radionuclides that prohibits or significantly challenges its acceptability at existing and planned future disposal facilities for LLW that practicably be managed as LLW (on the basis of radiological and physico-chemical properties) through the application of a treatment process or decay storage.

- Compilation of an indicative national inventory of cross-boundary waste, based on a 2009 study [Ref. 1] and review of the UKRWI 2010 [Ref. 2] has identified (at best current estimate) a total volume of 156,000m^3. This is split 54% LLW to 46% ILW in terms of radiological classification of raw waste. The waste inventory is dominated by concrete (43% by volume), mixed waste (25%) and metal (19%). The majority of the waste (approximately 93%) is expected to arise from the NDA estate, and Magnox Ltd. is expected (based on this analysis) to generate the largest volume of such cross-boundary waste. This data has been identified to be an upper bound of the inventory owing to the uncertainties and assumptions in the inventory analysis.

- Optioneering for cross-boundary waste is a regulatory expectation for the management of radioactive waste (as part of the demonstration of BAT and ALARP). Demonstration of BAT is a requirement for waste acceptance for LLWR and, whilst not a specific requirement for RWMD, typically forms a component in conjunction with a LoC of a RWMC for HAW where this is applicable.

- A model for identification and usage of key decision making factors for cross-boundary waste optioneering relevant to a specific cross-boundary waste has been defined. This is, based on feedback from NDA estate SLCs, complementary to site procedures for waste management optioneering.

- A number of generic waste management decision making factors relevant to cross boundary wastes have been identified. These include ease of processing, strategic considerations, cost, stakeholders, LLWR WAC / ESC compliance, timing / scheduling, safety / environmental risk and packaging / transport. These factors have been divided into a set of sub-factors, expressed as questions, which consider specific elements of each factor.

- Prioritisation of factors and sub-factors should be undertaken on a case-by-case basis, owing to domination of local factors (e.g. nature of waste / wastestream, timescales, corporate SLC priorities) in the prioritisation of factors and sub-factors.

- Norms for carbon footprinting and lifecycle LLW waste management costs have been derived.

- Generic information sources that may assist waste practitioners in undertaking optioneering have been identified and relevance to the decision making factors has been mapped.

- A number of generic issues and barriers have been identified that may impact on the efficacy of decision making for cross-boundary wastes. The issues identified include the lack of visibility of integration between LLWR and RWMD for disposal decisions, limitations in knowledge management, limitations to infrastructure / systems and a lack of national strategic view of the importance of LLWR versus GDF. Recommendations have been made to improve the integration of decision making for LLWR / RWMD, to develop improved knowledge management systems and to undertake a national strategic study to consider the value of LLWR and GDF in a UK context.

Based on the issues and barriers associated with decision making for LLW / ILW cross-boundary wastes, a number of recommendations can be made for further work to support waste practitioners in decision making and hence execution of robust, underpinned waste management solutions:

- Improved, more integrated and more visible linkage between RWMD and LLWR for decision making associated with cross-boundary wastes should be established. This may be achieved through ensuring RWMD participation in Strategic Waste Projects Committee or the review of LoCs for wastes that could be managed as LLW in Strategic Waste Management Committee. Any such linkages should be more clearly publicised in relevant procedures and on the websites of the relevant organisations.

- Establish – in conjunction with consignors, EA, SEPA, ONR and RWMD – a knowledge management system that would include a bibliography of and / or actual BAT and LoC assessments (where security allows), that could be used by waste practitioners.

- Undertake and disseminate a strategic study to assess the national value of LLWR and GDF, in volumetric and radiological terms, for cross-boundary wastes.

- Undertake the necessary technical work and stakeholder engagement to develop and implement a process for decision making for waste management on the basis of safety case rather than radiological classification, so as to optimise the use of national radioactive waste disposal capacity.

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Appendix 1: Schedule of wastestreams included in inventory analysis

Table 3 - Schedule of wastestreams included in Section 4 Inventory Analysis from UKRWI 2010 [Ref. 1-2]

Company	Site	Wastestream No.
EdF	Dungeness B	3J04, 3J20
EdF	Hartlepool	3K04, 3K22
EdF	Heysham 1	3L04, 3L19
EdF	Heysham 2	3M04, 3M17
EdF	Hinkley Point B	3N04
EdF	Hunterston B	4B06
EdF	Torness	4C02
MOD	AWE Aldermaston	7A07, 7A109, 7A110, 7A111, 7A117, 7A21, 7A22, 7A29, 7A13
MOD	Rosyth Royal Dockyard	7E27, 7E29
RSRL	Harwell	5C18/C, 5C51, 5C08
RSRL	Winfrith	5G03/C
Magnox Ltd.	Oldbury	9E01, 9E17, 9E45
Magnox Ltd.	Berkeley	9R10, 9A36, 9A39, 9A42, 9A43, 9A57, 9A58, 9A59, 9A75, 9A916, 9A917, 9A105, 9A313, 9A314, 9A315, 9A317, 9A318, 9A319, 9A320
Magnox Ltd.	Dungeness A	9C16, 9C20, 9C21, 9C12
Magnox Ltd.	Hinkley Point A	9D17, 9D18, 9D22, 9D23, 9D24, 9D25, 9D26, 9D27, 9D28, 9D29, 9D30, 9D32, 9D33, 9D34, 9D39, 9D40, 9D41, 9D42, 9D43, 9D44, 9D45, 9D46, 9D47, 9D49, 9D50, 9D51, 9D52, 9D54, 9D60, 9D64, 9D65, 9D66, 9D67, 9D68, 9D69, 9D70, 9D72, 9D917, 9D918, 9D919, 9D920, 9D921, 9D106, 9D314, 9D315, 9D317, 9D318, 9D319, 9D320, 9D321
Magnox Ltd.	Sizewell A	9F20, 9F21, 9F22, 9F38, 9F39, 9F42, 9F44, 9F43, 9F32, 9F18, 9F25, 9F26, 9F27, 9F14, 9F105, 9F314, 9F315, 9F316, 9F318, 9F319, 9F320, 9F321, 9F28, 9F29
Magnox Ltd.	Bradwell	9B16/C, 9B13, 9B15, 9B17, 9B18, 9B33, 9B34, 9B35, 9B36, 9B37, 9B40, 9B41, 9B42, 9B60, 9B61, 9B62, 9B63, 9B53, 9B913, 9B314, 9B02, 9B64, 9B65
Sellafield Ltd.	Sellafield	2A311, 2A313, 2D11, 2D115, 2D116, 2D117, 2D118, 2D120, 2D136, 2D317, 2D14, 2D19, 2D21, 2D23, 2D27/C, 2D42, 2D57, 2D77/C, 2F06/C, 2F07, 2F15, 2F21/C, 2F26, 2F27, 2S10/C, 5F10/C, 2S31, 2S302, 2S308/C, 2S313

Appendix 2: Key sources of generic information to support decision making

A range of information sources exist to support decision making with respect to wastes at the LLW / ILW radiological classification boundary. Whilst a significant proportion of information sources are waste specific or site specific, there are a range of generic information sources which may be useful to waste practitioners. These are summarised in Table 4. It should be noted that these sources of information should not be used in isolation and that dialogue with LLWR, RWMD and the regulators is a vital source of information to support decision making.

Table 4 – Summary of key information sources to support LLW / ILW cross-boundary waste decision making

		Decision Making Factors							
Information Source	**Description of information source**	**LLWR WAC / ESC**	**Cost**	**Stakeholders**	**Schedule / Timing**	**Ease of processing**	**Strategy**	**Safety / Environmental Risk**	**Packaging and transport**
Carbon footprint (ILW) [available via Appendix 3]	Provision of carbon cost (te CO_2 / m^3 waste) for different ILW management options.								
Carbon footprint (LLW) [available via Appendix 3]	Provision of carbon cost (te CO_2 / m^3 waste) for different LLW management options.								
EGG01 - Supplemental Guidance on LTP Cost Assumptions for LLW Activities [Ref. 29]	Provides estimating principles and cost norms for LLW waste management activities to support cost estimating.								
Guidance material on the transport of radioactive material [Ref. 33]	Suite of guidance documents relating to the requirements for the transport of radioactive material developed by ONR.								
Information on LoC process [Ref. 21-22]	High-level generic information providing waste consignors with an overview of the LoC process.								

Information Source	Description of information source	Decision Making Factors: LLWR WAC / ESC	Cost	Stakeholders	Schedule / Timing	Ease of processing	Strategy	Safety / Environmental Risk	Packaging and transport
Interactions with waste packagers on plans for packaging radioactive waste [Ref. 36]	Annual reports detailing RWMD interactions with waste packagers within a specific year. Provides waste packagers with lists of waste covered by LoC, lists of waste packaging design assessments undertaken during that year and a list of waste packaging specifications / guidance.								
Joint Regulatory Guidance on HAW management [Ref. 7-8, 11-14]	Provision of technical guidance information relating to minimisation, characterisation, segregation, conditioning, disposability, storage and records management applicable to HAW.								
Letter of Compliance Disposability Assessment Reports [Ref. 35]	Executive summaries of disposability assessment reports issued by RWMD in response to Letter of Compliance submissions by Consignors; providing waste consignors with indicative detailed information relating to what LoCs have been approved or rejected by RWMD.								
LLW Combustibles Strategic BPEO [Ref. 39]	Document providing national-level strategic optioneering for waste management of combustible LLW. Provides information about potential waste management options for certain waste types.								

Information Source	Description of information source	Decision Making Factors							
		LLWR WAC / ESC	Cost	Stakeholders	Schedule / Timing	Ease of processing	Strategy	Safety / Environmental Risk	Packaging and transport
LLW Metals Strategic BPEO [Ref. 37-38]	Document providing national-level strategic optioneering for waste management of LLW metals. Provides information about potential waste management options for certain waste types.								
LLW Service Pricing [Ref. 30]	Provides information about service pricing under the LLWR contract. This information has been extrapolated to a LLW cost model, provided in Appendix 3.								
LLW Strategic Review 2010 [Ref. 34]	Provides a summary of waste inventory, proposed waste management strategies for the NDA estate and available assets / infrastructure for the UK for the management of LLW.								
LLWR Environmental Safety Case [Ref. 23]	Suite of documentation comprising the 2011 Environmental Safety Case for LLWR. It should be noted that the ESC will be enacted, in terms of changes impacting waste consignors, via the Waste Acceptance Criteria. The key document for waste consignors with respect to the impact of the ESC on radiological and volumetric capacity is report LLWR/ESC/R(11)10026 Waste Acceptance.								

Information Source	Description of information source	Decision Making Factors							
		LLWR WAC / ESC	Cost	Stakeholders	Schedule / Timing	Ease of processing	Strategy	Safety / Environmental Risk	Packaging and transport
LLWR Waste Acceptance Criteria for Combustibles [Ref. 25]	Waste acceptance criteria for treatment of combustible LLW via the LLWR framework. Provides waste consignors with information about the conditions, limitations and restrictions relating to the treatment of combustible LLW.								
LLWR Waste Acceptance Criteria for Disposal [Ref. 18]	Waste acceptance criteria for disposal of LLW to the LLWR. Provides waste consignors with information about the conditions, limitations and restrictions relating to disposal of LLW.								
LLWR Waste Acceptance Criteria for Metal Treatment [Ref. 26]	Waste acceptance criteria for treatment of metallic LLW via the LLWR framework. Provides waste consignors with information about the conditions, limitations and restrictions relating to the treatment of metallic LLW.								
LLWR Waste Acceptance Criteria for Supercompactable Waste Treatment [Ref. 24]	Waste acceptance criteria for treatment of supercompactable LLW via the LLWR framework. Provides waste consignors with information about the conditions, limitations and restrictions relating to the treatment of supercompactable LLW.								

Information Source	**Description of information source**	**Decision Making Factors**							
		LLWR WAC / ESC	**Cost**	**Stakeholders**	**Schedule / Timing**	**Ease of processing**	**Strategy**	**Safety / Environmental Risk**	**Packaging and transport**
Packaging Specifications for Higher Activity Waste [Ref. 27]	Packaging specifications developed by RWMD for the management of higher activity waste. Provides waste consignors with information about the packaging requirements for the geological disposal model.								
Strategic Guidance on the management of LLW and LLW / ILW cross Boundary Pond Furniture [Ref. 15]	Strategic guidance document developed by LLWR in collaboration with NDA-estate providing information on inventory, a compilation of information on currently used waste management approaches and ongoing R&D.								
Transport regulations	Provision of information relating to the methods, controls, requirements and restrictions associated with the safe transport of radioactive waste.								
UK Management of Solid Low Level Radioactive Waste from the Nuclear Industry: Metal Decontamination Study [Ref. 2 31]	Provision of technical information about the UK site and overseas assets / infrastructure relating to the decontamination of LLW metal; including some details relating to waste acceptance criteria. Some limited information is provided on costs for metal decontamination.								

Information Source	**Description of information source**	**Decision Making Factors**							
		LLWR WAC / ESC	**Cost**	**Stakeholders**	**Schedule / Timing**	**Ease of processing**	**Strategy**	**Safety / Environmental Risk**	**Packaging and transport**
UK Radioactive Waste Inventory 2010 [Ref. 2]	Public record of the most comprehensive and up-to-date national inventory of radioactive waste. Provides waste consignors with a national picture of the waste inventory and enables consignors to identify sites with similar waste management challenges.								
US Department of Energy - Energy Citations Database [Ref. 37]	Database of links to research and development citations, principally from the US Department of Energy, including those relating to decommissioning and radioactive waste management.								
Waste Minimisation Database [Ref. 32]	Database of consolidated information relating to best practice and technologies for radioactive waste management.								

Appendix 3: Carbon Footprint Norms for Treatment and Disposal

Table 5 provides a summary of carbon footprint norms associated with various LLW management options to support estimation of the carbon cost for executing particular options [Ref. 42].

Table 5 – Summary of carbon footprint norms for LLW management options

Waste Management Option	Carbon per unit volume of waste ($te(CO_2)/m^3$)
LLW disposal to LLWR	- 1.05
LLW disposal (metallic waste) to LLWR	- 1.87
Transport of LLW to LLWR	- 0.13
Segregated waste service – metal treatment	- 0.74
Segregated waste service – metal treatment (benefit)	+ 1.08
Segregated waste service – incineration	- 0.03
Segregated waste service – VLLW disposal (disposal site < 100km of consignor)	- 0.03
Segregated waste service – VLLW disposal (disposal site > 100km of consignor)	- 0.1
Vault construction	- 0.16

Key assumptions for carbon footprint norms specified in Table 4:

- LLW disposal to LLWR excludes the carbon associated with the disposal of consignments of metallic waste to the vaults.
- Transport of LLW to LLWR assumes waste is transported by road.

Table 6 provides a summary of carbon footprint norms associated with the geological disposal of ILW to support estimation of the carbon cost for executing particular options [Ref. 43].

Table 6 – summary of carbon footprint norms for ILW management options (geological disposal)[7]

Waste Management Option	Carbon per unit volume of waste ($te(CO_2)/m^3$)
Geological disposal (assuming transport of waste by road/rail)	Minimum: - 6.03 Maximum: - 6.90
Geological disposal (assuming transport of waste by sea/road/rail)	Minimum: - 5.92 Maximum: - 6.79

Key assumptions for carbon footprint norms specified in Table 6:

- Norms includes carbon costs associated with Stage 5 (surface investigations) and Stage 6 (underground operations) of geological disposal model.
- Norms do not include carbon associated with the manufacture of containers (it assumes containers have been suitably conditioned for disposal).
- Norms calculated using Derived Inventory Case excluding Plutonium and Uranium.
- Road / rail model assumes 30% of waste transported by road and 70% by rail.
- Sea / road / rail assume 80% of waste transported by sea, 10% by road and 10% by rail.

[7] Variation in specified norms associated with differing geological models for GDF.

Appendix 4: LLW Lifecycle Cost Model

Figure 13 provides a generic LLW lifecycle model, illustrating different potential waste management options and outcomes for waste which is a LLW cross-boundary waste. A summation of the costs for the various routes has been extracted and is provided in Table 7. This cost model is provided to support waste practitioners in undertaking consideration of lifecycle cost.

It should be noted that these as these costs have been derived based on LLWR cost norms, the cost ranges cover the LLW radiological spectrum. In the context of LLW / ILW cross-boundary wastes, given that these occupy the higher range of the radiological classification, it is deemed likely that the costs will be towards the maximum end of the defined cost ranges. It should also be noted that this is provided for guidance purposes only to support generic cost estimating and that there are significant range of waste and site specific variables that will impact the cost model for a specific waste(stream) / project. The data within the model can be further enhanced and augmented by waste practitioners with the inclusion of site or waste(stream) specific cost information where available.

Assumptions

- Costs derived from LLWR cost norms [Ref. 29]. The assumptions used for derivation of the LLWR cost norms apply in this case. An extract of the data from Ref. 29, used in derivation of the cost model, is provided in Table 7 with identification of the estimating range used in the cost model and specific assumptions specified in the Comments column.

Table 7 – Summary of recommended treatment and disposal costs [Ref. 29]

Activity	Estimating Norm	Unit	Estimating range (for model)	Unit	Comments
Metal Recycling	£3,500	te	£2000-£4000	m^3	▪ Average value per tonne of **raw** metal ▪ Likely range may be £2,000-£4,500/te depending on metal type, treatment requirements and contamination levels). ▪ When converting from volume a typical density of 1m^3 = 1te could be assumed for decommissioning wastes
Compaction at Sellafield WAMAC facility for loose wastes	£3,128	m^3	£3,128	m^3	▪ Average value per m^3 of **raw** compactable waste ▪ Rate includes final disposal charges and rental of TC05 containers ▪ End of service at 2020 is based on current assumed life of WAMAC
Compaction at Sellafield WAMAC facility for drummed wastes	£590	drum	£2950	m^3	▪ Based on nominal 210 litre drum ▪ Rate includes final disposal charges ▪ Assume drum compaction capability is available from supply chain post-2020 at same cost or lower
Incineration	£1,350	m^3	£1,350	m^3	▪ Average value per m^3 of **raw** combustible waste ▪ When converting from volume a typical density of 3m^3 = 1te could be assumed for decommissioning wastes
Disposal of EW to Landfill	£150	m^3	£150	m^3	▪ Average value per m^3 of **packaged** waste ▪ Includes landfill tax at standard rate
Disposal of LLW/VLLW to Landfill	£500	m^3	£250-£850	m^3	▪ Average value per m^3 of **packaged** waste ▪ Likely range £250-£850/m^3 depending on activity levels ▪ When converting from volume a typical density of 1m^3 = 1te could be assumed for decommissioning wastes ▪ Includes landfill tax at standard rate
Disposal to LLW to LLWR vault	£2,911	m^3	£2,911	m^3	▪ Value per m^3 of **packaged** waste ▪ Assume same gate price for future LLW Repositories ▪ Typical packing factors are 8m^3 – 10m^3 raw waste per HHISO container with external volume of 19.5m^3

Activity	Estimating Norm	Unit	Estimating range (for model)	Unit	Comments
Activity Surcharge for LLWR disposal only (LLW)	£1,000	m^3	£10-£17500	m^3	▪ Average value per m^3 of **raw** waste ▪ Average across multiple nuclides ▪ Likely range £10 - £17,500/m^3 depending on activity levels and radionuclide composition ▪ See LLWR Service Pricing List for radionuclide specific charges
Activity Surcharge for LLWR disposal only (VLLW)	£100	m^3	£10-£1100	m^3	▪ Average value per m^3 of **raw** waste ▪ Average across multiple nuclides ▪ Likely range £10 - £1,100/m^3 depending on activity levels and radionuclide composition ▪ See LLWR Service Pricing List for radionuclide specific charges
Transport	£600 (UK)	Trip	£200-£2700 £20-£270	trip m^3/trip	▪ Average value (likely range £200-£2700 dependent on distance travelled and requirement for specialist equipment) ▪ Estimating range for model calculated on full HHISO volume basis (average waste payload $10m^3$)
	£6,800 (Overseas)	Trip	£20-£680	m^3/trip	▪ Estimating norm based on average value for Europe ▪ Estimating range for model calculated on estimating range for UK trip with maximum changed for overseas trip, on basis of full HHISO volume basis (average waste payload $10m^3$)
Packaging	£8,000 (HHISO)	Container	£800-£1429	m^3	▪ Estimating range derived from minimum cost per m^3 for HHISO and THISO ▪ HHISO average waste payload = $10m^3$ ▪ HHISO external volume = $19.5m^3$ ▪ THISO average waste payload = $7m^3$ ▪ THISO external volume = $13m^3$
	£10,000 (THISO)	Container			
	£45 (210L drum)	Drum	£225-£1654	m^3	▪ Estimating range derived from minimum cost per m^3 for 210L drum and 210L + THISO ▪ HHISO average waste payload = $10m^3$ ▪ THISO average waste payload = $7m^3$ ▪ 210L drum average waste payload = $0.2m^3$ ▪ VLLW bag average waste payload = $1m^3$
	£250 (VLLW bag)	Bag			

- Costs do not include the cost of design, construction, commissioning and operation of facilities (existing or new) for interim storage and waste treatment, as these are likely to be site / waste specific. Process steps where these costs may be applicable are indicated in dotted lines on Figure 13, and should be included by waste practitioners where relevant.

- The model defines no interim storage costs for waste (which should be identified by individual sites).

- Characterisation cost is modelled on analysis costs only derived from Ref. 44 and is summarised in Table 8; based on a minimum cost of one sample (for full radiological and chemical suite of analytes) per HHISO and a maximum case of one sample (for full radiological and non-radiological suite of analytes) per 210L drum. Characterisation cost does not include costs relating to planning, sampling, sample transport, data interpretation and reporting.

Table 8 – Summary of characterisation costs for LLW cost model [Ref. 44]

Analytical suite	Mean cost (£/sample)	Minimum cost (£/m^3)	Maximum cost (£/m^3)
Radiochemical	2598	137	11809
Chemical	398	21	1805
Total	2996	158	13614

Notes:

- Radiochemical analytical suite includes gamma spectroscopy, alpha spectrometry, uranium isotopes, plutonium alpha isotopes, Sr-90, C-14, H-3, Fe-55, Pu-241 and I-129.
- Chemical analytical suite includes arsenic, barium, cadmium, chromium, copper, mercury, molybdenum, nickel, lead, antimony, selenium, zinc, chloride, fluoride and sulphate.

- Cost of waste generation / retrieval has been excluded from the cost model as this is considered to be a site / waste specific cost. Costs for this process step should be included by waste practitioners as required.

- Costs have been corrected to be on £ per m^3 unit basis, with the exception of transport costs which have been corrected to be on a £ per m^3 per trip basis.

- Treatment costs for off-site transport are derived based on estimating costs / ranges for incineration and metal treatment.

- Costs for disposal to LLWR presented as £2911/m^3 (packaged waste) + £10-£17500/m^3 (raw waste) to include cost of disposal plus activity surcharge.

- Costs for disposal to specified landfill (VLLW) presented as £500/m^3 (packaged waste) + £10-£1100/m^3 (raw waste) to include cost of disposal plus activity surcharge.

- Where the process crosses into ILW cost model, Appendix 5 should be used.

Use of Cost Model

Figure 13 provides a model lifecycle cost model for LLW management which can be used for waste management cost estimating purposes. The lifecycle cost for a particular waste management scenario can be determined by identifying the applicable process steps for the specific waste management scenario and adding the cost components multiplied by the relevant waste disposal volume. In order to take account of the changing volume of waste, the costs should be calculated in the form:

$$C_{TOTAL}(£/m^3) = \sum_{C_R}(Cost * Volume) + \sum_{C_P}(Cost * Volume) + \sum_{C_T}(Cost * Volume) + \sum_{C_{TP}}(Cost * Volume)$$

Where:

- C_{TOTAL} = total cost for waste option
- C_R = costs associated with the raw volume of waste (retrieval, characterisation, initial packaging and, for disposals to LLWR or specified landfill, radionuclide surcharge)
- C_P = costs associated with the packaged volume of raw waste (transport of packaged raw waste, treatment and – for options not including additional treatment – disposal to LLWR)
- C_T = costs associated with treated volume of waste (packaging)
- C_{TP} = costs associated with the packaged volume of waste post treatment (transport of packaged volume and disposal).

To use the cost model, the process steps relevant for the specific waste management scenario on Figure 13 should be identified. The cost for each process step is calculated by multiplying a relevant figure from the cost range by the volume of waste expected at that specific step at the process (with the exception of transport where the cost should be multiplied by the relevant volume of waste and the relevant volume of trips required to transport the waste). The process boxes are annotated (with labels C_R, C_P, C_T and C_{TP}) to indicate the relevant waste volume for that particular step (i.e. for process steps labelled C_R, the cost should be multiplied by the volume of raw waste). The total cost for the scenario is derived by the addition of the costs for the relevant process steps for that scenario.

Worked Example

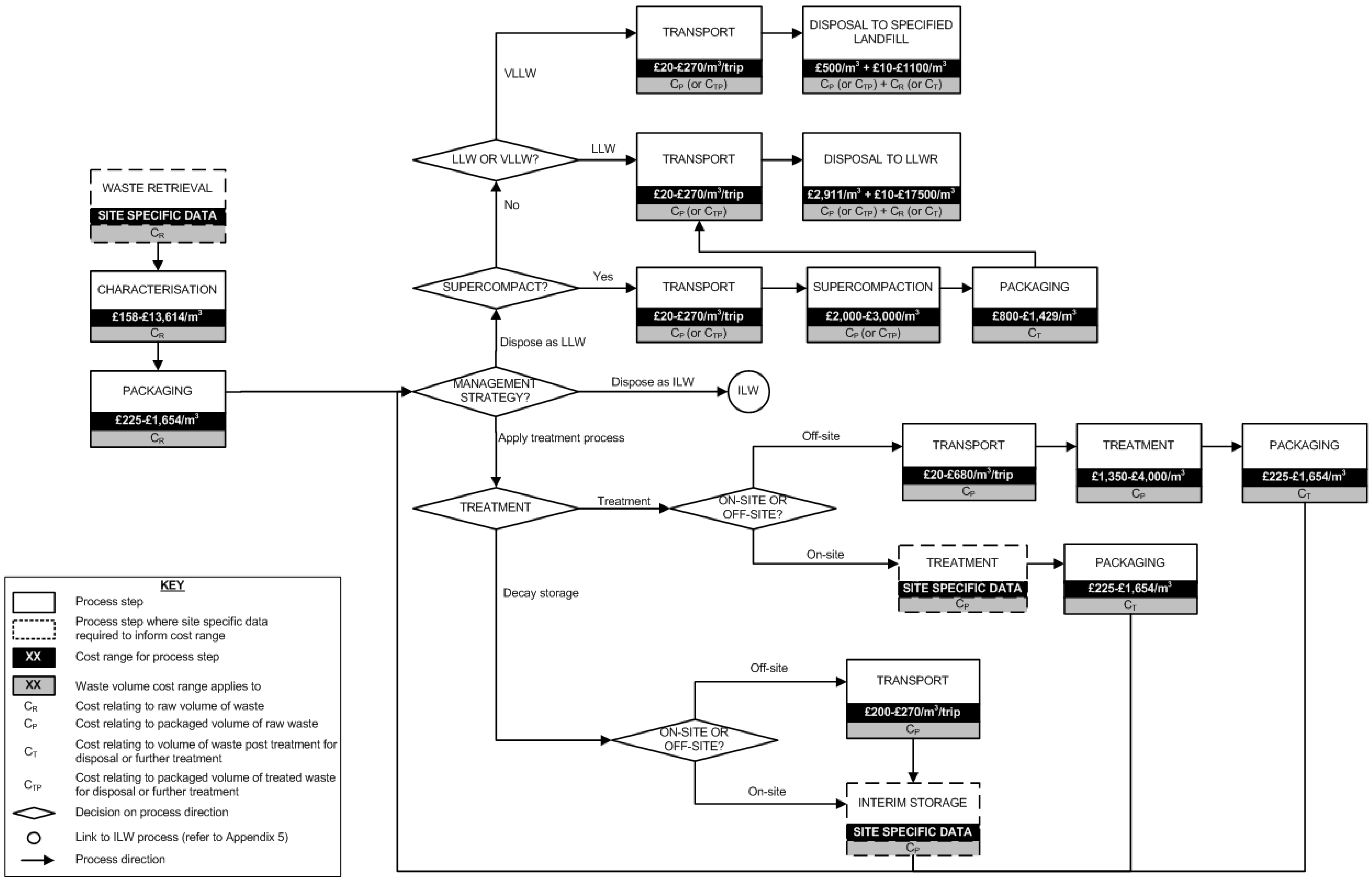
Table 9 provides a summary of a worked example, illustrating the use of the cost model described in Figure 13, for a scenario involved the treatment and disposal of 150te of metallic waste at an off-site UK treatment facility to define the minimum and maximum cost range for this scenario.

Table 9 – Worked example illustrating usage of cost model (for waste scenario – treatment / disposal of 150te metallic waste at off-site UK facility, secondary waste to be disposed of to LLWR)

Cost Element	Cost basis	Quantity	Estimating norm or range	Cost Estimate	Notes
Raw waste		150te = 150m3	[redacted]		• Assumes a 1te=1m3 equivalence
HHISO		15	[redacted]		• Assumes a HHISO payload of 10m3
Characterisation	Maximum	150m3	£13614 / m^3	£2042100	
	Minimum	150m3	£158 / m^3	£23700	
Packaging	Maximum	750 x drums	£225 / m^3	£168750	• Assumes 0.2m^3 volume per drum
	Minimum	8 x ISO containers	£1654 / m^3	£13232	• Assumes isofreights can be re-used up to 3 times (but last use must be for disposal)
Transport of waste for treatment	Maximum	2 trips	£270 / m^3 / trip	£40500	• Assume 4 HHISO per shipment
	Minimum	4 trips	£20 / m^3 / trip	£3008	• Assume 188 drums per shipment
Treatment	Maximum	150m^3	£4000 / m^3	£600,000	• Assume maximum treatment cost
	Minimum	150m^3	£1350 / m^3	£202,500	• Assume minimum treatment cost
Packaging	Maximum	15m^3	£1429 / m^3	£21435	• Assume 90% volume reduction, so 10% volume of secondary waste for disposal from each HHISO (15m^3 total). • Assume use of new THISO container (maximum waste payload 7m^3 / THISO)
	Minimum	15m^3	£1654/m^3	£0	• Assume 90% volume reduction, so 10% volume of secondary waste for disposal from each HHISO (15m^3 total). • Assume final use of existing two HHISO containers.
Transport of secondary	Maximum	1 trip	£270 / m^3 / trip	£4050	

Cost Element	Cost basis	Quantity	Estimating norm or range	Cost Estimate	Notes
waste for disposal	Minimum	1 trip	£20 / m^3 / trip	£300	
Disposal to LLWR	Maximum	2 x 19.5m3	£2911	£113,529	• Cost charged on packaged waste volume (2 x HHISO x 19.5m^3)
	Minimum	3 x 13m^3	£2911	£113, 529	• Cost charged on packaged waste volume (3 x THISO x 13m^3)
Activity surcharge for disposal to LLWR	Maximum	15m^3	£17500	£262,500	
	Minimum	15m^3	£10	£150	
Total	Maximum	£3,252,864	[redacted]		
	Minimum	£356,419			

Figure 13 – LLW Waste Management Option Lifecycle Cost Model



Appendix 5: ILW Lifecycle Cost Model

At present, there is no formal cost model for the management of HAW although RWMD Upstream Optioneering project is currently undertaking work to develop cost norms, and hence a cost model, for this purpose. It is anticipated that a cost model for the management of ILW shall be available by the end of FY 2012/13.