LLW Repository Ltd

Low Level Waste Repository

LLWR Lifetime Plan

Assessment of options for reducing future impacts from the LLWR.

10002 LLWR LTP Volume 2 Issue 01

Date: April 2008

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Verification Statement

This document has been verified and is fit for purpose. An auditable record has been made of the verification process. The scope of the verification was to confirm that:

- the document meets the requirements as defined in the task specification/scope statement;
- appropriate references are provided and all are correct;
- the constraints are valid;
- the assumptions are reasonable;
- calculations described are correct and appropriate;
- the document demonstrates that the project is using the latest approved data; and
- the document is internally self-consistent.

HISTORY SHEET

10002 LLWR LTP Volume 2

Issue Number	**Date**	**Comments**
Issue 01	30/04/2008	Issue to Environment Agency

Assessment of Options for Reducing Future Impacts from the LLWR

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10002 LLWR LTP Volume 2 issue 01

Executive Summary

The Low Level Waste Repository (LLWR) has been the principal facility in the UK for the disposal of Low-level Radioactive Waste (LLW) since 1959. Disposals at the site are authorised by the Environment Agency (EA) under the Radioactive Substances Act 1993. The LLWR receives wastes from a range of consignors including nuclear power stations, fuel cycle facilities, defence establishments, general industry, isotope manufacturing sites, hospitals, universities and from the clean-up of historically contaminated sites. For the first thirty years of operation, wastes were tipped into a series of Trenches (Trenches 1 to 7). More recently, wastes have been grouted within steel containers and emplaced in an engineered vault (Vault 8). Planning permission has been granted for the construction of Vault 9, initially as a storage facility, and there is further scope for additional Vaults within the area for disposals.

This report is one of five top-level documents that together provide a submission to the Environment Agency, setting out our response to Requirement 2 of Schedule 9 of the Environment Agency's current Authorisation. Volume 1 summarises the whole of our submission. Volume 2, this document, describes an options assessment focused on the alternative steps that could be taken to reduce the radiological impact from the Trenches and sets it in the context of the wider programme of optimisation work undertaken at the LLWR since 2002. More detail on our understanding of the site and the potential long-term impacts is provided in Volumes 3 to 5 and in supporting references. Our submission includes:

- information to show that our work is founded on national and international best practice;
- an assessment of options, to determine the best way of managing the long-term impact of the Trenches;
- an analysis of the total 'radiological capacity' of the Vaults (i.e. the total quantity of radionuclides that can be disposed while remaining consistent with the safety case);
- an updated view of site characteristics, the evolution of the engineered barriers and long-term performance, to support the previous analyses.

The options assessment reported here builds on the conclusions of the key options assessment undertaken by BNFL in 2004, which considered approaches to the remediation of the LLWR. The 2004 study was based on a detailed analysis and involved evaluating sixteen options in terms of a number of diverse attributes. The results of this analysis were a key input to the current options assessment. More recently, options for the future use of the LLWR site were discussed with stakeholders as part of the NDA End States Analysis. Stakeholders were not in favour of large-scale disturbance of the site. The assessment reported here takes forward the End States Analysis at a more detailed technical level.

The objective of the current assessment is to identify a preferred strategy for the future management of solid waste disposed to the facility. It is focused on the Trenches, noting that other options assessment work addresses the design of the Vaults. The Trenches options assessment was mainly implemented through a series of expert and stakeholder workshops and has been undertaken within a Best Practicable Environmental Option (BPEO) framework, drawing also on a new review of national and international best practice relevant to repository design and management. There has been a strong focus on stakeholder engagement as part of this work. Two workshops have been held with local stakeholders to present the results of this work for comment.

In this study we have:

1. Reviewed the potential ‘threats’ to the LLWR in terms of the issues that might give rise to radiological impacts in the future. These are:
    - Sea-level rise and coastal erosion;
    - Inadvertent human intrusion;
    - Release of radioactive contaminants in groundwater; and
    - Release of radioactive gas.
2. Developed and assessed a comprehensive ‘toolkit’ of management options and technologies, based on a detailed review of national and international practice.
3. Characterised a number of strategic options for further evaluation (identified using a screening process). These are:
    - Repository Cap
    - Engineered Barriers
    - Coastal Defences
    - Vertical Drains
    - Bulk or Local Retrieval
    - Institutional Control
    - In-situ Remediation
4. Assessed the potential application of these options at the LLWR.
5. Identified those options that should form part of future strategy.

As a result of this process, we have confirmed that our proposed future strategy should include the following elements:

- The use of a repository cap designed to limit the infiltration of groundwater and reduce the likelihood of human intrusion;
- The use of a system of barriers and drains to control groundwater flow within the LLWR during the post-closure period, noting that further optimisation studies are required;
- Active institutional control of the facility for as long as is reasonably practicable.

These measures are already part of the LLWR's Lifetime Plan or are the basis of stated assumptions within it.

We do not consider that retrieval of all the wastes in the facility is necessary because the post-closure radiological impacts are within the annual dose region where intervention is not normally justifiable (see Volume 5). There is a disproportion between the high costs, of many hundreds of millions of pounds that would be associated with such actions. If wastes were to be removed, a new and better disposal facility would be required, which would probably have to be at greater depth than the LLWR. Besides the direct costs of retrieval, the costs of a new disposal facility and transport to the facility also have to be considered. In addition, the conventional risks to workers and to members of the public would be significant.

There are certain disposals of waste to the Trenches with higher concentrations than average of certain key radionuclides, for example ^{226}Ra. In the event that these wastes were inadvertently excavated, and a dwelling was subsequently built on the excavated material, annual radiation doses of some tens of milliSieverts are calculated. This level of dose is within the region where intervention may be justifiable, so that it is appropriate to consider the possibility of mitigating actions related to these specific disposals. Options include localised retrieval of the high activity wastes, the construction of local barrier layers in the cap to deter or limit human intrusion or the in-situ treatment of the wastes. As our assessment of the relevant impacts is at an interim stage, we have not reached a definite view about such options. In particular, we propose to keep the option of selective retrieval under review pending the more detailed analysis of long-term performance that is being carried out in support of the Environmental Safety Case to be submitted by May 2011.

It is not considered a viable long-term safety strategy to plan for the long-term coastal defence of the LLWR. This is primarily because, to prevent coastal erosion, defences would be needed many thousands of years in the future and for very long periods thereafter. We cannot claim that current organisations or appropriate funding would be in place to ensure that such defences are built and maintained. Reliance within a Safety Case on actions by future generations is inconsistent with Principle 1 of the relevant regulatory guidance, which requires that future safety is independent of long-term controls.

Further optimisation studies will be required to refine or review the conclusions of the current study. For example, the detail of LLWR's approach to institutional control will need to be developed and the hydrological performance and optimisation of some of the engineered barriers will be considered further. Other issues, such as the best use of the remaining disposal capacity and the management of the waste prior to disposal, will be considered in parallel with the development of a national strategy for the management of LLW.

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1 Introduction

The Low Level Waste Repository at Drigg (the LLWR) is the UK's principal facility for the disposal of solid low-level radioactive waste (LLW). The site is owned by the Nuclear Decommissioning Authority (NDA) and operated on behalf of the NDA by a Site Licence Company (SLC). United Kingdom Nuclear Waste Management (UKNWM) Ltd. holds a contract from the NDA for the management and operation of the LLWR and shares in the SLC were transferred to UKNWM Ltd. on 1st April 2008.

To dispose of radioactive waste the SLC requires an authorisation under the Radioactive Substance Act of 1993 (RSA93), which under amendments of 1996 is determined by the Environment Agency (EA) for facilities in England and Wales. The LLWR has operated under the terms of authorisations under RSA93 (and previously under RSA60); the authorisations are periodically reviewed and renewed by the regulatory agencies.

Before granting or renewing an authorisation, the EA must satisfy itself that the proposed disposals are consistent with Government policy, for example that radioactive wastes should be managed and disposed in ways to protect the public, work force and the environment (HM Government, 1995), and are in accord with its own guidance on requirements for authorisation (Environment Agencies, 1997). This may include consultation with other agencies as needed.

It is the duty of the SLC to make submissions to the EA concerning the management and safety of the facility, and provide all necessary evidence on which the EA can make its determination. Provided it is satisfied, the EA may then grant an authorisation, which may be subject to conditions and requirements concerning both the operation of the LLWR and future actions and submissions by the SLC.

The previous SLC, British Nuclear Fuels plc (BNFL), completed operational and post-closure safety cases (2002 OESC and 2002 PCSC) for the LLWR in 2002 (BNFL, 2002a; 2002b). These were reviewed by the EA, and following a period of consultation, a new single authorisation was granted (Environment Agency, 2006a), encompassing all aspects regulated by the EA under RSA93. The authorisation, with an effective date of 1st May 2006, is split into a number of schedules, of which Schedule 9 (see Appendix A) is a list of improvements and additional information that the operator must supply.

We (the SLC) have initiated a programme of work – the LLWR Lifetime Project – to address the requirements of Schedule 9. The present document is Volume 1 of a set of 5 volumes, with supporting references, that is designed to satisfy Requirement 2 of Schedule 9:

Volume 1: Managing existing liabilities and future disposals at the LLWR;
Volume 2: Assessment of options for reducing future impacts from the LLWR;
Volume 3: Inventory and near field;
Volume 4: Site understanding;
Volume 5: Performance update for the LLWR.

Volume 1 provides an overview of our submission and Volumes 2 to 5 provide more detailed information and analysis in support of Volume 1.

Requirement 2 states:

> *'The Operator shall provide the Agency with a full report of a comprehensive review of national and international developments in best practice for minimising the impacts from all waste disposals on the site. This shall include a comprehensive review of options for reducing the peak risks from deposit of solid waste on the site, where those risks arise from potential site termination events (e.g. coastal erosion and glaciation) and potential future human action.'*

Requirement 2 is elucidated in the EA's Decision Document (see page 54 of Environment Agency (2006b)), which makes it clear that the LLWR's submission should provide the EA with:

> *'…adequate information to allow the radiological capacity of the site to be determined…'* and
>
> *'…the outcome of a wide-ranging risk management study … that demonstrates that future impacts will be As Low As Reasonably Achievable …'*.

The LLWR has maintained regular dialogue with the EA in relation to the different Requirements in Schedule 9 and the technical approaches that might be followed in responding to them.

Our overall approach to addressing Requirement 2 is set out in subsection 1.4 of Volume 1. The key deliverables needed to address Requirement 2 are:

- information to show that our work is founded on national and international best practice (see Section 3 of Volume 1 and Section 5 of this Volume);
- an assessment of options, to determine the best way of managing the long-term impact of the Trenches; (this document);
- an analysis of the total 'radiological capacity' of the Vaults (see Section 6 of Volume 1);
- an updated view of site characteristics, the evolution of the engineered barriers and long-term performance (Volumes 3, 4 and 5).

The EA's requirement specifically mentions future human actions and termination events (such as coastal erosion and glaciation). Our strategy has considered all pathways whereby radiological impacts can arise. However, our focus is on the impacts from future human actions and coastal erosion, since the 2002 PCSC suggested that these are the largest impacts that may arise. We have not considered glaciation because the facility will by then have been destroyed by coastal erosion (Thorne and Kane, 2007). Supporting assessments have reconsidered these impacts and also those from the release of radioactive contaminants in dissolved groundwater and from the release of radioactive gases (see Volume 5).

The objective of the assessment described in this Volume is to identify those options that should be adopted in order to best manage the future impacts from the facility. It addresses the management of solid waste disposed to the facility. It does not consider managing contamination that has migrated from the facility, for example in groundwater, or the management of contaminated land at the site.

The options assessment is focused on the Trenches, noting that the impacts of the Vaults are being assessed and optimised separately through implementation of the Conditions for Acceptance and design optimisation studies for the future vaults. However, many of the management options that will be considered will apply to both the Vaults and the Trenches.

In all of the analysis presented in this set of reports, we focus on the post-closure performance of the LLWR. This is because:

- the site is considered to be safe now in that the radiological impacts are very low;
- any impacts can and will be managed appropriately during the operational period;
- other studies are or will be concerned with appropriate optimisation of operational performance, for example in relation to the performance of the interim trench cap and the design of Vault 9.

The chemotoxic impacts of the facility are addressed in Barber and Henderson (2008), which is to be submitted against the EA's Requirement 13 of Schedule 9. This assessment is at a preliminary stage, and has been based on a cautious approach and therefore its conclusions are not carried through to this assessment.

It is important to see this study in the context of a range of options studies that have been undertaken by the LLWR since 2002 and those that will be undertaken in the near future (see subsection 2.1). One earlier options assessment was directed at the management of future impacts from the Trenches (BNFL, 2004b). It involved detailed analysis and scoring of a number of options and is an important input and basis for the current analysis. It is also important to note that other options assessments are or will consider issues in relation to the design of Vault 9 (Fleming, 2007; British Nuclear Group Project Services, 2007) and the future use of the remaining disposal capacity. These options assessments contribute together to a demonstration that Best Practicable Means (BPM) have been used to ensure that risks and radiation doses are As Low as Reasonably Achievable (ALARA).

As noted in Volume 1, the current submission does not provide a full safety case; rather an interim update is provided, pending the completion of a full Environmental Safety Case (ESC) in 2011. Prior to the 2011 ESC, a number of technical issues will have been resolved and substantial progress will have been made in the development of a national LLW strategy. This will facilitate an updated view on the management strategy for the site and the completion of a comprehensive safety assessment. On the basis of the interim position reported in this set of Reports, there are some conclusions that we consider are robust, but other conclusions that are less definite.

The current strategy has been developed at an overview level. It will also be necessary to pursue further detailed optimisation in relation to certain design features and management strategies. We return to these aspects in Section 7.

The rest of Volume 2 is structured as follows.

- Section 2 outlines the methodology by which the future management strategy for the site was developed.
- Sections 3 to 6 summarise the approach and outcome of the assessment.
- Section 7 provides a summary of the options that have been selected and the justification for that choice.

2 Approach

2.1 Context for the Current 2007/08 Studies

In the 2002 Post-closure Safety Case (PCSC) (BNFL 2002b), a number of radiological impacts were calculated that were sufficiently high that consideration of intervention was required (see Section 1 of Volume 1). This was identified by the Environment Agency in their review of the PCSC (Environment Agency, 2005a) and in Requirement 2 of Schedule 9 of the Authorisation.

Our updated view of performance (see Volume 5) now suggests that the radiological impacts from the Trenches are below relevant intervention criteria (except in cases where exposure occurs to wastes with higher than average concentrations of key radionuclides or more cautious parameter choices are made than in our base-case calculations). However, even in those circumstances, there is still a need to consider the appropriate design for the facility and to demonstrate the application of good science and engineering. Further consideration is also required of those circumstances that might give rise to doses in excess of the 10 mSv yr^{-1} criterion. In Volume 5, we explain why intervention criteria are considered to be appropriate criteria for all scenarios, against which to measure the performance of the Trenches.

Subsequent to the 2002 PCSC, a detailed options assessment was undertaken (BNFL, 2004b). This was based on two expert workshops, which resulted in the identification and detailed assessment of sixteen alternative options. These were scored against ten attributes. Data were drawn from supporting reports, in particular one that provided a detailed analysis of costs (Halcrow, 2002). These source data were reviewed for currency and used within the current study. Specifically, the 2004 study was used to audit the long list of options and to provide the basis of a detailed analysis of each option, which was then supplemented by further work as part of this study. The 2004 study is discussed in more detail in the next subsection and a summary of the results of the analysis is reproduced in Appendix A.

In the current study, we have tried to focus on the decision logic i.e. the reasons for our choices rather than on the quantitative analysis of different options. We note that strategy development is rarely a simple choice between alternatives. There are a wide range of factors that cannot easily be scored or ranked. In this sense, we consider that the current analysis is complementary to that offered in 2004.

Recently, we carried out a Site End State study in association with the West Cumbria Sites Stakeholder Group (WCSSG). In consultation with a wide range of stakeholders, including the NDA, the EA, the Health and Safety Executive (HSE) and local stakeholders, we identified preferred Site End Uses of 'waste management' and 'recreational and nature conservation'. Three potential End States were considered: 'disturb', 'partial disturb' and don't disturb'. Following stakeholder consultation, a preferred End State of 'don't disturb' was determined and recommended to the NDA (Wood, 2007). The options assessment described in this submission addresses the future management strategy from a more detailed and technical perspective, whilst noting the preferences and conclusions from the Site End State analysis.

The main focus of the 2007/08 studies reported here is the long-term threats to the Trenches. Other optimisation issues are being addressed elsewhere. For instance, there was a major recent exercise to develop and optimise the new Modular Vaults Design for Vault 9 (Fleming, 2007). An additional focus for the future vaults is on appropriate control of the disposed inventory by means of the Conditions for Acceptance (CFA) to ensure that disposals are consistent with the Safety Case for the site. As noted in Volume 1, decisions on the use of the remaining disposal capacity for the site are closely linked to the national LLW strategy. It is also expected that this strategy will develop new approaches to the treatment of LLW, and hence the characteristics of waste consigned to the LLWR will change. As this strategy is not yet available, these issues are not assessed in this submission. Development of the overall strategy for the site will continue to be iterative as the implications are explored with stakeholders and key uncertainties identified and subjected to further study. In particular, many of the strategic issues identified here will require more detailed optimisation.

2.2 BPEO Guidance

Guidance from the environment agencies on the conduct of nuclear BPEOs is contained in Environment Agency & SEPA (2004) ('the Guidance'). The strategy development methodology that we have used is consistent with the Guidance. It complies with the six key characteristics set out in Section 2 of the Guidance:

- The process is essentially strategic – it is geared towards identifying a preferred overall strategy from the perspective of the environment as a whole, as opposed to detailed optimisation of the selected scheme.
- A structured and systematic process is used to identify and compare strategic options. It is an open and transparent process, documented to make explicit the reasoning, data and assumptions.
- Alternatives have been evaluated in terms of their projected implications for environmental quality and practicability, as well as the overall strategic objectives that reflect the wider context in which the decision is being taken.
- The process does involve consideration of environmental effects in both the short term and the long term.
- Life cycle considerations such as energy demand have been considered.
- There has been an accent on consultation as an integral part of the study process.

The Guidance also says (Section 2) that:

> *'The aim of a BPEO study is to ensure that the rationale behind a strategic decision, involving technical, scientific and more qualitative judgements (including their consistency with the over-riding principles of precautionary action and sustainable development), is made visible. A BPEO study may be required to inform the operator's or the regulator's decision-making; however, it is rarely the sole criterion for making the choice.'*

We take this to be consistent with our aim of making explicit both the multi-attribute and decision logic elements of the process.

Section 11 says that: *'…the value of multi-attribute methods within the BPEO framework is to provide the basis for a systematic qualitative comparison of options, rather than implying that quantitative study alone is sufficient as a basis for determining the preferred option. The ranking of options on the basis of aggregate (weighted) scores alone is rarely satisfactory as a basis for decision making. If a numerical scoring system is used, the top scoring option may be the starting point for identification of a preferred strategy, but the conclusion may still be that it is not the BPEO.'* This is consistent with our experience here, that the scoring and ranking in the 2004 work was an important contribution, but that it was the qualitative work and the decision logic that ultimately defined the outcome.

2.3 Process Employed in the 2004 Studies

The 2004 management option studies provided detailed assessments of the radiological performance benefits for a range of strategic options and assessments against a comprehensive set of attributes.

In the first of these studies (BNFL, 2004a), we examined whether there were any management strategies that could be implemented that would give a significant potential for overall reduction of the radiological impact from the waste currently disposed of in the Trenches and Vault 8 and from waste for potential future disposal to the Drigg facility. Only two such strategic options were identified; encouraging dilution and dispersion of radionuclides from the Trenches whilst maintaining the role of the Vaults as providing containment of radionuclides; and the closure of the Drigg facility and the retrieval of wastes for disposal at a new facility. Encouraging dilution would result in higher short-term risks from the groundwater pathway and, in addition, this option is inconsistent with the objective of containment.

The second study (BNFL, 2004b) comprised a preliminary options assessment employing a conventional multi-attribute approach, though with a more detailed emphasis than the strategic option studies that are the main focus of the current report. Technical preparatory work was reviewed and extended by a team of experts (including members of the current project team) over the course of two one-day workshops (BNFL, 2004b). The options considered were

- Extended period of institutional control;
- Coastal defences;
- Retrieval of waste;
- Site closure and storage of future arisings;
- Increased cap thickness;
- Increased cap performance;
- Eliminate surface pathways in short term;
- Active barrier;
- Encourage dilute and disperse from Trenches;
- In-situ deep soil mixing and grouting of Trenches;
- Insertion of an impermeable barrier underneath Trenches 1-3;

- In-situ vitrification of trench waste;
- Compaction of trench waste;
- Excavation of trench waste and disposal in new Vaults;
- Improvement of vault waste form; and
- Improvement of vault design.

The attributes applied were:

Environment and safety	• Chemical impacts • Radiological impacts • Resource use • Disturbance / nuisance • Worker dose • Conventional safety • Acceptability of waste form (in-situ) • Minimisation of waste at source)
Technical	• Technical confidence • Compatibility with existing systems • Implementation time
Economic	• Acceptability • Costs

The results tables from this assessment are included in Appendix A. The data tables and scoring/weighting details are in the original reports.

The baseline option (continued development as specified in the then current site development plan) scored highest, suggesting that it was an appropriate solution for the optimum management of the long-term risks and associated uncertainties.

Other options scoring favourably included increased cap thickness, improvement in vault design, increased cap performance and an extended period of institutional control. Those options that enable intervention or improvement without requiring contact with the disposed waste tended to score more favourably.

The lowest scoring options included excavation of trench waste and disposal into new Vaults and in-situ vitrification. These options, which require direct contact, excavation or exposure of the waste, scored less well as they involve direct interaction with the wastes, potentially giving rise to increased doses and risks during implementation.

All of the options addressed in the 2004 were carried forward to the current analysis, except that the option of encouraging dilute and disperse was omitted as it is fundamentally inconsistent with the objective of containment. Those options related to improved Vault waste design and improved Vault wasteform were not addressed because the focus is on the Trenches rather than the Vaults and vault design issues have been considered as part of the optimisation work to support a new design for Vault 9. In addition to the options considered in 2004, we have considered selective retrieval, as this was one of the issues raised in the

Environment Agency's review of the 2004 analysis (Environment Agency, 2005b). A further issue raised in the Environment Agency's review was the lack of independent involvement in the decision making process. Engagement with stakeholders has been a key priority for the current analysis.

2.4 Process Employed in the 2007/08 Studies

In summary, our methodology consisted of five stages. We:

1. Reviewed the potential 'threats' in terms of the issues that might give rise to radiological impacts in the future.

2. Developed and assessed a comprehensive long list of detailed management options and technologies, based on a detailed review of national and international practice.
3. Identified and characterised a short list of options (derived from the long list by using a screening process).

4. Assessed the potential use of those options at the LLWR.

5. Identified those options that should form part of future strategy.

It is important to note that most of the options can be combined. Indeed, it is likely that a suitable management strategy will involve the application of several options. Some of the options considered are part of the current Lifetime Plan for the site, but could be modified or omitted with appropriate justification. The rest are potential additional options that could be added to the LLWR's Lifetime Plan, were this to be considered appropriate.

The process was mainly implemented through a series of expert and stakeholder workshops.

- An internal expert workshop in November 2006 to conduct an initial review of the threats in advance of the toolkit workshops, and to review the proposed toolkit methodology.
- An external Stakeholder Workshop in December 2007 to present and obtain feedback on the proposed methodology and the toolkit development programme – documented in an agreed workshop report (Collier, 2008a).
- An internal Screening Workshop to review the output from the toolkit development, to carry out screening to generate a shortlist, and to derive and characterise strategic options for analysis – documented in *The Toolkit Report* (Collier, 2008b) and its supporting references.
- A combined internal/external expert Screening Review Workshop in January 2008 to scrutinise and update the output from the internal Screening Workshop – also documented in *The Toolkit Report* and its supporting references.
- A further external Stakeholder Workshop in January 2008 to present and obtain feedback on the output from the toolkit and strategic option development, and on the proposed assessment methodology – documented in an agreed workshop report (Collier, 2008c).

- A combined internal/external expert Assessment Workshop in March 2008 to carry out a structured review of the strategic options against the threats – documented in the *Assessment Workshop Report* (Penfold, 2008a) and its supporting references.
- A presentation of the results to the LLW Subcommittee of the WCSSG, which took place in early April 2008.

The *Toolkit Report* and the *Assessment Workshop Report* are referred to regularly throughout Volume 2 and are the key process references. Work to characterise the strategic options was carried out separately to the programme of workshops and is documented separately in six supporting references (see below). For convenience, the 5 stages in the methodology are outlined below. Subsequent sections provide more detailed descriptions.

2.4.1 Threats (See Section 3)

The key threats to long-term safety fall within the following categories (BNFL 2002b):

- Inadvertent human intrusion
- Sea-level rise and coastal erosion
- Release of radioactive contaminants dissolved in groundwater
- Release of radioactive gases

2.4.2 Toolkit (see Section 4)

The core of our approach has been to identify a 'toolkit' of options, which is available for use now and in the future to remediate all or part of the facility. The Toolkit component of the process had three objectives:

- Develop a fully comprehensive range of potential detailed management and technology options that might be applied at LLWR;
- Provide a starting point for the development of higher level strategic options for the current strategy and as a basis for future review; and
- Contribute to a wider review of best practice.

2.4.3 Strategic Options (see Section 5)

Building on this work and the results of the 2004 studies, a set of seven strategic options was derived by grouping and screening. These were assessed against a range of attributes, based on BNFL (2004b) and further review and consideration undertaken in this study.

- Repository Cap
- Engineered Barriers
- Coastal Defences
- Vertical Drains
- Bulk or Local Retrieval
- Institutional Control
- In-situ Remediation

2.4.4 Assessment (see Section 6)

A key part of the assessment process took place at the workshops, where participants considered each threat in turn and considered whether there were any suitable management options that could mitigate the potential impacts. The suitability of each option was considered in terms of the BPEO attributes, focusing on the key arguments and issues. The output was a set of assessment tables that are included in Section 6 of the current document.

The assessment was based in part on work in our 2004 options assessment (BNFL, 2004b), and six new detailed assessment reports which address all of the strategic options identified above:

- Caps & engineered barriers (Grimwood, 2008);
- Coastal defences (Towler, 2008a);
- Vertical drains (Paulley, 2008a);
- Retrieval of waste (Paulley, 2008b);
- Institutional control (Penfold, 2008b);
- In-situ remediation (Towler, 2008b).

These reports include a discussion of best practice where appropriate and a survey of experience in the use of the option at other disposal facilities.

2.4.5 Synthesis (See Section 7)

The final step was to extract the key elements from the assessment results and identify those that should form a component of the long-term management strategy. At this stage this strategy is at a high level. As part of future work, it will be optimised and developed further. The strategy presented at the end of the current document proposes including some of the individual strategic options and omitting others. Some options may have a supporting part to play. Further work is identified.

Some of our conclusions concerning some of the options depend on a small number of key issues and arguments rather than a detailed balance between all of the attributes that have been assessed. These aspects are emphasised in the discussion in Section 7.

2.5 Stakeholder Engagement

Stakeholder engagement has been integral to this process. As noted above, we have held two project-oriented stakeholder workshops to explain our approach and methodology and to seek stakeholder views as an input to the analysis. The first one focused on the toolkit development process, the second one focused on the toolkit work conclusions and the assessment process.

This is, of course, not the end of the stakeholder programme associated with strategy and environmental and safety case development. We are committed to continuing engagement in relation to the issues set out in this series of documents and more generally with our stakeholders, who include:

- Local residents;
- Councils at the parish, district and county level;
- The WCSSG Sub-Committee on LLW;
- Trade unions and employees;
- National government and politicians;
- Regulators such as the EA and the HSE;
- The Nuclear Legacy Advisory Forum (Nuleaf);
- Waste consignors.

We have regular engagement with stakeholders on all LLWR matters. For example, the WCSSG LLWR Sub-Committee has received numerous presentations on issues specifically relating to repository operations and individual projects, including this project. Regular interface meetings are held involving Cumbria County Council, the EA, the HSE and the NDA.

Quarterly liaison meetings take place between the SLC and Drigg and Carleton Parish Council where any concerns can be raised and addressed. This forum is also used to provide an update on current operations and projects and to discuss future plans for the Repository.

We will be talking to our stakeholders through these and other forums and will develop with them an engagement plan for future phases of work.

2.6 Best Practice

To take forward our understanding of best practice, we have carried out a wide ranging review of possible techniques and options (Amin, 2007), which has provided the starting point for the list of options considered in this analysis (it was used as the basis for the initial long list of options). Reports have been written on each of the strategic options, which provide a discussion of the use of each option in other repositories and comment where appropriate on best practice. Further details are provided in Section 5.

In terms of mitigating the impacts from existing near-surface facilities, we consider that best practice involves:

- The use of a systematic BPEO process to analyse the different options (Environment Agency and SEPA, 2003);
- Evaluation of possible intervention against established criteria (ICRP, 1999);
- Consideration of a wide range of options, taking account of their advantages and disadvantages;
- Use of an integrated approach covering all parts of the future life cycle of the waste (IAEA; 2007).

With respect to possible retrieval, the IAEA further emphasises the need for adequate understanding and characterisation of the waste, the availability of appropriate facilities for storage and disposal and the need for waste acceptance criteria to be implemented for those facilities (IAEA, 2007). More specific examples and issues are discussed in Section 5.

3. Threats

This section describes the selection of the key long-term impacts or threats to the repository and describes their main features. Our revised assessment of these impacts is presented in Volume 5.

3.1 Overview

The key radiological impacts arising are:

- Inadvertent human intrusion, which could lead to the radiation exposure of individuals during the excavation of waste or following its distribution in the environment;
- Sea-level rise and coastal erosion which might lead to inundation and/or disruption of the facility and the dispersal of radioactive material on the foreshore;
- Release of radioactive contaminants dissolved in groundwater as engineered barriers degrade over long periods of time and contaminants gradually migrate from the site in groundwater; and
- Release of radioactive gases, produced as the waste degrades, which might then result in the contamination of soils and foodstuffs or which might collect in buildings.

These were identified as part of the 2002 PCSC. A full discussion of the radiological impacts corresponding to the pathways listed above is provided in Volume 5.

We estimate that the facility will be destroyed by coastal erosion within some thousands of years (Thorne and Kane, 2007) i.e. before glaciation can occur. Hence, glaciation is not considered in the current analysis, although it was addressed in the 2004 radiological impact and options assessment studies (BNFL, 2004a & 2004b).

3.2 Human Intrusion

During the planned period of post-closure institutional control of the LLWR, active measures will prevent activities that could result in unintentional intrusion into the wastes. Even after this, it is reasonably likely that knowledge of the repository will persist for a period of several hundred years as a result of passive institutional control measures and memory of the facility.

If the currently planned final cap were built, only a few activities (e.g. construction of a major road or rail link or site investigation activities) would be sufficient to reach the waste since it would be necessary to penetrate typically 8m of cover. Large human intrusions, such as those associated with a major road are unlikely to occur (see Volume 5).

The highest radiation doses for human intrusion arise if a large construction project results in the distribution of waste in the environment. Subsequently occupants of a house constructed on the waste, which is assumed to be mixed with uncontaminated cap material, would receive radiation doses as a result of radon inhalation (see Volume 5). In these circumstances, a radiation dose of 0.7 mSv yr^{-1} has been estimated (based on a house constructed on 40% waste with average Trench radium contents, mixed with 60% of uncontaminated cap). Further dilution, as assumed in previous calculations (including the 2002 PCSC) would reduce this dose significantly. On the other hand, the ^{226}Ra parent of radon is concentrated in some regions of the trenches, which could lead to an increase in maximum doses (see Volume 5). It should be noted however that the current model of radon inhalation requires further development and evaluation to build confidence in these estimates of radiation dose.

3.3 Coastal Erosion

Coastal erosion is expected to affect the LLWR sometime between about 750 and 2500 years from now (Thorne and Kane, 2007). Wastes will be distributed on the beach and beach users may receive radiation doses via a number of exposure pathways, dominated by external irradiation and dust inhalation. Estimated radiation doses for the Trenches are 8 $\mu Sv\ yr^{-1}$ (see Volume 5).

3.4 Release in Groundwater

Radionuclides will be released from the LLWR in groundwater. Most contaminated water is expected to be discharged to the foreshore or sea. The expected radiation doses are very low as a result of dilution in marine waters (see Volume 5).

The preliminary estimate of the doses that might arise from the Trenches as the result of the abstraction of water from a well at the site boundary is 0.01 $mSv\ yr^{-1}$. For the Vaults, higher radiological impacts may arise, with estimated conditional risk of up to $2\ 10^{-5}\ yr^{-1}$ (see Volume 5).

It has been assumed in the assessment calculations that the vertical drains will continue to function over the period of interest. However, the possibility of local terrestrial discharge has been evaluated in two illustrative cases for the Vaults, resulting in estimated peak risks of around $9\ 10^{-10}$ to $2\ 10^{-8}$ (see Volume 5). Similar impacts might arise for the Trenches.

3.5 Gas Generation

The release of radioactive gas is certain to occur. ^{14}C-labelled methane and carbon dioxide resulting from the degradation of cellulosic wastes are expected to provide the highest impacts of less than 1 $\mu Sv\ yr^{-1}$ for the Trenches (see Volume 5). These arise as a result of the incorporation of ^{14}C in plants, which are then consumed.

3.6 Summary

The impacts from the Trenches are less than were estimated in the 2002 PCSC. The expected radiation doses that arise are less than the 10 $mSv\ yr^{-1}$ reference level, below which the ICRP consider that intervention is unlikely to be justifiable (see the discussion in Volume 5 and noting the exceptions identified in the following paragraph). Therefore, the requirement for intervention to mitigate the impacts is not established. Of course, it is still necessary to ensure that good science and engineering is applied in the design, operation and safety assessment of the facility.

However, there are a number of uncertainties associated with the radiation doses that might arise as a result of radon inhalation following human intrusion (see Volume 1). These include, for example, the possibilities that exposure might occur to wastes with higher than average concentrations of ^{226}Ra. As noted in Section 5 of Volume 1, doses of some tens of milliSieverts are calculated for excavation and building on wastes with higher than average concentrations of ^{226}Ra (see Section 5 of Volume 1).

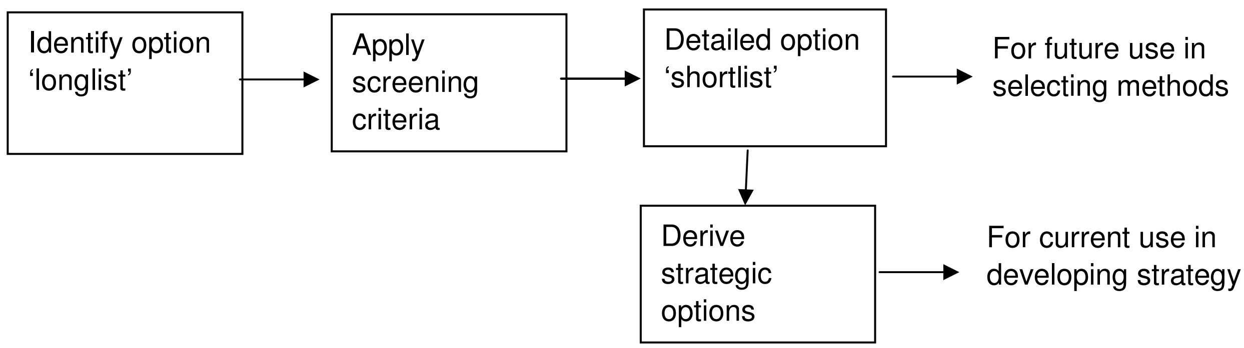
4 Toolkit Development

4.1 Overview

The Toolkit component of the process had three objectives:

- to develop a fully comprehensive range of potential detailed management and technology options that might be applied at LLWR;
- to provide a starting point for the development of higher level strategic options for the current strategy and as a basis for future review; and
- to contribute to the wider review of best practice.

The main steps are shown below and documented in detail in the Toolkit Report (Collier, 2008b), which with its supporting references is the key source for this section.



4.2 Option Longlist

The starting point for the toolkit was the specification of the range of approaches that might be needed and the generation of an initial 'longlist' without seeking to differentiate between those that might be directly applicable in the LLWR context and those that might not.

We commissioned a wide-ranging review of management approaches and technologies either currently or potentially being used for the remediation of radioactively or otherwise contaminated land, groundwater, wastes and old disposal facilities (Amin, 2007). The report included approaches ranging from those designed to address any issues of ground contamination to those more appropriate for application to a repository. Some were applicable to a whole repository while others could be applied to only a portion of the repository, for example to wastes with certain characteristics.

A long list of options was drawn up based on this survey. Some compound approaches were included where individual approaches would probably or necessarily be used in combination. Options were also added to cover areas not covered by the survey report e.g. institutional control, and the re-disposal of waste to the existing or a new facility. This was by reference to BNFL (2004b) and as a result of expert review. The data on each option were then entered on a pro forma within a Microsoft Access database so that the screening, assessment and future review processes could be tracked. The Toolkit will be reviewed at intervals to see whether new technologies have emerged or been applied elsewhere.

4.3 Screening

The next step was to screen the long list to assemble a toolkit of feasible approaches that could have a potentially beneficial impact at the LLWR. Each potential approach was tested against the following screening criteria and either included or rejected.

- Can the option be realistically implemented with current technical knowledge? Is the technology sufficiently mature that the option could be confidently included as part of the management strategy? Options that are screened out at this point will be re-appraised on a regular basis to capture R&D work being undertaken.
- Is the option likely to deliver significant benefits in terms of reducing impacts? Will the option deliver significant benefits in terms of reduced radioactive discharges or other forms of reduction against any of the threats being considered?
- Is the option consistent with current law, policy and regulatory guidance? Or is there any prospect that it might become consistent?

This process was carried out by the project team. However, to improve transparency and confidence, the long list, the screening process and the screening criteria were reviewed at a workshop in December 2007 involving external stakeholders and regulators (Collier, 2008a).

4.4 Shortlisted Options

The shortlisted options presented to that workshop (see the descriptions in Appendix B) were:

Base Liner
Excavation, Retrieval and re-Disposal
Grouting
In-situ Vitrification
Landfill Cap and Landfill Cap Enhancements
Linear Jet Grouting
Monitored Natural Attenuation
Passive/Reactive Walls
Physical Barriers
Solidification/Stabilisation (in-situ)
Institutional Control
Coastal Defences

Vertical Drains
Disposal of Retrieved Waste to another Facility
Re-disposal of Wastes to the LLWR
Compaction of Trench Waste

The options involving disposal or redisposal require use of some of the ex-situ waste treatment options as an intervening step and would necessarily take place after retrieval. Waste treatment options included as part of package or grouped options based on retrieval and disposal or redisposal are:

Chemical Extraction
Encapsulation
Enhanced Soil Washing
Ex-situ Vitrification
Incineration
Separation
Soil Washing
Solidification/Stabilisation (ex-situ)
Waste Segregation and Sorting

Included, as possibly viable with further development were:

Earthsaw™

Just over 50 remaining options were screened out. Three more were classified as 'possibly viable with development' but were screened out on the basis that they did not offer significant benefits in the context of the objectives of the current study.

5 Strategic Options

5.1 Derivation

The screened options identified in Section 4 were grouped into a series of strategic management options (see Table 5.1 and Appendix C) - also referred to in LLWR documentation as 'grouped options' - that could potentially mitigate against the threats described in the Section 3. These were then evaluated at the Assessment Workshop (see Section 6).

This analysis was carried out at an internal workshop, starting from the shortlist of detailed Toolkit management options and technologies and also taking into account options then being considered within LLWR. The output was reviewed at the combined internal/external Screening Review Workshop as described in the Toolkit Report, and again at the January 2008 external Stakeholder Workshop (Collier, 2008c).

Table 5.1 Strategic Options

Strategic Option (Grouped Option)	Toolkit Options	
Repository Cap	MO/07/044 MO/07/045	Landfill Cap Landfill Cap Enhancements
Engineered Barriers	MO/07/053 MO/07/054 MO/07/005 MO/07/047	Passive/Reactive Walls Physical Barriers Base Liner Linear Jet Grouting
Coastal Defences	MO/07/076	Coastal Defences
Vertical Drains	MO/07/077	Vertical Drains
Bulk or Local Retrieval	MO/07/027	Excavation, Retrieval and re-Disposal
Institutional Control	MO/07074	Institutional Control
In-situ Remediation	MO/07/033 MO/07/065 MO/07/040 MO/07/081	Grouting Solidification/Stabilisation (in-situ) In-situ Vitrification Compaction of Trench Waste

5.2 Preliminary Characterisation

The identified strategic options were characterised against an initial set of assessment criteria that reflected the issues considered in BPEO assessments. This was again first carried out at an internal workshop and then reviewed at the January 2008 Screening Review Workshop and the external Stakeholder Workshop. The aim was not to carry out a detailed assessment because information on several key factors such as cost was not available. Rather, the objective was to provide an initial indication of the pros and cons of the strategic options and systematically characterise them on a common basis. We felt it desirable to maintain continuity with the End State evaluation for the LLWR and hence used the same set of attributes (Wylie, 2007) as shown in Table 5.2.

Table 5.2 Attributes

Health and Safety	Public Radiological Exposure (short & long term) Public Conventional Safety (short & long term) Worker Radiological Exposure (short & long term) Worker Conventional Safety (short & long term) Risks to Future Users and Neighbours
Environment	Physical Environment Flora and Fauna Resource Use Waste Hierarchy
Technical	Viability
Socio – economic	Employment Traffic/Noise
Financial cost	
Regulator/Legal Requirements	

The output of this process was a set of assessment proformas including a short description of performance against those attributes that had the potential to differentiate the options. The initial results are provided in the Toolkit Report (Collier, 2008b).

After the selection and preliminary characterisation of the strategic options had been presented, discussed and feedback noted, we commissioned a series of substantial new briefing notes to support the assessment process. Each briefing note presented a full description of the option(s), relevant international guidance and regulations, and a description of its use elsewhere.

The notes included a more detailed characterisation of the strategic options and their applicability to the LLWR.

- Caps & engineered barriers (Grimwood, 2008)
- Coastal defences (Towler, 2008a)
- Vertical drains (Paulley, 2008a)
- Retrieval of waste (Paulley, 2008b)
- Institutional control (Penfold, 2008b)
- In-situ remediation (Towler, 2008b)

These notes are key references for the current document and the summary descriptions below are based on their contents. The assessment proformas for each of these strategic options were then developed further and are provided in Tables 5.3 to 5.9 at the end of Section 5.

5.3 Caps

5.3.1 Description

A cap is a barrier placed over a waste disposal facility. The design may vary, but generally includes a number of layers comprising natural and man-made materials. Cap designs range from simple earthen covers to more engineered structures. This strategic option is intended to capture the whole range of variants. A coarse distinction is made between "simple" caps such as those emplaced over municipal landfills and more highly engineered caps generally considered to be appropriate for radioactive waste repositories.

5.3.2 Experience and Best Practice

The use of a repository cap is not specifically required by regulatory guidance. However, it is difficult to envisage how a near-surface repository without some sort of cap could be considered to correspond to good engineering practice.

The LLWR's current approach to the design of a repository cap is set out in detail in Belton (2007). A review of cap performance issues and practice is provided by Halcrow (1998).

Essentially all the generic concepts and the practical examples cited in Grimwood (2008) contain some form of cap. These range from simple earthen or concrete covers that simply provide containment to more engineered structures, the purpose of which is to act as water shedding and intrusion barriers. The thickness of caps typically ranges from about 1 m to more than 10 m. It is also appropriate that the design of a repository cap takes account of potential releases of gas and to provide protection against erosive processes (but not coastal erosion).

A key barrier to human intrusion is physical thickness. However, specific layers can also be included for this purpose. These may be layers that deter or alert the human intruder to potential hazards and may consist of concrete or cobbles or some sort of sub-surface marker could be provided. The principal functional requirements in relation to minimising infiltration are:

- A vegetated soil top layer to protect the lower barrier layers and to enhance evapotranspiration;
- A conductive barrier to divert water laterally;
- A low permeability layer; and
- A fill material to provide the required gradient to the cap.

In addition, a drainage system around the perimeter of a cap is required to ensure the water from the cap itself is diverted away from the waste facility. Cut-off walls may also be used in conjunction with caps to assist in ensuring water is shed away from the facility.

Caps are likely to require provision for the venting of gas generated within the facility. Any gases generated within the waste, principally those from waste decomposition, need to be allowed to escape through the cap so that they do not migrate laterally or find other adventitious routes for migration (otherwise some degree of pressurisation may occur within the facility and this could cause damage). Passive venting of gases through the cap can be achieved by allowing routes for the gas to pass through the barrier layers, for example by having overlapping but not sealed clay or geosynthetic layers near the apex of the cap. For situations in which rates of gas generation are higher, for example at landfill sites where the rates of gas generation can be orders of magnitude higher than for the great majority of LLW, specific vent pipes are installed at required intervals and even gas pumping systems. Vent pipes have been installed in the interim cap at the LLWR to allow passive gas release, though the quantities of gas generated are very small.

In terms of the non-radioactive waste disposal industry, emplacement of caps over domestic landfill and hazardous waste sites is commonplace (Amin, 2007). The great majority of caps use geosynthetic membranes as the principal barrier, with a typical minimum thickness required of 5 mm (Halcrow 2003b).

As discussed in Grimwood (2008), many of the cap designs that have been proposed are to be applied to essentially monolithic style disposals in which the wastes and disposal modules are highly engineered, for example at the facilities at Centre de l'Aube in France and Rokkasho in Japan. In these concepts, only minimum settlement is expected. This is in contrast to situations such as the trenches at the LLWR where settlement and subsidence is expected to last for up to some few hundred years. Early emplacement of a final cap in these situations is much more challenging in terms of cap requirements and design and indeed the long-term performance cannot be expected to be as good as for the monolithic style disposal structures. At Chalk River in Canada a clay cap over disposed wastes failed at a relatively early stage due to cracking (IAEA, 2005).

Grimwood (2008) notes that very few final caps have actually been emplaced at near-surface disposal sites. Most examples of existing caps are interim/short term caps (e.g. Maxey Flats in the USA and Dukovany in the Czech Republic). In many cases final closure cap designs have been proposed but are not due to be constructed for some years. In some cases, this is to allow for continued monitoring of interim arrangements. In other cases it is recognised that periodic cap refurbishment, and possibly complete cap renewal, will be required (e.g. Centre de la Manche, France). The closest examples to the LLWR Trenches are the situations at Centre de la Manche in France and at West Valley in the USA. In both these cases, interim caps have been installed.

It is clear that it is best practice to construct an engineered cap designed to limit water infiltration and to isolate the waste from disturbance by human intrusion and surface processes. Our review suggests that careful consideration is required of the relative merits of interim and final caps and the optimal timing of their installation. This question is linked to the approach to monitoring and requires further consideration in the context of the LLWR.

5.3.3 Capability to Mitigate Threats

Engineered caps reduce the radiological impacts associated with human intrusion, groundwater and gas release. Whilst performance is subject to uncertainty, a cap can be expected to be effective for thousands of years or more (Paksy, 2008).

At the LLWR, an “interim” cap has already been placed on the Trenches., which provides for the management of operational impacts from groundwater and gas. This is achieved with an impermeable membrane within about 2 m of natural materials. Interim caps could play a role in limiting operational discharges, pending the installation of a final cap. Any interim cap could be relatively easily maintained to extend its life or, if required, periodically replaced.

The current strategy for the LLWR incorporates the emplacement of a much thicker final cap when the site is closed (Belton, 2007). A final cap with a thickness of more than 5 m will ensure that most human intrusion scenarios do not occur or are very unlikely. As noted in Volume 5, with a cap of this thickness only large intrusions (e.g. construction of a large road) or intrusions associated with site investigation require consideration. Other intrusions are unlikely to penetrate the cap.

A cap limits water infiltration into the facility and thus reduces the potential impacts from the groundwater pathway. The engineered cap also ensures that radon cannot reach the surface environment as a result of diffusion. If the cap were not present, infiltration of water would be higher and consequences arising from a potential water abstraction well would rise. There would be a high probability that exposures to radon would occur as a result of house construction on top of the facility. There would also be considerable more scope for the contamination of agricultural soils. Overall, radiation doses from certain pathways would be significantly higher than estimated in the current analysis, which is based on the assumption that a cap is constructed. Not emplacing a cap would not in our view be consistent with the use of Best Practicable Means to ensure that risks and doses are ALARA.

Further additional barriers (e.g. concrete rafts) could be used to address the impacts arising from any particularly hazardous wastes, given that their location is documented (Lennon et al., 2008). A thick anti-intrusion cap would only be needed once institutional control and site security is assumed to end, which might be more than 100 years after closure.

5.3.4 Potential for Application at LLWR

The characteristics of the cap in terms of application to the LLWR are summarised in Table 5.3.

As discussed in the previous subsection, and given the timescale of interest for the post-closure safety assessment, there is a potential for the cap to substantially limit the probability of human intrusion. Current plans are for a cap that is about 8m thick on average and this thickness will be effective in limiting the frequency of most sorts of intrusion. Similarly, there is potential for a cap to have significant function in limiting water inflows to the facility over the timescale of interest (Paksy, 2008; Thorne 2008). If a cap were not present, it is expected that radiation doses would be significantly higher than has been estimated and/or the probability that those radiation doses would arise would be increased. Higher infiltration into the facility would significantly increase consequences estimated for a water abstraction well, although this impact cannot be quantified at present. It would become much more likely that doses would be received via the radon pathway. As noted in Section 5 of Volume 1, dose estimates for radon inhalation following human intrusion ranged from 0.7 mSv yr^{-1} to a higher estimate of 38 mSv yr^{-1} for a case with waste with higher than average radium. Without a cap, such doses would be much more likely to be incurred. We consider it proportionate to construct a cap to ensure that the probability that these doses are received is significantly reduced.

Significant radiological hazards to workers should not arise as penetration or disturbance of the wastes is not involved. However, the normal safety hazards associated with construction projects and associated transport will arise.

Caps require large amounts of construction materials. Physical construction requirements (traffic, resource use, visual impact and energy usage) are significant, and would have a major impact on local communities in terms of disturbance and traffic movements.

There are also important design considerations. The limited area of land owned by LLWR means that care would be needed to ensure appropriate profiling to minimise the potential for erosion. Additional localised barriers may be needed to protect specific wastes or compensate for their characteristics (e.g. the potential for localised settlement). There is limited international experience with final cap design, especially for trench-type radioactive waste repositories. Long-term performance is therefore subject to uncertainty (see Paksy, 2008).

Early emplacement of a cap will make access to the wastes much more difficult. This could be detrimental if other management options (e.g. in-situ grouting) were identified as being necessary in the future. The timing of the emplacement of the cap is therefore important, as well as its physical size and design. Early emplacement may limit a flexible approach and preclude any future intervention that might otherwise be considered appropriate.

Cost estimates for reworking and maintaining the interim cap were put at around one million pounds, with the final cap estimated to cost some tens of millions of pounds (see Grimwood, 2008; Halcrow, 2002). Currently, a cost of around £40 million is estimated by the LLWR.

5.4 Engineered Barriers

5.4.1 Description

Engineered barriers are layers of specific materials placed around the repository to manage water movement, gas movement, and/or provide physical stability and protection. Typical barrier materials include:

- Clay, due to its low hydraulic conductivity and its wide occurrence in nature. Clay minerals also have properties that can retard the movement of a broad range of radionuclides.
- Concrete and cement improve structural stability and provide containment.

Barriers can be emplaced around, or even under, existing wastes using a variety of techniques developed in the civil engineering industry.

5.4.2 Experience and Best Practice

Cut-off walls and other barriers are generally employed to prevent lateral movements of groundwater in or out of a disposal facility. Such engineered barriers are discussed in more detail in Grimwood (2008). The Appendix to that reference provides a list of examples of the use of barriers in near-surface repositories. The LLWR's current approach to the design of cut-off walls is set out in detail in Nguyen (2007).

There are relatively few references in IAEA reports to barrier walls and sub-disposal barrier layers put in place after disposal operations, although IAEA (2003) notes that corrective actions include '*surface capping, cut-off walls and grout injection for engineered barriers'*. However, both vertical barriers and sub-disposal barriers are usually put in place as part of facility construction, rather than at a later date.

Example sites where barrier walls have been installed include a slurry wall used at West Valley in the USA and cut-off wall and bed of clinoptilolite used at Chalk River in Canada. A barrier wall is also a potential option being considered at Maxey Flats in the USA. Examples where lateral barriers have been included at the design stage include those of a soil and vermiculite /bentonite wall at Trombay in India and bentonite/sand backfill at Rokkasho in Japan.

No examples have been found in the reports reviewed where sub-disposal grout barriers have been emplaced after disposals have been completed. However, examples of both impermeable (e.g. Vaalputs, South Africa) and permeable vault bases (e.g. the IRUS concept, Canada) have been identified.

Barrier walls and sub-disposal liners (the latter using both natural and geosynthetic materials) are used for non-radioactive waste disposal facilities (see Amin (2007)). Barrier walls are also used in industry to control groundwater, either on a temporary or longer-term basis.

We conclude that cut-off walls and liners are sufficiently often used that it would be consistent with best practice to consider their utility at the LLWR. They are an accepted part of design for non-radioactive waste disposal facilities and remediation situations. However, this is not always the case for repositories for radioactive waste. We note that the function and design of such features is very dependent on the local situation, for example the site hydrogeology. In our view, the use of such features should be considered based on a detailed understanding of the geological and hydrogeological characteristics of the site.

5.4.3 Capability to Mitigate Threats

Engineered barriers can be effective in managing the threats associated with groundwater-mediated transport of contaminants. Their main function is to limit the release of contaminated groundwater from the repository and to reduce the likelihood that such groundwater moves horizontally and is therefore discharged to a local terrestrial receptor. Although such discharges may be associated with relatively low impacts (annual risks of considerably less than the regulatory target have been estimated - see Volume 5), there are uncertainties in these estimates and construction of such barriers would help to produce a more robust case.

We have undertaken some simple modelling to understand the nature of potential groundwater flows in the near field system following repository closure (Paksy, 2008). We consider that further work is needed to refine this understanding. Refinement of the design of the near-field barriers will build on this future work.

5.4.4 Potential for Application at LLWR

The key characteristics of the option are summarised in Table 5.4.

If an overall system of cut-off walls and vertical drains (see subsection 5.6) is engineered in an appropriate manner, then there are a number of potential benefits:

- bathtubbing, resulting in overflow of the facility and the discharge of contaminated water to local terrestrial receptors, would be prevented;
- the possibility of any sub-horizontal groundwater flow paths resulting in discharges to gullies, ditches and local water courses would be minimised;
- lateral inflows of water would be minimised.

In some cases, the associated radiological impacts may be low. However, a range of radiological impacts are possible and the possibility of such local discharges is an uncertainty in the safety case. A more robust safety case will be achieved if it is possible to demonstrate that the system of barriers and drains has been optimised to reduce the likelihood of such pathways. If water inflows to the facility by means of a cap and cut-off walls can be minimised, then there is an increased likelihood that the near-field system will be partially saturated. Vertical drains may also contribute to this objective.

The current reference closure strategy for the LLWR assumes that a deep cut-off wall is placed around the entire consented area. The design assumes the use of calcium bentonite and cement with a high proportion of inert fillers. The wall would be 1 m wide and 15 to 20 m in depth. A vertical drainage blanket would be included between the southern end of the

Trenches/Vaults and the cut-off wall to stop water levels building up within the consented area.

As discussed in the previous paragraph, cut-off walls would reduce the likelihood that contaminated water will be discharged local to the facility, for example following bathtubbing.

The implementation of engineered barriers at the LLWR would be more modest in scale that the emplacement of a large cap. Less material would be required, and there would be less off-site impact.

The technology for cut-off wall installation is mature, and application in sub-surface environments similar to the LLWR is not unusual in civil construction projects. Experience has been gained with the cut-off wall already emplaced at LLWR. Work to install a grout curtain at Dounreay has shown that such techniques can be applied under relatively challenging conditions.

The estimated cost of the deeper cut-off wall for the whole of the consented area is about £30 million (this is the figure allowed in the LLWR's future plans).

Active barriers and the insertion of impermeable barriers under the Trenches have been assessed previously (BNFL, 2004a; BNFL, 2004b) and were not considered to be effective. The technology of jet grouting is relatively novel on the scale that would be required at the LLWR and this has not been considered further.

5.5 Coastal Defences

5.5.1 Description

Coastal defences are any structures intended to prevent damage to land and property by the action of the sea.

Coastal defences can take a wide variety of forms. They include traditional structural barriers as well as artificial reefs or breakwaters, artificial headlands, dune management techniques, sediment trapping or enhancement and others. Hard defences such as rock revetments generally require least maintenance, but even these have a finite lifetime.

5.5.2 Experience and Best Practice

Towler (2008a) provides a discussion of the use of coastal defences and the different approaches that are possible. No examples have been identified where plans are even in place to provide for long-term coastal defences to protect a repository from erosion by the sea. Indeed the timescales of interest (thousands of years) and the magnitude of sea-level rise envisaged (more than 10m) in the LLWR's PCSC are outside normal design experience.

Some nuclear sites actively manage the coastline (for example the shingle beaches at Sizewell and Dungeness). Future coastal management of NDA sites has also been investigated (Thorne and Kane, 2005). However, these examples are addressing different timescales from those relevant at the LLWR.

Exploratory work has been undertaken, but there has been no detailed design of coastal defences for the LLWR and they have not been adopted in the existing reference strategy for the site.

The use of coastal defences is a normal part of shoreline management in the UK. There is very extensive literature on coastal defences and experience with its application. Detailed guidance is available to inform the development of a costal management strategy. For example, Scottish Natural Heritage (SNH) has produced a guide to managing coastal erosion in beach/dune systems, which is directly relevant to the LLWR site. A Shoreline Management Plan (SMP) exists for the coastal region relevant to the LLWR, which describes the strategy for managing the coastline (see Towler, 2008a).

We do not consider the construction of coastal defences, with an intent to protect a facility thousands of years in the future, to be part of best practice for near-surface waste repositories. Rather, we consider that it would be best practice to consider the issues of coastal erosion at the time of initial siting.

5.5.3 Capability to Mitigate Threats

If coastal defences exist and are maintained, then coastal erosion of the facility could be prevented. This would ensure that the arising radiation doses (estimated to be 8 μSv yr^{-1}) do not arise.

Although a wide variety of coastal defence options could be applied at the LLWR, all would require maintenance and periodic rebuilding. This cannot be assured for the timescales over which coastal erosion is a threat. Coastal defences must therefore be assumed to fail ultimately and would not therefore be capable of mitigating the threat.

However, more limited coastal defences could prove useful as a response to any flooding that might occur during the operational period as a consequence of sea level rise (e.g. to mitigate the possible adverse effects of storm surges).

5.5.4 Potential for Application at LLWR

The key characteristics of coastal defences are summarised in Table 5.5.

Coastal defences would be required for at least 4 km of coastline to protect the LLWR. This would require very large quantities of material and have major construction impacts (traffic, resource use, visual impact and energy usage). The defences may have also significant effects on habitat (both terrestrial and marine).

A wide variety of coastal management options could potentially be applied at the LLWR. There is ample experience with coastal defences in the UK. However, the timescales of interest and the magnitude of sea-level rise are challenging. Defences would be required over a long period and would need to deal with many metres of sea-level rise.

It would be necessary to develop any solution jointly with other parties as part of the SMP. Coastal defences may also be required for Sellafield, and synergies could be exploited. Decisions on the use of coastal defences would need to be made as part of the SMP.

The most important issue, however, is the lifetime of coastal defences. Even if this were maximised, the defences would need periodic maintenance and rebuilding. By comparison, the threat of coastal erosion will be present for many thousands of years. This means that the defences would have to be maintained into the far future, which is inconsistent with the regulatory principle that safety should be independent from controls (Environment Agencies, 1997). It is not reasonable to assume as part of any safety case that an organisation will be present in thousands of years to finance, build and maintain coastal defences.

Costs for coastal defences are substantial. The defence of the LLWR for a thousand years would probably cost hundreds of millions of pounds. Medium term defences against storm surges with a 50 year lifetime might cost £15 million or so.

5.6 Vertical Drains

5.6.1 Description

Vertical drains are conduits that provide a vertical pathway for groundwater flow from the facility. They are usually assumed to be an excavated hole that is filled with a high permeability material like crushed rock. However, the implementation of a system of drains, which will remain open over long periods of time, is complex. Both small numbers of large drains, and large numbers of small drains, have been considered. There is a likelihood that they will degrade in some way over time.

The objective of a vertical drain would be to reduce the likelihood of bathtubbing (overtopping of water from the facility after it fills with water) or the occurrence of sub-horizontal groundwater pathways, since both of these may result in the discharge of contaminated groundwater local to the facility. Rather a vertical drain would encourage the downwards flow of water.

5.6.2 Experience and Best Practice

The potential use of vertical drains is discussed in detail in Paulley (2008a). International best practice and associated guidance offers little in the way of specific recommendations regarding the use of vertical drains. However, the IAEA (2002) state:

> *"Underground drains may be used to keep the disposal units dry, if the wastes are placed above the water table."*

A number of facilities in other countries utilise vertical drains (or 'deep drains' as the are often termed) as part of their drainage system. Approaches include the following:

- Use of a permeable base to engineered vaults in order to ensure that any water that could enter the facility through cap failure or through lateral groundwater movement is drained. Such a strategy may be particularly relevant for near-surface facilities situated within permeable geological formations and/or with comparatively deep water tables.

- Use of drainage systems to manage any water that infiltrates the facility (in some cases including vertical or 'deep' drains). The drain design must be sufficiently robust in order to function in the long term. Where vertical or deep drains are not utilised, leachate may be drained to underground collection and storage tanks, which may be linked to remote discharge points (e.g. to the sea) via further drainage systems.

- Use of drainage systems, which may include vertical / deep drains, to manage cap runoff and other engineering, surface or near-surface water flow. Again underground collection and storage tanks may be utilised with such systems.

The information available for such facilities does not typically provide detailed analyses of the role and design of vertical drains. However, it is clear that all near-surface repositories feature some suitable means for managing any leachate from the disposal system, at least during the operational phase. In some cases the vertical drains connect to underground collection and storage tanks rather than to deep hydrogeological features.

The use of drains as part of a system to manage operational leachate is in our view established as best practice. It is also appropriate to consider and take appropriate measures to minimise the likelihood of bathtubbing through the provision of appropriate drainage features. However, the specific use of vertical drains to direct flows to deep hydrogeological features during the post-closure period is not necessarily established as part of best practice. It seems appropriate to consider vertical drains as part of a potential system to ensure appropriate near-field hydrological performance during the post-closure period.

5.6.3 Capability to Mitigate Threats

Vertical drains can reduce the potential impact of the groundwater pathway by reducing the probability that any leachate is discharged to surface receptors in the vicinity of the LLWR. The potential role of vertical drains needs further evaluation in the context of all of the system of near-field barriers and their function as degradation occurs.

5.6.4 Potential for Application at LLWR

The characteristics of Vertical Drains are summarised in Table 5.6.

A system of engineered barriers and vertical drains, if optimised in an appropriate manner can have a number of potential benefits (see subsection 5.4)

The current plan for the LLWR assumes that a series of 2m diameter drains will be constructed between the Trenches and Vaults. The total cross-sectional area of the drains would be around 3370 m^2, and the drains will be around 25 m in length. They would be installed using a rotary piling rig and the top of each hole (and potentially some of the depth) would be cased to avoid collapse. Upon completion they will be filled using single sized stones. Previous designs (e.g. the 2002 PCSC design, BNFL (2002b)) assumed that a single much larger engineered drain would be emplaced.

The option is associated with only relatively modest costs and limited disruption (£5 million is currently estimated by the LLWR). It would not involve extensive engineering work and would not lead to any significant off-site effects in terms of large numbers of traffic movements. The technology is mature and no unusual requirements are anticipated.

Consideration of the pros and cons of using vertical drains and their design needs to be further considered as part of future detailed design optimisation, drawing on an improved understanding of near-field hydrology.

5.7 Retrieval

5.7.1 Description

One way of dealing with the threats to the LLWR is to remove the waste, and dispose of it after further treatment, perhaps to another facility.

Before any such work began, it would be necessary to decide the extent of retrieval, develop a robust plan, obtain the required equipment and train workers, and secure a final disposal route for the retrieved wastes. Waste retrieval itself would involve carefully removing the interim cap and any other engineered features, before excavating wastes. These would then need to be sorted characterised, possibly treated in some way that may vary from waste type to waste type, and repackaged. The wastes would then need to be stored pending disposal. These activities could be undertaken with standard nuclear industry operational procedures.

Retrieval can be applied to specific parts of the Trenches or the whole of the Trenches. However, the effectiveness of targeted retrievals is entirely dependent on knowing where the specific wastes are. A good understanding has been developed of the distribution of key radionuclides within the Trenches, based on disposal records (Lennon et al., 2008). However, there are still likely to be difficulties in targeting specific wastes that are well mixed with other waste streams.

5.7.2 Experience and Best Practice

Waste retrieval from existing disposal facilities is discussed in detail in Paulley (2008b). In recent years a number of operations have been undertaken nationally and internationally that have involved the retrieval of radioactive waste from historic storage or disposal facilities.

In 2007, the International Atomic Energy Agency (the IAEA) released a report entitled ‘Retrieval and Conditioning of Solid Radioactive Waste from Old Facilities’ (IAEA, 2007). This collated and reviewed experience of planned and actual retrievals from a variety of types of facility in order to provide guidance. The report emphasises that any waste retrieval programme must be undertaken in an integrated manner considering the entire life cycle of retrieval, treatment and re-disposal. In addition to the specific engineering and other technical requirements relating to the retrieval process itself, other aspects that must be in place for any retrieval plan include the following:

- sufficient waste consignment and/or characterisation data to support the proposed retrieval approach;

- defined Waste Acceptance Criteria (WAC) for storage and/or disposal in order to identify ex-situ waste sorting, segregation, treatment and conditioning process requirements;
- availability of facilities to undertake the above treatment and conditioning;
- availability of interim storage and ideally final disposal arrangements for the retrieved wastes;
- transport and other ancillary arrangements to support the above.

In terms of the main retrieval process, the following are required:

- creation of a robust, agreed retrieval plan (including the wider requirements described above):
- identification, design and obtaining of the equipment and procedures required to implement the retrieval plan;
- creation of controlled areas around the retrieval area:
- training of workforce, ideally using mock-ups, or if not, a small section of the waste with good characterisation data and comparatively low activity;
- Set up of retrieval equipment – including retrieval devices and the required engineering infrastructure – and retrieve wastes to buffer storage or other staging area prior to treatment, storage and disposal.

More detailed good practice guidance and regulatory requirements would apply to the activities in many of the above stages.

While significant retrievals have been undertaken from near-surface LLW facilities in other countries (see Paulley, 2008), retrievals of the scale that would be required for the LLWR have not. For example, some transuranic wastes have been retrieved from a portion of two disposal pits at the Idaho National Laboratory Site and packaged for disposal at the WIPP facility (USDoE, 2004; USDoE, 2005). However, this involves only a small fraction of the tens of thousands of cubic metres of waste in those pits. Retrieval of these wastes represented significant hazards (e.g. some were pyrophoric leading to flame events) and the feasibility study indicated that retrieval resulted in a minimal decrease in long-term risk.

Hazardous ILW was removed from trenches at Oak Ridge, Melton Valley in the US. This involved excavation, overpacking and storage of 45,000 cubic feet of remote handled transuranic waste. The wastes presented significant hazards, (e.g., some were pyrophoric leading to flame events when uncovered). A containment structure was constructed to facilitate this retrieval that could be moved from trench to trench.

Eleven thousand cubic metres of solid waste has been retrieved from concrete-lined trenches at La Hague and disposed of in the Centre de Stockage de la Manche (Bodin et al., 2000). A mobile structure was developed to move across the trenches to retrieve the wastes, providing containment and radiological protection for operators. Most wastes were crushed, centrifuged, dried in a cyclone and drummed. The drums were then compacted before being placed in disposal containers. Non-crushable wastes were manually sheared to reduce volumes.

Retrieval is envisaged for the Shaft at Dounreay and the BPEO for the Dounreay Pits has been identified as retrieval, both due in part to the anticipated impact of coastal erosion. The latter facility is perhaps the most similar to the LLWR of those examples considered.

Indeed the nearest equivalents in terms of the retrieval of all wastes in the Trenches relate to practices in other industry sectors - e.g. contaminated land cleanup and uranium mining/milling processes, or for sub-LLW facilities from US nuclear sites. In these cases the hazards are much lower and/or better quantified and hence risks are considerably better controlled that would be the case at the LLWR.

We conclude that retrieval is a potential approach to the remediation of an existing facility for the disposal of radioactive waste such as the LLWR Trenches, although there may be no close precedent in terms of volume and waste type. We consider that it is best practice to consider such retrieval in the context of intervention criteria and a comprehensive analysis of the advantages and disadvantages.

5.7.3 Capability to Mitigate Threats

Retrieval is the only option that has the capability to avert most of the potential radiological impacts, by removing the source of hazard (and noting that after retrieval small quantities of contamination may remain in the ground). However, it should be borne in mind that the waste needs to be disposed of elsewhere to acceptable standards. If there is to be a net benefit, the overall performance of the facility used to redispose the waste must be better than the performance of the LLWR. Otherwise retrieval and redisposal will only result in transferring the future radiological impacts to another location.

Selective retrievals of ^{226}Ra have the capacity to reduce the highest estimated radiation doses (see Volume 5).

5.7.4 Application at LLWR

The characteristics of the retrieval option are summarised in Table 5.7.

It is necessary to consider retrieval of all the wastes and the possibility of selective retrievals. Complete retrieval of the waste in the Trenches would involve almost one million m^3 of waste. Selective retrieval of waste would probably need to involve less than one hundred thousand m^3 (see below).

The highest calculated radiation doses arise when, following human intrusion, individuals inhale radon within a house constructed over average Trench wastes mixed with uncontaminated cap materials (see Volume 5). If this waste has high concentrations of ^{226}Ra, then radiation doses might arise of about 38 mSv yr^{-1} (based on an average across twenty adjacent trench bays including those with the highest ^{226}Ra concentrations – based on the data used in Lennon et al., 2008 – see Volume 1). However, as discussed in Volumes 1 and 5, radiation doses of this magnitude are unlikely to arise and this should be kept in mind when considering the arguments for and against intervention.

Full retrieval and disposal to another location would completely remove any radiological impacts. Partial retrieval could substantially reduce the radiological impacts that might arise. In order to reduce the average radiation dose associated with human intrusion or coastal erosion by an order of magnitude would require the average specific activity in the Trenches to be reduced by an order of magnitude. Inspection of Figure 2 of Lennon et al. (2008) shows that this would require retrieval of less than 5 % of the waste volume in the case of ^{226}Ra, assuming that the wastes could be targeted correctly. There are around 50 trench bays with an order of magnitude more than the average ^{226}Ra concentration (that is around 2.5% of the total number of bays). It seems that selective retrieval of around 50,000 m^3 of waste could significantly reduce the highest doses that might arise.

Partial or large-scale waste retrieval would have a significant impact locally in terms of disturbance and traffic movements. Considerable resource utilisation would be involved. It would have a substantial visual impact and disturbance, and involve a great deal of transport. Local stakeholders argued against it during the NDA 'End State' workshops, although there would be benefits to the local community (e.g. in terms of improved transport infrastructure). Selective retrieval would involve much lower adverse impacts than complete retrieval.

During any retrieval operations, there is a risk that workers could encounter unexpected items of waste. Non-radioactive hazards (e.g. asbestos) will also be present in addition to radiological hazards. Worker safety will therefore be an important factor. Whist radioactive waste has been retrieved from other repositories, there is limited international experience of work on the scale that would be required at the LLWR in terms of the hazards, engineering and volumes likely to be involved.

Retrieved waste will require characterisation, sentencing, treatment and packaging, which may involve considerable additional work. A dedicated waste treatment facility would probably be needed and the task may take many years.

Many transport movements would be required and these would involve associated health and safety risks.

Another important issue is that a new disposal route would be needed for the retrieved waste. Re-disposal of the waste at the LLWR would be unlikely to mitigate a number of radiological impacts that might arise, although it would offer the opportunity of more flexible waste sentencing and the use of volume reduction technologies. In particular, on-site re-disposal would mean the threat of coastal erosion would remain. Any other disposal facility would need to offer a substantially better long term safety performance for such retrieval and redisposal to be worthwhile.

The cost of retrieving wastes from the Trenches and the Vaults was estimated as £250 million (Halcrow, 2002). It is not clear that this estimate provides for all of the waste treatment and characterisation that would be required and it is acknowledged that it does not cater for the costs of disposal elsewhere. Based on indicative costs for the LLWR, it is likely that the costs of disposal elsewhere would run into many hundreds of millions of pounds owing to the large waste volume that requires disposal. On the other hand, BNFL (2004b) noted that savings could be made in future costs at the LLWR. An example is provided from the Idaho National Laboratory Site where of order 10,000 m^3 of TRU wastes were to be retrieved from two pits at a projected cost of $180 million (roughly equivalent to £100 million), although around half of that of that cost relates to disposal at the WIPP facility (USDoE, 2005). It can be seen that the overall costs including redisposal are likely to be substantial and would be at least many hundreds of millions of pounds. Even for focused retrieval, it is anticipated, on the basis of the US example, that the costs would be substantial.

5.8 Institutional Control

5.8.1 Description

The long-term control of a closed radioactive waste site by a designated authority is referred to as "Institutional Control". The nature of control can vary. There may be active measures (monitoring, surveillance, remedial work) or passive control (restrictions on land use and arrangements for the preservation of information).

There is international agreement that the safety of radioactive waste disposal should not rely indefinitely on institutional control. It is also generally agreed that control should not be assumed to last for more than a few hundred years. This is mainly because it is unfair to place a burden on future generations. Indeed, such indefinite management is inconsistent with a regulatory principle that safety should be independent of controls.

Nevertheless, it is obviously of benefit if the knowledge of the repository is retained for as long as possible. Measures such as records management and markers to identify the waste are therefore also considered as part of institutional control.

A measure of control may also be exerted by ensuring that site use and ownership of the site at the end of the institutional control period is such that the likelihood of future human disturbance of the facility is minimised.

5.8.2 Experience and Best Practice

Institutional Control is discussed in Penfold (2008). A detailed plan for institutional control at the LLWR has not yet been produced. All near-surface repositories for LLW assume a period of institutional control after the closure of the site. However, there are few examples of sites that can be fully regarded as "closed". Most plans for institutional control are, therefore, limited in detail.

In the document "Scientific and Technical Basis for the Near Surface Disposal of Low and Intermediate Level Waste" (IAEA, 2002), IAEA describes the concept of institutional control in the following terms:

> *'For near surface repositories where the disposal units are close to the surface (within a few metres), institutional controls are needed to provide assurance of the adequate performance of the waste isolation barriers during the initial period when the activity of short lived radionuclides is still high. The anticipated*

> *duration of institutional controls is an important strategic decision with significant implications for various aspects of the development of the disposal system, including the definition of waste acceptance criteria. If disposal takes place at greater depths, of tens of metres, as in the case of rock cavity repositories or moderately deep boreholes, which are also considered types of near surface disposal system, less reliance is placed on relevant threats by which the facility could be disrupted.'*

By considering typical LLW (and LILW) facilities, their location and inventory, IAEA (2002) provides an indication of a typical duration of institutional control. A few hundred years is typical, and the IAEA comments that a period of 300 years would result in a major decline in the concentrations of key radionuclides such as ^{137}Cs and ^{90}Sr. Mitigating the risks from exposure to the wastes during this period (e.g. as a result of inadvertent human intrusion) is therefore considered to be a major benefit to post-closure safety. It is notable that in its analysis, the IAEA (2002) only considers relatively short-lived LILW. The guidance provided regarding timescales therefore needs to be scrutinised in relation to the LLWR, where longer-lived wastes exist in the trenches, and disruption by a natural event is currently considered very likely to occur within a few thousand years.

The IAEA also discusses the activities that can be undertaken during a period of institutional control. An important distinction is made between "active" and "passive" institutional control:

- active institutional controls include monitoring, surveillance and, if necessary, corrective actions; and
- passive institutional controls include land use control and record keeping.

In relation the former, it is recognised that in accordance with the principle of not imposing undue burdens on future generations, active institutional controls should not be used to justify a reduction in the level of performance designed into a multiple barrier isolation and containment system. Furthermore, safety should not rely solely on institutional controls that require extensive and continuing active measures.

The IAEA has also addressed the future management of radioactive legacies (a practice it refers to as 'stewardship'[1]) in a separate report (IAEA, 2006). This considers situations in which radioactive materials may require prolonged periods of control. Whilst the document is substantially influenced by situations such as legacies from uranium mining and milling and nuclear weapons development and manufacture, it nevertheless includes historic civil LLW disposal facilities within its scope. In relation to such situations, the IAEA (2006) considers that, where significant radioactive material remains at or near the surface as a result of a historic activity,

[1] "Stewardship" is used to refer to the specific practice of managing radioactive legacies by controlling them for prolonged periods, longer than considered appropriate for modern radioactive waste disposal facilities.

"An optimization between social and economic costs on the one hand and level of protection on the other has to be found. With long lived radionuclides present, maintenance of institutional control is likely to be required for nearly unlimited periods of time." (IAEA, 2006)

This is clearly very different to the view that is generally accepted in relation to the institutional control of many modern radioactive waste disposal facilities where long-term safety is required to be independent from controls (Environment Agencies, 1997).

Penfold (2008) discusses plans for institutional control at a range of near-surface disposal facilities. There are a range of different views about the approach and the timescales that it is appropriate to consider. Overall, it is clear that institutional control is best practice for a near-surface waste repository. However, the detailed approach and timescales over which various controls should operate are less clear and require detailed evaluation.

5.8.3 Capability to Mitigate Threats

While active institutional control is maintained, activities that could lead to human intrusion can be prevented. Potential exposure to radioactive gases can also be prevented. Groundwater migration can be monitored, and, if necessary, remedial measures taken. Similarly, the potential for coastal erosion can be monitored (although it is not expected to affect the site until well after the assumed period of control).

Passive controls have the capacity to substantially reduce the likelihood of human intrusion. However, their effectiveness will reduce with time.

In principle, therefore, control of the site is very effective in respect of the threats to the LLWR. However, international and national practice and regulation recognises that such controls cannot be relied on more than a few hundred years after closure. Measures to maintain knowledge of the site beyond the assumed period of control are important.

5.8.4 Application at LLWR

The key characteristics of this option are set out in Table 5.8.

Institutional control has been a feature of LLWR plans for many years. The 2002 PCSC (BNFL, 2002a & 2002b) assumed a 100 year period of active institutional control. A detailed definition of roles, responsibilities and funding arrangements has not, however, been defined. This aspect needs to be further developed in the future. Institutional control should complement other options, and where possible enhance their effectiveness or longevity.

Institutional control arrangements also need to link to the interests of local communities and local issues. For example, it may also be possible to integrate institutional control plans with those of other nuclear legacies, especially in west Cumbria. While institutional control provides an ongoing reminder of the nature of the site, it also provides a degree of reassurance that the waste is secure and controlled.

It is judged that institutional control with extensive environmental monitoring could cost about £1 million per year. If monitoring is omitted, costs would be significantly less. It is important that funding arrangements are in place to ensure that such controls can be guaranteed over the requisite period.

5.9 In-situ Remediation

5.9.1 Description

In-situ remediation involves modifying the properties of the waste to improve its long-term safety performance. This can reduce the release of contaminants from the wastes and/or stabilise the material. There are three main approaches relevant to the LLWR.

- Grouting involves filling voids within the wastes by injecting cement grout under pressure through boreholes drilled into the wastes. It is commonly used in the construction industry.
- In-situ vitrification involves passing an electrical current through the ground. This causes soil to melt. Organic materials are totally destroyed, and gases are driven off. The remaining material cools to form a glass. This approach has been applied to contaminated soil.
- Compaction involves dropping a large heavy weight onto the ground, or temporarily emplacing a thicker cap, to reduce the voidage in the wastes and promote settlement.

5.9.2 Experience

In-situ remediation includes a range of techniques, such as grouting and vitrification, for immobilisation of the waste in situ. The possible approaches to in-situ remediation and examples are discussed in detail in Towler (2008b). In-situ remediation is a potential technology for remediating contaminated land (e.g. Amin ,2007) and has primarily been applied for this purpose, rather than for the remediation of disposal facilities. The majority of examples of in-situ remediation are associated with technological development, field trials and demonstration exercises, in particular on US DoE sites. Although the majority of examples are associated with relatively small-scale trials, it should be recognised that in-situ remediation need not be applied to the entire trench wastes, but could potentially be targeted at selected disposals.

Examples of the in-situ remediation of LLW disposal facilities could not be found, except for the in-situ vitrification of pits predominantly containing contaminated soils in Australia. However, following an explosion, use of the technique was discontinued. The material composition of these wastes is significantly different to the LLWR trenches. In-situ remediation has been more widely used for non-radioactive contaminated land and waste disposals. Grouting has been used in a range of situations such as remediating historic drains.

In-situ remediation has been used for non-radioactive contaminated land and waste disposals. Generally, the approach has been to excavate the material for disposal elsewhere or emplace barriers. However, solidification using cement has been undertaken for relatively large volumes of contaminated material (of the order of 10,000 m^3)

5.9.3 Capability to Mitigate Threats

Grouting will increase the effective pH of the Trenches. This is likely to have an impact in terms of the concentrations of any pH sensitive radionuclides in solution. However, the consequences for the groundwater pathway are not the largest radiological impact and the solubility of certain key radionuclides would not be reduced by grouting. Grouting would have little impact on the doses received as a result of radon inhalation following human intrusion or on external irradiation pathways that control the radiation doses received following coastal erosion (although in the latter case the wasteform might be a little more resilient). There would an impact on the release of ^{14}C-labelled carbon dioxide, which would be expected to react with the cementitious grout. However, ^{14}C-labelled methane would still be released.

Vitrification would very substantially reduce the release of radionuclides dissolved in groundwater. ^{14}C-labelled gases would in large part not be produced during the post-closure period since many source materials would be volatilised during the vitrification process. Radon emanation would also be expected to be low from this wasteform. However, a stable wasteform would result in a longer residence time for contaminated material on the beach following coastal erosion.

5.9.4 Application at LLWR

The characteristics of this option are set out in Table 5.9

Grouting could be difficult to implement reliably on a large scale. The quality of the product is likely to be variable and the benefits of such grouting are uncertain. The cost of in-situ grouting is estimated to be £21 million (Halcrow, 2002)

Vitrification produces a waste form that, under certain circumstances, is very beneficial due to its impermeable nature and stability. However, it likely to be very problematic to apply to the Trenches on account of their low silica content as well as being extremely costly, and yet offers no benefit in respect of coastal erosion. Conventional health and safety issues may also arise. The costs of vitrification are likely to be substantial, maybe up to of order £500 million (BNFL, 2004b).

Whilst these options are considered inappropriate to be applied at a large scale, they could be useful for localised application to specific wastes. For example, grouting or compaction could be used to improve stability of areas with high voidage. Vitrification could possibly be applied to wastes such as mineral sands.

Table 5.3 Repository Cap: Summary of Assessment against Attributes

OPTION	**REPOSITORY CAP**
SHORT DESCRIPTION	A cap is a barrier placed over a waste disposal facility. The design may vary, but generally includes a number of layers comprising natural and man-made materials. The purpose of a cap is to protect the wastes from future human disturbance and to act as a barrier to limit the infiltration of groundwater.
Attributes	**Characteristics of the Option**
Human Health & Safety: Public and Worker, Radiological and Conventional	The construction of a cap would reduce the likelihood of post-closure human intrusion impacts arising in the future. Without a cap the likelihood of such exposures would be unacceptably high. The cap will prevent radon exposures (unless human intrusion occurs), which would give rise to doses of the order of milliSieverts and will significantly reduce infiltration into the facility. If it is assumed that the transport of building materials to the site is by rail, then conventional health and safety risks to the public will be minimal. Road transport of large volumes of material would pose risks. Only limited radiation doses to workers would arise as a result of exposure to radioactive wastes because significant penetration of the facility is not required. Conventional health and safety risks would occur to workers during construction of the cap.
Environment: Physical Environment, Flora and fauna, Resource use, Waste Hierarchy	The construction of a permanent deep cap will have a significant environmental impact through resource use. Good practices will be required during construction to manage risks but environmental impacts not associated with construction will be minimal. Managing radiological impacts to man is assumed here also to protect fauna and flora.
Technical: Viability	There is confidence that a cap could be constructed and would protect against intrusion and groundwater ingress for an extended and sufficient period, although the ultimate lifetime will depend on detailed design work to follow. The cap must address the potential subsidence in the Trenches as a result of waste degradation (Grimwood, 2008).

Table 5.3 (Cont.)

Socio – economic: Employment, traffic/Noise	Once in place, impacts will be minimal. There will be major imports to site. Major construction projects bring employment but also increased traffic and noise that will need managing. There will be a major visual impact during construction and, until vegetation cover is complete, once built. This can be managed through good design.
Financial cost	Grimwood (2008) suggests a £20 million estimated cost. Halcrow (2002) estimated a marginal cost of about £8 million for either increasing the thickness of the cap or enhancing its performance. £40 million is currently estimated by the LLWR.
Regulator/Legal Requirements	A cap is included in current plans for the site. It is difficult to see how the LLWR could be acceptable in terms of best practice/BPM if a modern engineered cap were not constructed.
Summary	This option is regarded as a viable strategy because: - It is a useful defence against key threats; - Adverse impacts are containable, through it is a major construction project; - It is technically feasible and the cost is likely to be proportionate.

Table 5.4 Engineered Barriers: Summary of Assessment against Attributes

OPTION	**ENGINEERED BARRIERS**
SHORT DESCRIPTION	Engineered barriers are layers of specific materials placed around the repository to manage water movement, gas movement, and/or to provide physical stability and protection.
Attributes	**Characteristics of the Option**
Human Health & Safety: Public and Worker, Radiological and Conventional	The construction of engineered barriers such as cut-off walls could prevent for a time or reduce the likelihood of the discharge of contaminated water locally around the facility. It is not clear that a barrier beneath the waste would be beneficial in the post-closure period because it would increase the saturation of the waste and could lead to bathtubbing. Both sorts of barrier have the capacity to limit radionuclide migration in groundwater during the operational period, when drainage of the facility will be provided. Engineered barriers generally represent significant construction projects, though on a lesser scale than some cap options. If it is assumed that the transport of building materials to the site is by rail, then conventional health and safety risks to the public will be minimal. Only limited radiation doses to workers would arise as a result of exposure to radioactive wastes because significant penetration of the facility is not required except in the case of barriers beneath the waste requiring trench penetration, in which case there would be potential risks to manage. Health and safety risks would occur to workers during construction of the barriers.

Table 5.4 Cont.

Environment: Physical Environment, Flora and fauna, Resource use, Waste Hierarchy	The construction of barriers would have an impact through resource use, but would not be expected to have other significant environmental impacts.
Technical: Viability	Barriers underneath a repository are usually put in place as part of the construction of the facility. It is less common for such engineered barriers to be put in place after disposal operations. A cut-off wall has been successfully emplaced at the LLWR after disposal operations and this is a widely used engineering approach. The insertion of active barriers and barriers beneath the trenches has been assessed previously – see BNFL (2004a and 2004b) – and was not considered viable.
Socio – economic: Employment, traffic/Noise	Once in place, impacts will be minimal. Major construction projects bring employment but also increased traffic and noise that will need managing. There will be visual impact during construction.
Financial cost	The estimated cost for a deeper cut-off wall around the site is about £30 million.
Regulator/Legal Requirements	Current plans envisage a deep cut-off wall is placed around the whole of the disposal area.
Summary	Cut off walls are in the current plan and are judged to be viable and cost-effective. Active barriers and barriers beneath the trenches are not, because the benefits are not clear and because the technology is not judged mature enough.

Table 5.5 Coastal Defences: Summary of Assessment against Attributes

OPTION	**COASTAL DEFENCES**
SHORT DESCRIPTION	Appropriate structures would be constructed to prevent or delay the erosion of the LLWR by the action of the sea. These might include traditional structural barriers as well as artificial reefs or breakwaters, artificial headlands, dune management techniques, sediment trapping or enhancement and others.
Attributes	**Characteristics of the Option**
Human Health & Safety: Public and Worker, Radiological and Conventional	The construction of coastal defences would preclude or delay radiological impacts arising in the future to members of the public from coastal erosion. To the extent that the facility would be preserved for a longer period of time, consequences from other pathways could occur over a longer period of time than would otherwise be the case. If it is assumed that the transport of building materials to the site is by sea, then conventional health and safety risks to the public will be minimal. No radiation doses to workers would arise as a result of exposure to radioactive wastes because penetration of the facility is not required. Health and safety risks would occur to workers during construction of the defences.
Environment: Physical Environment, Flora and fauna, Resource use, Waste Hierarchy	The construction of erosion barriers will have a major visual and environmental impact. In particular, they will have a major impact on the evolution of the coastline over a scale wider than that of the actual barrier (see Towler, 2008).

Table 5.5 (Cont.)

Technical: Viability	There is confidence that defences could be constructed and would protect against erosion. The difficulties relate to the required lifetime of the defences, which would be many thousands of years, and the magnitude of the sea level rise that needs to be addressed (see Thorne and Kane, 2007).
Socio – economic: Employment, traffic/Noise	Plans for coastal erosion would need to be integrated with the local Shoreline Management Plan (see Towler, 2008). It is likely that most materials would be supplied by sea, which would minimise road traffic.
Financial cost	The defence of the LLWR for a thousand years would probably cost hundreds of millions of pounds.
Regulator/Legal Requirements	This option is inconsistent with the regulatory principle that safety should be independent from controls i.e. it is unreasonable to assume that an appropriate organisation would be available to finance, construct and maintain coastal defences thousands of years in the future (see Environment Agencies, 1997).
Summary	This option is not regarded as a viable strategy because: - it assumes an organisation would be in place with the ability to carry out the construction and maintenance; - it is inconsistent with a fundamental regulatory principle that safety should be independent of future controls; - the magnitude of sea level rise would mean that defences would be difficult and expensive. The possibility of defences during the operational period to protect against the risk of flooding is an option should it be required. This conclusion does not of course preclude the possibility that future generations might decide to construct coastal defences. However, it is not acceptable for the LLWR Safety Case to rely on such an assumption.

Table 5.6 Vertical Drains: Summary of Assessment against Attributes

OPTION	VERTICAL DRAINS
SHORT DESCRIPTION	Vertical drains are conduits that provide a vertical pathway for groundwater flow from the facility.
Attributes	**Characteristics of the Option**
Human Health & Safety: Public and Worker, Radiological and Conventional	Vertical drains could help prevent for a time or reduce the likelihood of the discharge of contaminated water locally around the facility. Conventional and transport hazards associated with the handling of excavated material would need managing. Radiological hazards to workers would need to be managed if, as currently envisaged the drains are emplaced after emplacement of the waste. Excavated material would have to be handled and disposed. Health and safety risks would occur to workers during construction of the drains. Excavated material is assumed to be removed by rail; if not, there would be some transport risk.
Environment: Physical Environment, Flora and fauna, Resource use, Waste Hierarchy	There would be secondary environmental impacts associated with handling and disposing of excavated wastes and material.

Table 5.6 Cont.

Technical: Viability	Implementation would be a substantial undertaking, but the technologies required are mature and the option is judged viable.
Socio – economic: Employment, traffic/Noise	The transport and use of heavy machinery and transport of excavated material – if not taken by rail - would have a local impact, and there would be potential visual and noise impacts to manage.
Financial cost	For the current LLWR design, approximately £5 million is estimated.
Regulator/Legal Requirements	There are potential regulatory issues to consider, including the discharge of drainage waters.
Summary	The current plan for the LLWR assumes that a series of drains will be constructed between the Trenches and Vaults. However, consideration of the pros and cons of using vertical drains and their design needs to be further considered as part of future detailed design optimisation.

Table 5.7 Retrieval: Summary of Assessment against Attributes

OPTION	**RETRIEVAL**
SHORT DESCRIPTION	One way of dealing with the threats to the LLWR is to remove the waste, and dispose of it after further treatment, perhaps to another facility. Retrieval can be applied to specific parts of the Trenches or the whole of the Trenches.
Attributes	**Characteristics of the Option**
Human Health & Safety: Public and Worker, Radiological and Conventional	Full retrieval will be effective against the threats considered during this assessment and partial retrieval may reduce the radiological consequences. The wastes would, of course, need to be re-disposed elsewhere. Although there would be little benefit, re-disposal of the waste at the LLWR would be unlikely to mitigate a number of impacts that might arise. In particular, the threat of coastal erosion would remain. Depending on the scale, retrieval would pose significant conventional and radiological challenges to worker safety, including the risk of encountering unexpected radiologically or conventionally hazardous materials. There would be conventional construction risks if new facilities were required and if large quantities of waste were moved off site there would be transport and accident hazards, although thee could be reduced if rail links are used.
Environment: Physical Environment, Flora and fauna, Resource use, Waste Hierarchy	Considerable resource utilisation would be involved and there may well be secondary wastes from the handling and processing of retrieved wastes, from construction of new waste facilities, and from transport if disposed of off-site.

Table 5.7 Cont.

Technical: Viability	Implementation would be a huge undertaking for full retrieval from the Trenches and still significant even for localised retrieval. In principle the technologies required exist and there is experience of retrieval, but arguably not at the scale and complexity required for complete retrieval of wastes from the LLWR.
Socio – economic: Employment, traffic/Noise	Partial or large-scale waste retrieval would have a significant impact locally. It would have substantial visual impact and disturbance, and involve a great deal of transport, although this could be by rail. Local stakeholders argued against it during the NDA 'End State' workshops. Selective retrieval would involve much lower impacts.
Financial cost	Including the cost of disposing the waste to another facility, complete retrieval will cost many hundreds of million of pounds (see the discussion in subsection 5.7).
Regulator/Legal Requirements	There are major regulatory issues associated with large-scale retrieval, and with implementing large-scale re-disposal elsewhere.
Summary	The only option that can avert the consequences of coastal erosion and human intrusion is retrieval of the wastes. However, it would cause significant disruption and cost a large amount of money to avoid radiation doses of the order of milliSieverts or less. On this basis, retrieval of all the wastes is considered to be disproportionate, and does not form part of the strategy. Selective retrieval also needs to be considered. We propose to review the arguments for selective retrieval as part of the 2011 ESC, as our view of facility performance and the range of radiation doses that might arise are insufficiently refined at present.

Table 5.8 Institutional Control: Summary of Assessment against Attributes

OPTION	**INSTITUTIONAL CONTROL**
SHORT DESCRIPTION	The long-term control of a closed radioactive waste site by a designated authority is referred to as "Institutional Control". The nature of control can vary. There may be active measures (monitoring, surveillance, remedial work) or passive control (restrictions on land use and arrangements for the preservation of information).
Attributes	**Characteristics of the Option**
Human Health & Safety: Public and Worker, Radiological and Conventional	While active institutional control is maintained, activities that could lead to human intrusion can be prevented. Potential exposure to radioactive gases can also be prevented. Groundwater migration can be monitored, and, if necessary, remedial measures taken. Similarly, the potential for coastal erosion can be monitored. Institutional control is not usually associated with any direct health and safety impacts.
Environment: Physical Environment, Flora and fauna, Resource use, Waste Hierarchy	Institutional control is not usually associated with any significant direct environmental impacts,
Technical: Viability	Institutional control is clearly viable; the limitation is in the period over which it can be claimed (active control is unlikely to be possible for more than a few hundred years).

Table 5.8 Cont.

Socio – economic: Employment, traffic/Noise	In the short to medium term there are local impacts associated with limitations on land use and restrictions on access, and minor impacts from maintaining active control over the site. The passive control phase has few impacts and should not constrain achievement of the end uses sought by the community.
Financial cost	It is judged that active institutional control with extensive environmental monitoring could cost about £1 million per year. If monitoring is omitted, costs could be significantly less.
Regulator/Legal Requirements	There is international agreement that the safety of radioactive waste disposal should not rely on institutional control for more than a few hundred years. Such indefinite management is inconsistent with a regulatory principle that safety should be independent of controls.
Summary	Institutional control is an essential part of the management strategy for the site. The benefits and length of the planned period of institutional control should be as long as can reasonably be achieved. Work is needed to develop the detail of the active and passive institutional control plan for the site.

Table 5.9 In Situ Remediation: Summary of Assessment against Attributes

OPTION	**IN SITU REMEDIATION**
SHORT DESCRIPTION	In-situ remediation involves modifying the properties of the waste to improve its long-term safety performance. This can reduce the release of contaminants from the wastes and/or stabilise the material. There are three main approaches relevant to the LLWR: grouting/solidification; in-situ vitrification and compaction.
Attributes	**Characteristics of the Option**
Human Health & Safety: Public and Worker, Radiological and Conventional	Grouting achieves only relatively limited performance improvements, and may be problematic to reliably implement on a large scale. Vitrification would reduce the radiological impact of human intrusion, groundwater and gas pathways, perhaps significantly. However, it could increase the impact of coastal erosion as contaminants would less readily disperse. Compaction could ensure that the chance of subsidence of the cap is reduced. Grouting requires a large number of boreholes and transport of large volumes of material to the site. Construction risks include those associated with high pressure grouting equipment and radiological risks during excavation. Vitrification hazards include explosion risks, use of high electrical currents and off-gassing. There are implementation risks to manage for compaction, but of a much lower order.
Environment: Physical Environment, Flora and fauna, Resource use, Waste Hierarchy	Potential grouting and solidification impacts include traffic and material transport, noise and energy use. The grouting process itself would have a local chemical impact on groundwater. Vitrification has the greatest potential to reduce contaminant releases but there are short-term impacts, particularly high energy use (maybe requiring new power supplies) and offgassing.

Table 5.9 Cont.

Technical: Viability	Injection grouting of the trench wastes will be technically very challenging. Boreholes will probably have to be drilled on a 5 m x 5 m grid, necessitating approximately ten thousand boreholes if all trench wastes were to be treated. Vitrification would be very problematic to apply to the Trenches, on the grounds of the low silica content of the wastes. To treat all of the trenches the total mass of material to be vitrified is roughly 2 million tonnes. Compaction of the trench wastes would technically be simple, but may not be required if confidence can otherwise be established in cap longevity.
Socio – economic: Employment, traffic/Noise	The socio-economic impacts of the three technologies are tabulated in Towler (2008) (Table 3) against the following headings: transport; noise; resources; perceived risk; local jobs; and discharges. Grouting and solidification generally have the highest adverse impact but also some benefit through greater local employment.
Financial cost	For the assessment, grouting was assumed to cost around £20 million. Vitrification was assumed to cost up to £500 million, and compaction up to £20 million.
Regulator/Legal Requirements	The implications vary with the technology, but there would be work to do for all of them. Compaction would probably have the fewest implications, vitrification the most.
Summary	We consider that grouting has limited overall benefit in relation to the key impacts of coastal erosion and human intrusion. Vitrification is expensive, difficult to implement given the low silica content of the Trenches and associated with health and safety concerns. Compaction is a viable strategy, but would only be required if there was otherwise doubt about the longevity of the cap.

6 Assessment

6.1 Approach and Information Sources

An Assessment Workshop was held in March 2008 (Penfold 2008a), at which we adopted a systematic approach to the identification and assessment of threats, options and criteria. We focused on the key issues rather than on quantitative scoring and weighting.

This approach is complimentary to the quantitative approach adopted in some previous studies, notably the preliminary assessment of options described in BNFL (2004a and 2004b). These reports contain detailed information and a multi-attribute analysis of a wide range of options and threats, including consideration of practicability, health and safety, and costs. Information from this work was fed into the Assessment Workshop either directly or through the option briefing notes described earlier (each of which included a detailed characterisation and an assessment of the option and its applicability to the LLWR). Appendix A contains more information on the 2004 methodology and results. The summary of option characteristics in the Tables at the end of Section 5 is based on this range of information and our additional work during this analysis.

6.2 Workshop Process

The potential impacts or threats and strategic options described in previous sections of the current document were first reviewed again for completeness and to confirm a consistent understanding of their key features.

Workshop participants then considered the potential of each strategic option in turn to mitigate each threat, based on overall effectiveness and also taking account of the characteristics of each option in terms of the attributes: human health & safety; environment; technical: socio-economic; financial cost; and regulator/legal requirements (see Tables 5.3 to 5.9).

The following steps were undertaken:

1. Review the strategic option to determine whether there are any precedents or external factors that preclude or constrain its implementation;
2. Evaluate the option for overall effectiveness to deal with different threats;
3. Consider the features of the option based on an assessment against the BPEO attributes (with the exception of costs);
4. Review the costs of each option; and
5. Determine which options correspond to the use of Best Practicable Means to ensure that risks and radiation doses are ALARA, based on the information in Steps 1- 4.

The process does not necessarily result in the selection of a single option either overall or in relation to the mitigation of any particular threat.

The final step was to review the emerging suite of options, check their compatibility, and identify any outstanding issues or areas of uncertainty before synthesising the strategy and documenting the logic underpinning its derivation.

6.3 Outcome of the Assessment

The different threats and the options that might mitigate them are shown in Table 6.1. The reasons for the selections of particular options are set out in Table 6.2.

On the basis of the arguments set out in these Tables, the long-term management strategy involves:

- Arrangements for active and passive institutional control;
- Construction of an engineered cap optimised to provide good protection against groundwater ingress, gas release and human intrusion over a time period of thousands of years; and
- An engineered system, potentially involving cut-off walls and vertical drains to ensure optimal near-field hydrology and based on further more detailed optimisation studies.

We do not favour retrieval of all the wastes or the construction of long-term coastal defences.

We believe that it is appropriate to take a decision on localised intervention as part of the 2011 ESC. This is because some of our assessment findings and models have only recently been developed and require more substantiation in order to support a firm view. Localised intervention would be most relevant, according to our current view, in relation to wastes with high concentrations of ^{226}Ra.

The key arguments in relation to these decisions and related issues are discussed in Section 7.

Table 6.1 Effectiveness of Options against Threats.

	Human Intrusion	Sea Level / Erosion	Ground Water	Radioactive Gas
Repository Cap ##	**L, C**		**C**	**C**
Engineered Barriers ##			**C**	
Coastal Defences		**L**		
Vertical Drains ##			**C**	
Bulk or Local Retrieval	**L, C**	**L, C**	**L, C**	**L, C**
Institutional Control ##	**L**	**L, C**	**L**	**L, C**
In-situ Remediation	**C**	**C**		**C**

Key

= already in baseline plan
L=reduces likelihood of potential hazard being realised
C=reduces consequences should potential hazard be realised

Table 6.2: Selection of Strategy Components

Threat	Capability of Options	Strategy Components
Human intrusion	**Institutional control** can be assumed to restrict access to the site for up to several hundred years and will prevent unintentional intrusion. Knowledge that would deter intrusion may be retained thereafter, however this cannot be relied upon. A **cap** will deter intrusion for the period of interest without maintenance. Only certain intrusions – those involving site investigation or major construction projects would be expected to penetrate a thick well-designed cap. However, capping forecloses other options. Deferred construction of the final cap is preferred to both permit further understanding of long-term performance to be gained, and to permit other measures to be applied prior to capping, if they are deemed necessary. **Full retrieval** of wastes would negate the threat. However, the costs and other detriments mean that it is not justifiable on a large scale. The low radiological impacts and the low probability that they are received are not sufficiently large to justify large-scale intervention. **Localised retrieval** could reduce the maximum radiation doses that might arise. Given our interim position on long-term performance, we will review the position on localised retrieval as part of the 2011 ESC. No other options are sufficiently effective to be relevant.	Institutional control is regarded as an essential component of the site management strategy. A cap designed to deter intrusion, provides effective defence against inadvertent human intrusion and is identified as an important component of the strategy. Retrieval is considered to be a disproportionate response. However, the position with respect to localised retrieval will be reviewed as part of the 2011 ESC.

Table 6.2 (Continued)

Threat	Capability of Options	Strategy Components
Coastal erosion	The threat of erosion and/or rising groundwater can be averted by **coastal defences**. However, they would require maintenance for many millennia. This cannot be relied upon. Full **retrieval** would be effective and partial retrieval may reduce the consequences of coastal erosion. However, the disruption and costs are disproportionate in terms of the potential doses that might be averted. If knowledge of the site persists, access to areas contaminated as a result of coastal erosion could be restricted. However, coastal erosion is not expected for about a thousand years, and **institutional control** cannot be relied upon over such timescales. Localised **coastal defences** may be useful in preventing storm surges affecting the LLWR when sea level has risen significantly. No other options are sufficiently effective to be relevant.	No proportionate or reliable method of averting coastal erosion was identified. Institutional control may help to mitigate impacts if knowledge of the site and wastes remains, or is re-instated, when coastal erosion occurs.

Table 6.2 (Continued)

Threat	Capability of Options	Strategy Components
Groundwater	Impacts can be reduced by making the repository resistant to the inflow and outflow of water with a **cap** and other **engineered barriers**. Further work is required to clarify the optimal arrangement of those barriers. Changing the waste form would reduce the rate of release of contaminants. The additional benefits do not warrant the **in-situ remediation** of all trench wastes. Full **retrieval** would be effective and partial retrieval could offer significant benefits. However, given the costs and other detriments it is not justifiable, as other measures are sufficiently effective. **Institutional control** is useful in allowing the performance of caps and other engineered barriers to be monitored.	A cap is required to minimise water infiltration into the facility. Other engineered barriers will be needed to minimise the likelihood of near-surface discharges and pathways. However, the arrangements require more detailed optimisation studies to substantiate them.

Table 6.2 (Continued)

Threat	Capability of Options	Strategy Components
Gas	A **cap** is capable of ensuring that the release of radon does not occur as a result of diffusive processes. The highest releases of radioactive and bulk gasses occur during the period during which **institutional control** can be planned for. Site control can ensure that exposures are largely avoided. Retrieval would be effective. However, it would be very disruptive and other methods are sufficiently effective as the relevant impacts are below the relevant intervention criteria. No other options are sufficiently effective to be relevant.	The assessment concluded that a cap is an important contribution to mitigating the impacts from radioactive gases. A period of institutional control is also of benefit, in limiting the potential for exposure when the generation of ^{14}C-labelled gas is greatest.

7 Conclusions

This section presents and discusses the overall management strategy proposed on the basis of the assessment reported above. This strategy identifies a number of components at an overview level. These need to be developed further and, in addition, their timing and complementary performance requires further evaluation. These areas for further evaluation are identified in subsection 7.3

Some of the strategic options under consideration are already part of our plans for the site. The characteristics of these options have been reviewed as part of this process.

As noted previously in Section 2, our updated view of performance (see Volume 5) suggests that the radiological impacts of the Trenches are below the relevant criteria. However, higher radiation doses of greater than 10 mSv yr^{-1} can arise if the implications of uncertainty or variability in the concentrations of key radionuclides in the waste are considered (see Volumes 1 and 5).

7.1 Options for Implementation

We are confident that three complementary options should form part of the long-term management strategy, as discussed below. These options are already parts of the plans for the LLWR site and provided the assumptions used as a basis for the 2002 PCSC.

7.1.1 Engineered Cap

An engineered cap, optimised to minimise the likelihood of human intrusion, limit infiltration and to prevent the diffusive release of radon is considered to be an essential part of the strategy. If a cap was not present, certain radiological impacts, due to most pathways, could be significantly higher than estimated in the update of post-closure performance or significantly more likely to occur. In any case, an engineered cap should be considered part of best practice in the design of near-surface radioactive waste repositories.

We believe that further consideration should be given to deferring the construction of a large “final” cap. Such deferment would allow a better understanding of the long-term performance of caps to be gained, which may be relevant in circumstances where waste degradation and subsidence is expected. Deferment would also provide a window in which other management options, which might require access to the waste, could be added to the strategy if necessary. It would also allow for further waste settlement to take place, which preferably should be complete before the final cap is constructed.

The cap over the Trenches, according to the current design, is on average about 8m thick, including profiling as well as the cap itself. An 8m thick cap would be effective at reducing the probability of human intrusion. There are a number of issues that need to be considered in future optimisation, these include the implications thinning and steeper slopes near the margin of the facility and the performance of the cap if it is damaged by human intrusion.

7.1.2 Engineered Barriers and Vertical Drains

There is a need for a system involving some combination of engineered hydrological barriers and vertical drains. The purpose of such features will be to minimise the likelihood of bathtubbing (when the facility fills up with water and overtops), the possibility of discharges of contaminated water local to the facility and near-surface pathways and lateral inflows of groundwater to the facility. The highest radiological consequences from the Vaults are currently calculated, using a preliminary model, for a water abstraction well at the Site Boundary (a conditional risk of 2 10^{-5} per year – see Volume 5). Any increases in inflows to the facility as a result of lateral groundwater flow could well have an adverse impact on this pathway. Further, there are uncertainties in relation to the consequences that might arise for bathtubbing. In view of these uncertainties with respect to post-closure performance, we consider that it is appropriate to plan for a system of near-field barriers and drains. Such barriers are also effective during the operational period.

As discussed in Volume 1, further work is needed to understand the function of the different near-field features in controlling groundwater flows in the near field of the repository. Further work would help to quantify the benefit of alternative strategies. Pending the development of such a model and associated optimisation, it is appropriate to conclude now that a system of barriers and features is required, but the characteristics of that system, including the need for vertical drains should be reviewed further.

7.1.3 Institutional Control

Institutional control is an essential part of the management strategy for the site. It will prevent human intrusion and the receipt of radiation doses from gas pathways for an important period of time. The facility can be managed to ensure that releases to groundwater are appropriately low and monitoring can confirm the initial evolution and performance of the disposal system. The institutional control period covers the time period during which many short-lived radionuclides will decay and also the period of maximum gas production (see Volume 5). Institutional control is regarded as part of best practice for a near-surface waste repository.

Plans for active institutional control should be put in place for as long as is reasonably practicable. This is likely to be for a period of some hundreds of years. We consider that this approach is appropriate because of the low cost of maintaining control against the significant benefits. The resources for planned institutional control is a key issue that requires consideration.

In addition, the workshop identified the need to maximise the potential for knowledge of the site and its wastes to be retained in the longer term. Further consideration of the use at the LLWR of measures including records and markers is necessary.

Work is needed to develop the detail of the active and passive institutional control plan for the site. A key issue to consider is whether the deferred construction of engineered measures (e.g. cap, limited coastal defences) could be accommodated. Institutional control may also be linked to continued monitoring of the site and the nature of this monitoring will need to be evaluated.

7.2 Options not selected

The workshop identified a second set of options that were concluded to be impractical or disproportionate to apply to all wastes in the Trenches. However, some of the options could be suitable for targeted use in specific areas. The workshop concluded that these options should not form part of our current strategy. However, their localised use should be reviewed as part of the 2011 ESC. Those options that are of potential utility in this respect are identified in the following discussion.

7.2.1 Coastal Defences

We do not consider that coastal defences are a viable component of our management strategy in the long term. Reliance on such defences is inconsistent with the principle that safety should be independent from controls. In addition, there are considerable difficulties in protecting the coastline on the long term against sea level rise of order 10m or more.

Coastal defences could be constructed now or at the end of the period of institutional control. However, defences will only have a short lifetime and will require continued maintenance.

However, smaller scale defences may be useful in mitigating earlier effects of flooding due to sea-level rise on the LLWR (e.g. storm surges). The workshop concluded that this option should be considered if assessments indicate that such a situation could pose a significant threat to the LLWR during the period of active institutional control.

7.2.2 Retrieval

The only option that can avert the consequences of coastal erosion is retrieval of most or all of the wastes. However, such retrieval would entail radiological and conventional risks during implementation and cost a large amount of money. Considering the Trenches as a whole, the radiation doses estimated for the Trenches are well within the region within which intervention is not likely to be justifiable. The retrieval process would result in considerable disruption and safety impacts to workers and the general public as a result of transport associated risks. On this basis, retrieval of all the wastes is considered to be disproportionate, and does not form part of the strategy.

We have considered the higher radiation doses that might arise if exposure occurs to wastes with higher than average ^{226}Ra concentrations. Receipt of such radiation doses is not likely to occur. However, as our view of performance is an interim one, we propose that the option of selective retrieval should be kept under review. We will reconsider the question as part of the 2011 ESC.

7.2.3 In-situ Remediation

Grouting achieves only relatively limited performance improvements. It would not impact significantly on the doses that would be received as a result of human intrusion and coastal erosion. For the groundwater pathway and well, it would only reduce the radiological impact of a few radionuclides that are potentially solubility limited. As can be seen from Volume 5, the main consequences for the water abstraction well arise for the Vaults, owing to their different radionuclide inventory. The Vaults are already grouted and overall there would be little benefit in grouting the Trenches from this perspective. Grouting may also be problematic to reliably implement on a large scale, in terms of achieving a uniform and high quality product. We do not therefore propose that it should be part of the future strategy.

Vitrification would reduce the impact of human intrusion, groundwater and gas pathways, perhaps significantly. However, it would increase the impact of coastal erosion, as wastes would less readily disperse. Furthermore, it would be very problematic to apply to the Trenches on the grounds of the low silica content of the wastes, and it is extremely costly. It is also associated with potential safety issues that are significant in relation to the low radiation doses that would be averted.

Compaction is of benefit in terms of reducing the potential for subsidence of the cap. We consider that compaction would only be required if there was doubt about the engineering lifetime of the cap.

These techniques could be used selectively in particular areas, were it to be decided that localised intervention is necessary. However, no requirement for such localised action has been identified at this stage.

7.3 Areas for Future Consideration

The work to develop a long-term management strategy for the LLWR has identified a number of areas where options need to be reviewed in the light of better information and other cases where more detailed design optimisation is required. These will be progressively resolved so that the 2011 ESC submission can present a more detailed strategy for the LLWR.

7.3.1 Cap

Considerable work has already been undertaken to design a cap for the LLWR (Belton, 2007). However, the strategy development work has highlighted the potential benefits of maintaining the interim cap for a longer period before constructing the final cap. This approach can provide for flexibility and allow work to be undertaken to build confidence in long-term performance. This strategy needs to be explored further. Further optimisation is required to consider the performance of the cap in different circumstances of relevance to post-closure safety.

7.3.2 Engineered Barriers

As discussed above, there is confidence that engineered barriers are an essential component of the strategy for the site. However, further detailed consideration is needed of the interplay between the cap, the cut-off walls and the vertical drain and other near-field engineered features. Future design optimisation should build on consideration of flows within a model at a more realistic and detailed level than in the recent Engineering Performance Assessment (see Paksy, 2008).

7.3.3 Institutional Control

The work has highlighted that there is clearly an important role for the planned institutional control of the LLWR. However, detailed proposals have yet to be developed. Further work is

needed to develop an integrated site management strategy and establish funding provisions. The various phases of post-closure site management need to be determined.
The potential for deferred construction needs to be taken into account. The plans also need to be integrated with local plans and if possible those for other Cumbrian nuclear sites. In addition, methods for maintaining knowledge of the site after the planned period of control need to be developed.

7.3.4 Selective Application of Specific Options

The selective application of retrieval and in-situ remediation need further exploration. Further consideration is needed in the light of a fuller performance assessment. We therefore propose to revisit these questions as part of the 2011 ESC.

In relation to the use of localised coastal defences, the key issue is the nature and timing of sea-level rise. If flooding were have significant potential to affect the vaults or trenches during the period of institutional control, localised sea defences might be appropriate. This option will be kept under review as our understanding of climate change and sea-level rise develops.

7.4 Conclusions

We have conducted a systematic analysis of the options for the future management of the site using a BPEO methodology and involving consultation with local stakeholders. This has built on a considerable body of analysis, including detailed briefing notes prepared for this study and previous options assessments, conducted by BNFL for the LLWR (BNFL, 2004b). Whereas the previous BNFL assessment was focused on a multi-attribute analysis, this exercise has involved discussions with stakeholders, a review of the key characteristics of each option and a consideration of each option in terms of its capability to address different threats or radiological impacts.

It is estimated that the performance of the Trenches is such that radiation doses will be within the region where intervention is not normally justifiable (except if exposure occurs as a result of human intrusion to wastes with higher than average concentrations of ^{226}Ra). Therefore, large-scale interventions that disrupt the facility should not be favoured. Rather the focus should be on demonstrating that good science and technology and practice have been employed and that there are good reasons for selecting the chosen strategy.

The long-term management strategy derived from the BPEO involves:

- Arrangements for active and passive institutional control;
- Construction of an engineered cap optimised to provide good protection against human intrusion over a time period of thousands of years;
- An engineered system, involving some combination of cut-off walls and vertical drains to ensure optimal near-field hydrology, noting that further design optimisation studies are needed to identify the best strategy.

Retrieval of a large portion of the wastes would be associated with detriments that are disproportionate compared to the benefits. The construction of coastal defences is not a viable plan as it cannot be relied on to provide protection over the relevant time scale and is inconsistent with the regulatory guidance that requires long-term safety to be independent of controls after closure.

A range of techniques has been identified that could be applied to the facility in the future were it ever deemed necessary to intervene to deal with wastes with particularly high localised concentrations of key radionuclides. We will keep under review the possibility of localised retrievals of certain wastes and will report again in 2011.

There is considerable commonality between these conclusions and those resulting from the earlier options assessment undertaken by BNFL (BNFL, 2004b). The main differences are that we do not consider coastal defences to be a viable strategy for reasons of practicability and principle and we believe that further investigation of selective retrieval is warranted.

8 References

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Appendix A: 2004 Option Assessments

The current work is only part of a much larger programme and the assessment process built on material prepared to support previous submissions and options assessment studies.

The 2004 management option studies (BNFL 2004a & 2004b), for instance provided detailed assessments of the radiological performance benefits for a range of strategic options and assessments against a comprehensive set of 'BPEO' criteria.

Through those studies, we examined whether there were any management strategies that could be implemented that would give a significant potential for overall reduction of the radiological impact from the waste currently disposed of in the Trenches and Vault 8 and from waste for potential future disposal to the Drigg facility. Only two such strategic options were identified; encouraging dilution and dispersion of radionuclides from the Trenches whilst maintaining the role of the Vaults as providing containment of radionuclides; and the closure of the Drigg facility and the retrieval of wastes for disposal at a new disposal facility.

Encouraging dilution is inconsistent with the optimisation principles of containment and shorter-term risks for the groundwater pathway would tend to be increased. However, the overall likely poor acceptability of this option to various stakeholders is an important consideration and it was not taken any further. Retrieval was taken forward to the second study.

We then carried out a preliminary options assessment study employing a conventional BPEO/BPM approach, though with a more detailed emphasis that the strategic option studies that are the main focus of the current report.

Detailed technical preparatory work was reviewed and extended by a team of experts (including members of the current project team) over the course of two one-day workshops. The options considered were

- Extended period of institutional control
- Coastal erosion (single overarching option)
- Retrieval of waste
- Site closure and storage of future arisings
- Increased cap thickness
- Increased cap performance
- Eliminate surface pathways in short term (single overarching option)
- Active barrier
- Encourage dilute and disperse from Trenches
- In-situ deep soil mixing and grouting of Trenches
- Insertion of an impermeable barrier underneath Trenches 1-3
- In-situ vitrification of trench waste
- Compaction of trench waste
- Excavation of trench waste and disposal in new Vaults
- Improvement of vault waste form and

The options considered were

1. Extended period of institutional control
2. Coastal erosion (single overarching option)
3. Retrieval of waste
4. Site closure and storage of future arisings
5. Increased cap thickness
6. Increased cap performance
7. Eliminate surface pathways in short term (single overarching option)
8. Active barrier
9. Encourage dilute and disperse from Trenches
10. In-situ deep soil mixing and grouting of Trenches
11. Insertion of an impermeable barrier underneath Trenches 1-3
12. In-situ vitrification of trench waste
13. Compaction of trench waste
14. Excavation of trench waste and disposal in new Vaults
15. Improvement of vault waste form and
16. Improvement of vault design.

The attributes applied were as follows.

Table 1. Attributes applied.

Environment and safety	• Chemical impacts • Radiological impacts • Resource use • Disturbance / nuisance • Worker dose • Conventional safety • Acceptability of waste form (in-situ) • Minimisation of waste at source)
Technical	• Technical confidence • Compatibility with existing systems • Implementation time
Economic	• Acceptability • Costs

Table 2 indicates the outcomes of the discussion against the 'technical confidence' criterion.

Options	Workshop score	Discussion on the day
Baseline option Option 5 - Increased cap thickness Option 7 - Elimination of surface pathways in the short-term	Best	Scoring of Options 5 and 7 were increased from very good in the pre-workshop assessment. These options were thought to offer the highest amount of technical confidence in terms of engineering. Some discussion questioned the required increase in thickness, the viability and the effectiveness in further reducing risks.
Option 13 - Compaction of trench waste Option 4 - Site closure and storage of future arisings Option 16 - Improvement of vault design Option 1 - Extended period of institutional control Option 15 - Improvement of vault waste form	Very good	Scoring of Options 4 and 13 was in line with the pre-workshop assessment. Scoring of Options 16, 1 and 15 was increased from the pre-workshop assessment as it was agreed that the techniques required were relatively standard. It was noted that the use of incineration would be an applicable method of improving the waste form, however, it is not applicable to all waste types (Option 15).
Option 3 - Site closure and retrieval of waste Option 14 - Excavation of trench waste and disposal in new vaults Option 10 – *In situ* grouting of trenches Option 2 - Coastal defences	Good	Scoring of Options 3 and 14 was in line with the pre-workshop assessment. Scoring of Options 10 and 2 was increased from the pre-workshop assessment because the options involve relatively standard techniques, albeit at very large scale. Option 2 was considered comparable to these other options in terms of technical confidence in construction. Longevity was considered to be less relevant under this criterion and there is historical evidence of such structures having been maintained over millennia. It was noted that the retrieval of larger items from the vaults could be problematic (Option 3 - site closure and retrieval of waste). It was further noted that the longevity of the coastal defences (Option 2) would be limited and that this would have to be investigated in more detail to ensure that maximum benefit was gained from the timing of emplacement.
Option 6 - Increased cap performance Option 9 - Encourage dilute and disperse from trenches	Medium	Scoring of Option 6 was in line with the pre-workshop assessment. Scoring of Option 9 was increased from the pre-workshop assessment as it was agreed that the techniques required were relatively standard.
Option 8 -Active barrier	Bad	Scoring in line with pre-workshop assessment.
Option 11 - Insertion of an impermeable barrier underneath Trenches 1-3	Very bad	Scoring decreased from pre-workshop assessment because it was decided that there was generally little confidence that this technique would be successful.
Option 12 – *In situ* vitrification of the trench waste	Worst	Scoring in line with pre-workshop assessment. It was noted that there was some uncertainty over the technology and its applicability to the situation, geology and scale of application, leading to vitrification being considered the worst relative option.

Table 3 indicates the outcomes of the discussion against the compatibility with existing systems' criterion.

Options	Workshop score	Discussion on the day
Option 1 - Extended period of institutional control Option 2 - Coastal defences Option 6 - Increased cap performance		workshop assessment. Scoring of Option 6 was increased because it was noted that the design of the cap would need to be integrated as part of the overall approach, so as not to affect the overall cap profile. Hence, compatibility would be an inherent requirement.
Option 5 - Increased cap thickness Option 7 - Eliminate surface pathways in short-term Option 15 - Improvement of vault waste form Option 16 - Improvement of vault design Option 4 - Site closure and storage of future arisings Option 8 -Active barrier	Very good	Scoring of Options 5, 7, 15 and 16 is in line with the pre-workshop assessment. It was noted that Options 15 and 16 could only be applied to future disposals and would therefore not impact on wastes presently disposed within the trenches and Vault 8. Any intent to improve the waste form for previous disposals would represent a significant deviation from the current site development plan. Scoring of Option 4 was increased from the pre-workshop assessment. It was noted that Option 4 was potentially compatible with Drigg site operations. However, compatibility issues relating to an assumed new disposal facility are beyond the scope of this assessment and are therefore not considered. Scoring of Option 8 was also increased from the pre-workshop assessment as it was assumed that the active barrier would be included as part of the closure engineering.
Option 10 – *In situ* grouting of trenches Option 11 - Insertion of an impermeable barrier underneath trenches 1-3 Option 12 – *In situ* vitrification of trench waste Option 13 - Compaction of trench waste	Good	Scoring is in line with the pre-workshop assessment.
Option 9 - Encourage dilute and disperse from trenches Option 14 – Excavation of trench waste and disposal into new vaults	Bad	Scoring is in line with the pre-workshop assessment. Discussion between the attendees indicated that both of these options were considered worse than the options classified as 'good'. However, performance against this criterion was considered significantly better than Option 3.
Option 3 - Site closure and retrieval of waste	Worst	This option was considered to be incompatible with the existing facilities and the notion of Drigg as a disposal site.

Table 4 indicates the outcomes of the discussion against the 'radiological impact' criterion.

Options	Workshop score	Discussion on the day
Option 3 - Site closure and retrieval of waste	Best	This option involves removal of the inventory and thus presents the greatest reduction in radiological impact of the dispersed inventory. However, the boundaries of the assessment do not take account of radiological impacts at the alternative disposal location. However, it is considered that that risks associated with any new facility should be below 1E-06 y^{-1} .
Option 9 - Encourage dilute and disperse from trenches Option 10 -*In situ* grouting of the trenches	Bad	It was considered that these options were likely to give rise to slightly decreased overall risks compared with the baseline option. However, risk target exceedances were still considered likely. This is in line with the pre-workshop assessment.
Baseline option Option 1 - Extended period of institutional control Option 2 - Coastal defences Option 4 - Site closure and storage of future arisings Option 5 - Increased cap thickness Option 6 - Increased cap performance Option 13 - Compaction of trench waste Option 14 - Excavation of trench waste and disposal in new vaults Option 15 - Improvement of vault waste form Option 16 - Improvement of vault design	Very bad	It was concluded that there was little difference in the performance of the majority of options against the baseline option in terms of radiological impact. This was due to the fact that actions intended to reduce risks via one pathway generally lead to increased risks via another pathway(s). Given that the baseline option gives to risks significantly in excess of 1E-6 y^{-1}, these options were scored as very bad. The scoring was in line with the pre-workshop assessment.
Option 7 - Eliminate surface pathways in the short-term Option 8 -Active barrier Option 11 – Insertion of an impermeable barrier underneath Trenches 1-3 Option 12 -*In situ* vitrification	Worst	It was considered that these options were likely to give rise to increased risks over and above those determined for the baseline option. This is in line with the pre-workshop assessment. It was noted that Option 12 would change the chemical composition of the waste, thus potentially enhancing the mobility of some radionuclides. Off-site doses could also be increased during the post-operational management phase due to off-gases generated through implementation of the option.

Table 5 indicates the outcomes of the discussion against the ‘chemical impact’ criterion.

Options	Workshop score	Discussion on the day
Option 3 - Retrieval of waste	Best	Scoring in line with pre-workshop assessment.
Option 9 - Encourage dilute and disperse from the trenches Option 10 -*In situ* grouting of trenches	Bad	It was considered that these options were likely to give rise to slightly decreased overall impacts compared with the baseline option. This is in line with the pre-workshop assessment.
Baseline option Option 1 – Extended period of institutional control Option 2 - Coastal defences Option 4 - Site closure and storage of future arisings Option 5 – Increased cap thickness Option 6 – Increased cap performance Option 13 - Compaction of trench waste Option 14 - Excavation of trench waste and disposal in new vaults Option 15 - Improvement of vault waste form Option 16 - Improvement of vault design	Very bad	It was concluded that there was little difference in the performance of the majority of options against the baseline option in terms of chemical impact. This was due to the fact that actions intended to reduce impacts via one scenario generally lead to increased impacts via another scenario(s). Because limited technical work has been undertaken to date to assess chemical impacts associated with the Drigg site, scoring is in line with the radiological impact criterion. Therefore, these options were scored as very bad. The scoring was in line with the pre-workshop assessment.
Option 7 - Eliminate surface pathways in the short-term Option 8 -Active barrier Option 11 – Insertion of an impermeable barrier underneath Trenches 1-3 Option 12 -*In situ* vitrification	Worst	It was considered that these options were likely to give rise to increased impacts over and above those determined for the baseline option. This is in line with the pre-workshop assessment. It was noted that Option 12 would change the chemical composition of the waste, thus potentially enhancing the mobility of some radionuclides. Off-site impacts could also be increased during the post-operational management phase due to off-gases generated through implementation of this option.

Table 6 indicates the outcomes of the discussion against the ‘resource use’ criterion.

Options	Workshop score	Discussion on the day
Baseline option Option 9 - Encourage dilute and disperse from the trenches	Best	This is in line with the pre-workshop assessment, although it was agreed that Option 9 may be marginally better than the baseline option due to slightly lower resource and energy use (e.g. in relation to construction of the cap).
Option 1 - Extended period of institutional control Option 4 - Site closure and storage of future arisings Option 5 - Increased cap thickness Option 6 - Increased cap performance Option 11 - Insertion of an impermeable barrier underneath trenches 1-3 Option 16 - Improvement of vault design	Very good	All scores agreed with pre-workshop assessment except for improvement of vault design. This score was increased due to a consensus that performance of Option 16 would be better than Option 2, coastal defences. It was noted that the high score for Option 4 is due to boundaries for this assessment excluding evaluation of the effects and issues associated with a new facility.
Option 2 - Coastal defences Option 13 - Compaction of trench waste	Good	Agreed with pre-workshop assessment.
Option 3 - Site closure and retrieval of waste	Medium	Score lowered from pre-workshop assessment due to recognition of the significant quantities of energy required for retrieval operations. It was noted that this relatively high score is due to boundaries for this assessment excluding evaluation of the effects and issues associated with a new facility.
Option 7 - Eliminate surface pathways in the short-term Option 8 -Active barrier *In situ* grouting of trenches Improvement of vault waste form Option 10 – *In situ* grouting of trenches Option 15 – Improvement of vault waste form	Bad	Scores lowered from pre-workshop assessment due to agreement that performance of all options would be worse than for coastal defences.
Option 14 - Excavation of trench waste and disposal in new vaults	Very bad	Scores lowered from pre-workshop assessment due to agreement that performance of option would be worse than for options scored as ‘bad’.
Option 12 -*In situ* vitrification of trench waste	Worst	Agreed to represent worst score.

Table 7 indicates the outcomes of the discussion against the 'disturbance/nuisance' criterion.

Options	Workshop score	Discussion on the day
Baseline option Option 6 - Increased cap performance Option 9 - Encourage dilute and disperse from the trenches Option 1 - Extended period of institutional control	Best	All these options were considered to perform similarly to the baseline option. Given that implementation of other options represents additional disturbance/nuisance, these options were considered best. There was some debate as to whether Option 9 would require introduction of additional controls, potentially restricting fish consumption and therefore fisherman's livelihoods. Issues related to any long-term land use restrictions associated with Option 1 are not included in this score. Option 1 was considered to represent minimal additional impact when spread throughout the period of extended institutional control.
Option 16 - Improvement in vault design Option 15 - Improvement of vault waste form Option 8 -Active barrier	Very good	Some relatively insignificant impacts over and above the baseline option were considered to be associated with these options (e.g. import of relatively small quantities of additional material).
Option 11 - Insertion of an impermeable barrier underneath trenches 1-3 Option 4 - Site closure and storage of future arisings Option 10 -*In situ* grouting of trenches Option 5 - Increased cap thickness	Good	It was noted that there would be issues in relation to noise (from drilling), in relation to the implementation of Option 11. Implementation of Option 4 would need to consider visual impact issues associated with the construction of a storage facility at Drigg and additional transport (the stored waste would eventually be moved to a new facility leading to a net positive movement of material compared with the baseline option). The additional material required for the implementation of Options 10 and 5 were noted to be less than a third of the total volume of material required for the post-closure engineering.
Option 2 - Coastal defences	Medium	It was noted that the Drigg coastal Site of Special Scientific Interest (SSSI) would be impacted by this option.
Option 7 - Eliminate surface pathways in short-term	Bad	It was considered that this option scores lower than Option 2.
Option 13 - Compaction of trench waste	Very bad	Noise, although temporary, was considered to be a significant issue associated with this option.
Option 12 -*In situ* vitrification of trench waste Option 3 - Site closure and retrieval of waste Option 14 - Excavation of trench waste and disposal into new vaults.	Worst	Option 12 was considered particularly likely to cause disturbance to neighbours. Options 3 and 14 score badly due to transport issues.

Table 8 indicates the outcomes of the discussion against the ‘worker dose’ criterion.

Options	Workshop score	Discussion on the day
Baseline option Option 2 - Coastal defences Option 5 - Increased cap thickness Option 6 - Increased cap performance Option 7 - Eliminate short term pathways Option 16 - Improvement of vault design Option 1 - Extended period of institutional control Option 8 -Active barrier	Best	It was decided that all of these options would be classed as equal to the baseline option. All other options involve increased worker doses. Scoring of Option 8 was increased from the pre-workshop assessment due to the fact that doses associated with implementation are not expected to be significantly different to the baseline option. It is assumed that the barrier is emplaced at the same time as the post-closure engineering.
Option 15 - Improvement of vault waste form Option 4 - Site closure and storage of future arisings Option 9 - Encourage dilute and disperse from the trenches	Very good	Scoring in line with pre-workshop assessment. Scoring of Option 9 was not considered best due to the requirement for construction of slot drains between the trenches, and associated dose implications.
Option 10 -*In situ* grouting of trenches Option 11 - Insertion of an impermeable barrier underneath trenches 1-3 Option 12 -*In situ* vitrification Option 13 - Compaction of trench waste	Good	Scoring in line with pre-workshop assessment. These options involve limited intrusion into the wastes, but the volumes excavated (and hence potential exposures) would probably not be large.
Option 3 - Site closure and retrieval of waste Option 14 - Excavation of trench waste and disposal into new vaults	Worst	Options involving retrieval of waste were considered to score considerably worse than options involving more limited intrusion into waste during remediation activities.

Table 9 indicates the outcomes of the discussion against the 'conventional safety' criterion.

Options	Workshop score	Discussion on the day
Option 4 - Site closure and storage of future arisings	Best	Option considered best because construction requirements are lowest.
Baseline option Option 1 - Extended period of institutional control Option 5 - Increased cap thickness Option 6 - Increased cap performance Option 7 - Eliminate surface pathways in short-term Option 8 -Active barrier Option 9 - Encourage dilute and disperse from trenches Option 16 - Improvement of vault design	Very good	Construction risks only.
Option 10 -*In situ* grouting of trenches Option 11 - Insertion of an impermeable barrier underneath trenches 1-3 Option 13 - Compaction of trench waste Option 15 - Improvement of vault waste form	Good	Impacts associated with these options are associated with standard construction risks, including construction of an off-gas plant for Option 15. However, the scale of the engineering is greater than for those options considered very good.
Option 14 - Excavation of trench waste and disposal into new vaults Option 3 - Site closure and retrieval of waste	Medium	Impacts associated with these options are associated with standard construction risks, at a larger scale than for those options considered good. It was noted that the assessment of Options 3 and 14 does not include the issues with respect to transport and movement of waste.
Option 2 - Coastal defences	Bad	Scoring low due to large scale of required construction works, including large craneage over water.
Option 12 -*In situ* vitrification	Worst	It was noted that this option presented fire and explosion risks in addition to construction risks. The fire and explosion hazards may precipitate waste collapse.

Appendix B: Brief Description of Shortlisted Options

MO/07/005 Base Liner

Base liners are horizontal barriers installed under a disposal facility in order to prevent downward movement of contaminants. If vertical barriers (cut-off walls) are used which can be keyed into an impermeable confining layer underneath the contamination, then a base liner may not be necessary.

MO/07/027 Excavation, Retrieval and re-Disposal

Contaminated material is removed and transported to permitted on or off-site treatment and/or disposal facilities. Prior to excavation the waste could undergo some in situ treatment e.g. grouting.

MO/07/033 Grouting

Grouting is an engineering technique, which is used to improve the physical and chemical properties of weak and high voidage materials having a low organic content, in particular soils. It involves the injection of a liquid, usually cementitious grout.

MO/07/040 In-situ Vitrification

In-Situ Vitrification is a high temperature thermal treatment process that converts soil into a glass.

MO/07/044 Landfill Cap

The installation of a cap or barrier over a disposal facility is commonplace. The design of landfill caps is site specific and depends on the intended functions of the system. Landfill caps can range from a one-layer system of vegetated soil to a complex multi-layer system of soils and geosynthetics. In general, less complex systems are required in dry climates and more complex systems are required in wet climates.

MO/07/045 Landfill Cap Enhancements

The purpose of landfill cover enhancement is to reduce or eliminate contaminant migration (e.g. percolation). Water harvesting and vegetative cover are two ways for landfill cover enhancements. Water harvesting uses runoff enhancement to manage landfill site water balance. Vegetative cover reduces soil moisture via plant uptake and evapotranspiration.

MO/07/047 Linear Jet Grouting

For Jet Grouting, boreholes are drilled to the depth of the bottom of the liner and grout jetted through a rotating nozzle. Thus a series of intersecting disks are generated.

MO/07/049 Monitored Natural Attenuation

Natural sub-surface processes, such as dilution, volatilisation, biodegradation, adsorption, and chemical reactions with subsurface materials, are allowed to reduce contaminant concentrations to acceptable levels. Natural attenuation is not a "technology" per se.

MO/07/053 Passive/Reactive Walls

These permeable reactive barriers, which combine a passive chemical or biological treatment zone, allow the passage of water while causing the chemical removal of contaminants.

MO/07/054 Physical Barriers

Physical barriers (or slurry walls) are subsurface barriers consist of a vertically excavated trench that is filled with a slurry. The slurry hydraulically shores the trench to prevent collapse and forms a filter cake to reduce ground water flow. Slurry walls often are used where the waste mass is too large for treatment and where soluble and mobile constituents pose an imminent threat to a source of drinking water.

MO/07/065 Solidification/Stabilisation (in-situ)

In-situ solidification/stabilisation reduces the mobility of hazardous substances and contaminants in the environment through both physical and chemical means. Unlike other remedial technologies, solidification/stabilisation seeks to trap or immobilise contaminants within their "host" medium (i.e., the soil, sand, and/or building materials that contain them) instead of removing them through chemical or physical treatment.

MO/07/074 Institutional Control

Sites decommissioned to a condition that does not enable unrestricted use have residual hazards. These require control until an unrestricted end state can be reached. The period during which these hazards require control is known as the "*period of institutional control",* and the controls themselves are *"institutional controls"* (ICs). The overriding principle during the period of institutional control is the sustained continued protection of human health and the environment. The period ends when the site can be released for unrestricted use

MO/07/076 Coastal Defences

Structures of different sorts may be used to protect the coastline from erosion or to reduce the rate of that erosion.

MO/07/077 Vertical Drains

Vertical drains could be installed to create a preferential vertical groundwater flow pathway to the regional ground water system.

MO/07/078 Disposal of Retrieved Waste to another Facility

Any wastes that might be retrieved from the LLWR need a final management solution. One option would be to dispose some or all of the retrieved wastes to a different facility.

MO/07/079 Re-disposal of Wastes to the LLWR

Any wastes that might be retrieved from the LLWR need a final management solution. One option would be to redispose some or all of the retrieved wastes to the LLWR. If such wastes were to redisposed, it would be necessary to demonstrate compatibility with appropriate conditions for acceptance.

MO/07/081 Compaction of Trench Waste

The objective of this option is to improve performance of the final cap and also to reduce uncertainty in assessing cap performance for any future Safety Case. This may be achieved by reducing residual settlement (that is: settlement after the placement of the final cap) either by reducing the duration or the amount of settlement.

MO/07/013 Chemical Extraction

The technique is a decontamination process in which waste contaminated soil and extractant are mixed in an extractor, thereby dissolving the contaminants. The extracted solution is then placed in a separator, where the contaminants and extractant are separated for treatment and further use. Chemical extraction does not destroy wastes but is a means of separating hazardous contaminants from soils, sludges, and sediments, thereby reducing the volume of the hazardous waste that must be treated.

MO/07/023 Encapsulation

Wastes may be encapsulated in an appropriate matrix. The aim is to lock contaminants in a solid, monolithic block. Encapsulation should result in a passive wasteform.

MO/07/028 Ex-situ Vitrification

Ex-situ vitrification is used to encapsulate inorganic contaminants and destroy organic contaminants. It can be used on its own or to treat solid wastes from other treatment techniques. Heating devices include plasma torches and electric arc furnaces.

MO/07/038 Incineration

High temperatures, 870 to 1,200 ℃, are used to volatilise and combust (in the presence of oxygen) halogenated and other refractory organics in hazardous wastes. Often auxiliary fuels are employed to initiate and sustain combustion. Off gases and combustion residuals generally require treatment. A number of systems are available and include circulating bed combustor, fluidised bed, infrared combustion and rotary kilns.

MO/07/059 Separation

A wide range of processes are available to sort radioactive wastes before further processing. These include:

- Visual inspection;
- Sieving or other processes related to grain size;
- Characterisation in terms of activity or radionuclide content;
- Magnetic separation;
- Sorting on the basis of density.

Sorting is often required to ensure that sufficiently uniform waste streams are available for effective subsequent processing. It will be possible to ensure that subsequent treatment or disposal steps are well matched with wastes of specific characteristics. As a result, environmental and safety impacts may be reduced. There is further scope for application of the Waste Management Hierarchy to minimise the quantities of waste and maximise re use and recycling.

MO/07/063 Soil Washing

Soil washing is based on mineral processing techniques and is a water-based process for scrubbing soils ex-situ to remove contaminants. Although the process removes contaminants from soils the resulting contaminated water requires treatment.

MO/07/064 Solidification/Stabilisation (ex-situ)

Ex-situ solidification/stabilisation contaminants are physically bound or enclosed within a stabilised mass (solidification), or chemical reactions are induced between the stabilising agent and contaminants to reduce their mobility (stabilisation). Ex-situ solidification/ stabilisation, however, typically requires disposal of the resultant materials.

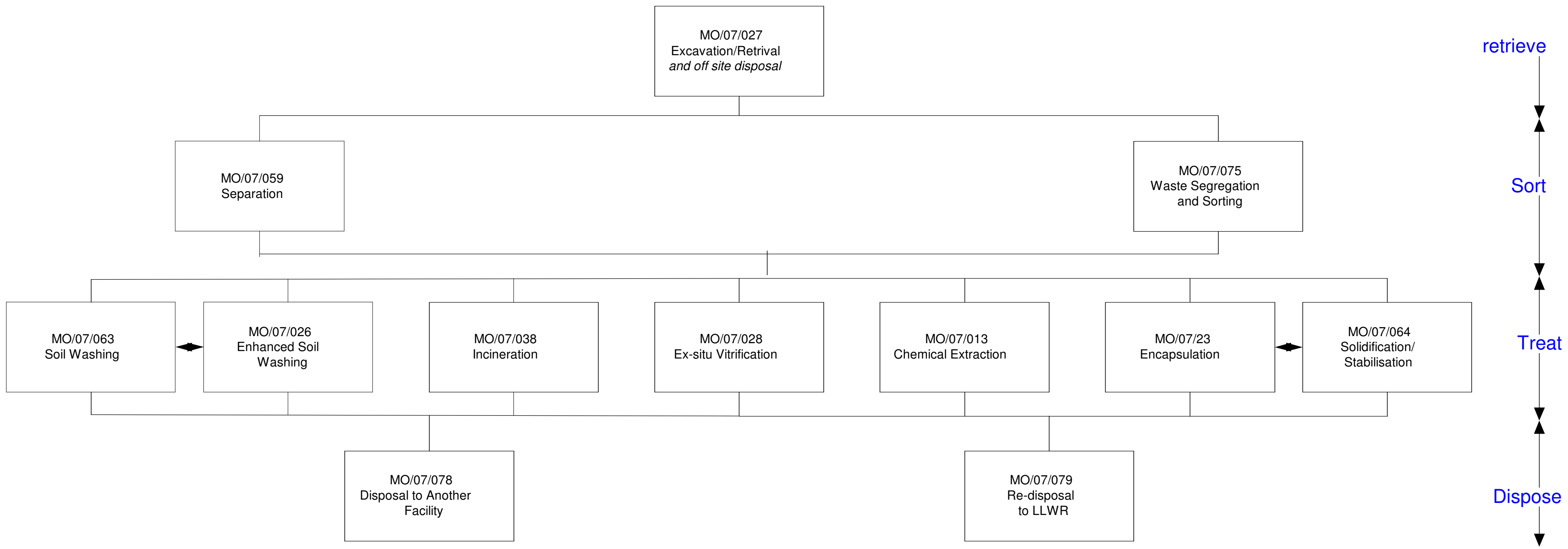
MO/07/075 Waste Segregation and Sorting

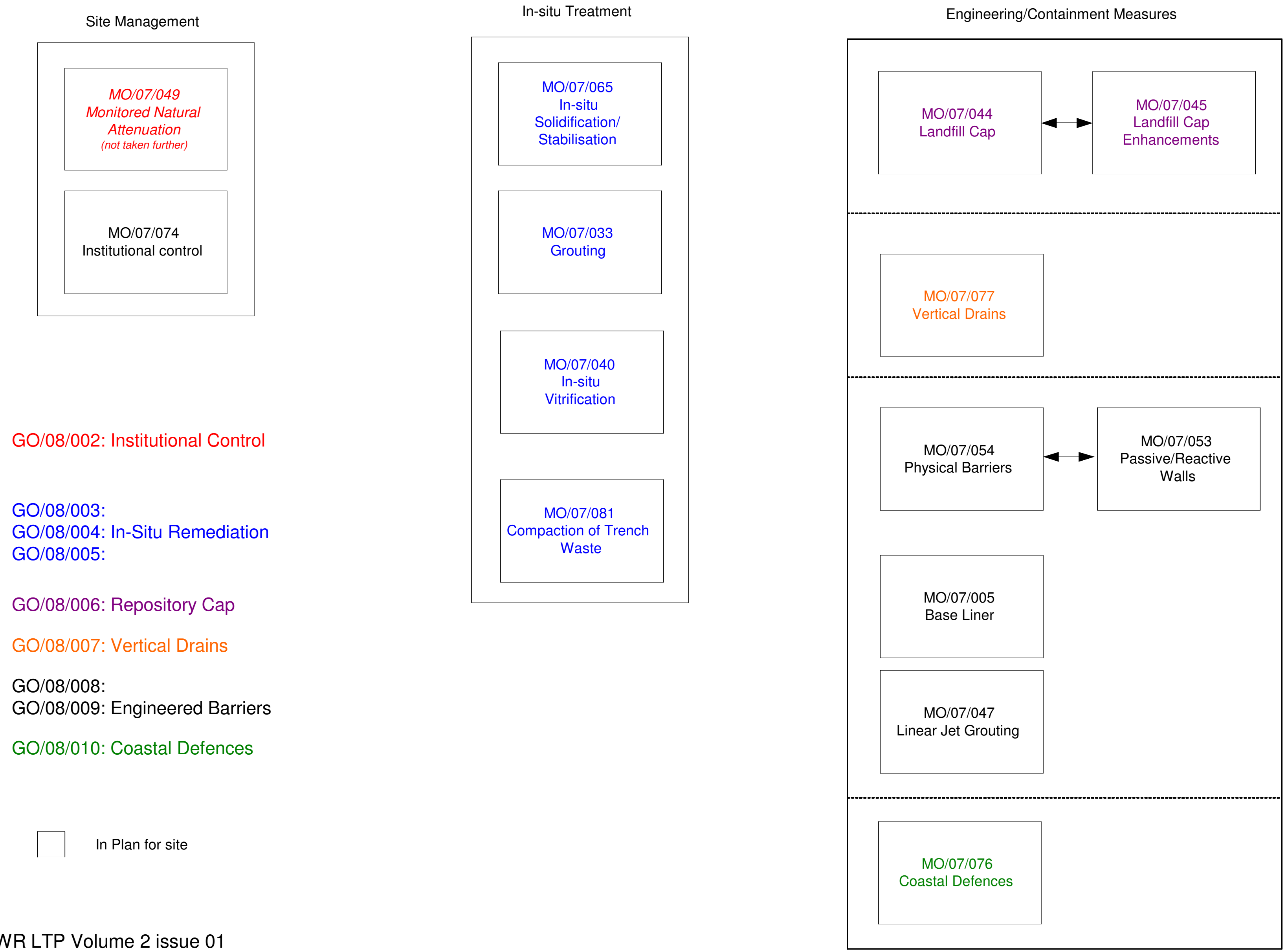
Waste on removal from the disposed areas will need to undergo a process of sorting and segregation prior to any other treatment. The initial action would be to segregate the waste into different types (e.g. compactable and non-compactable waste). Retrieved waste could then be sorted into suitable categories to undergo further treatment prior to redisposal

MO/07/021 Earthsaw™

The Earthsaw™ technology is a method of constructing a high integrity barrier under and around an existing landfill, waste burial site or underground tank without contacting or exposing any contaminated material. This technique requires the excavation of a vertical slurry trench around the site. The slurry is then replaced with a proprietary super dense grout, and a cable saw used to cut a horizontal path under the site. The earth block created 'floats' on the super dense grout, and additional grout is added to lift the block, forming a base liner of specified thickness and cut-off walls at the same time.

Appendix C: Options and their Groupings:




Site Management
MO/07/049
Monitored Natural
Attenuation
(not taken further)
MO/07/074
Institutional control
In-situ Treatment
MO/07/065
In-situ
Solidification/
Stabilisation
MO/07/033
Grouting
MO/07/040
In-situ
Vitrification
MO/07/081
Compaction of Trench
Waste
Engineering/Containment Measures
MO/07/044
Landfill Cap
MO/07/045
Landfill Cap
Enhancements
MO/07/077
Vertical Drains
MO/07/054
Physical Barriers
MO/07/053
Passive/Reactive
Walls
MO/07/005
Base Liner
MO/07/047
Linear Jet Grouting
MO/07/076
Coastal Defences
GO/08/002: Institutional Control
GO/08/003:
GO/08/004: In-Situ Remediation
GO/08/005:
GO/08/006: Repository Cap
GO/08/007: Vertical Drains
GO/08/008:
GO/08/009: Engineered Barriers
GO/08/010: Coastal Defences
In Plan for site

Appendix D: Workshop Attendance Lists:

Workshop 1 - December 2007:

Community Stakeholders

Adrian Dalton	LLWR Sub-committee of West Cumbria SSG
Alan Smith	Allerdale Borough Council
Cllr Allan	Holiday Copeland Borough Council
Jimmy Naylor	Drigg & Carleton Parish Council
Kneale Thompson	Drigg & Carleton Parish Council
Marjorie Higham	Drigg
Stephen Shepherd	Drigg & Carleton Parish Council
Sue Brown	LLWR Sub-committee of West Cumbria SSG
Tim Knowles	Cumbria County Council

Industry Stakeholders

Chuck Conway	UK Nuclear Waste Management Ltd
Dafydd Charles	Serco Assurance
Richard Cummings	Serco Assurance

LLWR SLC Independent Review Panel

David Bennett	Terrasalus Ltd
Steve Jones	Westlakes Scientific

Regulators

Andrew Fairhurst	Environment Agency
Ian Barraclough	Environment Agency, Nuclear Waste Assessment Team

LLWR SLC

Andy Baker
Andy Dietzold
Cath Giel
Chris Halliwell
James Fisher
Tony Wood

Facilitation Team
David Collier
Mike Egan

Workshop 2 – January 2008

Community Stakeholders

Cllr Eileen Eastwood	Copeland Borough Council
Cllr Allan Holiday	Copeland Borough Council
Jimmy Naylor	Drigg & Carleton Parish Council
Kneale Thompson	Drigg & Carleton Parish Council
Marjorie Higham	Drigg
Tim Knowles	Cumbria County Council
Richard Hardiman Drigg	

Industry Stakeholders

Chuck Conway	UK Nuclear Waste Management (observer)
Dafydd Charles	UK Nuclear Waste Management (observer)
Richard Cummings	UK Nuclear Waste Management (observer)
Anna Clark	NDA

LLWR SLC Independent Review Panel

David Bennett	Terrasalus Ltd
Steve Jones	Westlakes Scientific

Regulators

Andrew Fairhurst	Environment Agency
Ian Barraclough	Environment Agency, Nuclear Waste Assessment Team

LLWR SLC

Andy Baker
Andy Dietzold
Cath Giel
Chris Halliwell
James Fisher
Tony Wood

Facilitation Team

David Collier
Alan Paulley

Screening Review Workshop – January 2008

LLWR SLC

Andy Baker
Andy Dietzold
Tony Wood

External Experts

David Collier
Paul Grimwood
James Penfold
Alan Paulley

Assessment Workshop – March 2008

LLWR SLC

Andy Baker
Andy Dietzold
Tony Wood

External Experts

Paul Grimwood
James Penfold
Alan Paulley