LLW Repository Ltd

LLWR Environmental Safety Case

Design Optimisation for the LLWR 2011 ESC (Extended Disposal Area)

A report prepared by Quintessa for and on behalf of the Low Level Waste Repository Site Licence Company.

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Summary

LLW Repository Limited (LLWR Ltd) is undertaking a programme of work that will result in the publication of a new Environmental Safety Case by May 2011 (the 2011 ESC). The 2011 ESC will be submitted to the Environment Agency in support of a formal application for re-authorisation of disposal operations.

The 2011 ESC is based on a reference design that assumes five additional vaults will be created in the future (i.e. Vaults 10 to 14) and that the facility will reach volumetric capacity at c. 2080.

LLWR Ltd is also considering whether it could be possible – from an ESC perspective, whether it would be safe – to dispose a greater volume of LLW to the facility than is presently in the baseline plan. The aim is to examine whether, under defined assumptions regarding future waste treatment and diversion of low-activity LLW, the complete UK inventory of LLW, including predicted arisings from the UK nuclear decommissioning programme, could be accommodated at the LLWR. The additional vaults that would be required to dispose of LLW arisings beyond those associated with the baseline plan are referred to in the current study as the Extended Disposal Area.

This document presents the outcomes of studies exploring where on the site any such additional vaults might best be developed, and how the pre- and post-closure engineering for the facility could be optimised should the Extended Disposal Area be implemented. The siting and design optimisation outcomes are preliminary in nature, but sufficiently robust to meet their intended purpose. Alternative designs are presented, matched to alternative scenarios for potential future LLW arisings.

The main outcomes of the options studies reported are summarised below.

- If any additional vaults are to be implemented, the most suitable location is likely to be contiguous with the southern end of the trenches and the vaults planned in the existing reference design.
- The basic features of the design for any additional vaults should be essentially the same as in the 2011 ESC reference design.
- The vault bases and underlying passive drainage features could be developed at the same base level as Vault 14, in a manner consistent with site topography.

- ▲ The vault bases should be appropriately sloped to facilitate active leachate management via a system of sumps. Operational leachate from the southern end of the trenches should be collected separately and pumped directly to the marine holding tank.
- ▲ The maximum cap dome height for the reference design should be retained, with the profile of the cap extended to the south to accommodate any additional vaults. The different disposal volumes required for different inventory cases (with and without new nuclear build) can be addressed by minor changes to the profile slope within a broadly similar overall footprint.
- ▲ The cut-off wall should be implemented to a depth of four metres below the vault base slab (i.e. two metres deeper than in the reference design) around the south and east perimeters of the additional vaults, in order to provide confidence in containment against lateral inflows.

Contents

1 Introduction

LLW Repository Limited (LLWR Ltd) is undertaking a programme of work that will result in the publication of a new Environmental Safety Case by May 2011 (the 2011 ESC). The 2011 ESC will be submitted to the Environment Agency in support of a formal application for re-authorisation of disposal operations.

The 2011 ESC is based on a reference design described that assumes five additional vaults will be created in the future (i.e. Vaults 10 to 14) and that the facility will reach volumetric capacity at c. 2080 (LLWR, 2011a). Even under a programme of waste minimisation and treatment, coupled with the diversion of low-activity LLW, however, predictions of future arisings from the UK nuclear decommissioning programme indicate that this reference capacity will be insufficient to accommodate all future LLW disposal requirements (LLWR, 2011b). In addition, there is a strong likelihood that additional LLW will be generated as a result of any future new nuclear build programme.

LLWR Ltd is therefore considering whether it could be possible – from an ESC perspective, whether it would be safe – to dispose a greater volume of LLW to the facility than is presently in the baseline plan. Such a strategy (effectively involving the complete UK inventory of LLW, including predicted arisings from the UK nuclear decommissioning programme) would involve the creation of further vaults to be used for disposal of a significant additional proportion of future UK LLW arisings. In this document the additional vaults are referred to as the Extended Disposal Area, while the plan area associated with the reference design is referred to as the Reference Disposal Area.

An exploration of the potential design, capacity, and inventory that might be associated with implementation of the Extended Disposal Area is to be provided as a variant case within the 2011 ESC. An associated safety assessment will also be presented. The purpose of the variant case is to support planning for future LLW management in the UK. In particular, should such an extension to the lifetime and capacity of the LLWR be shown to be feasible, this could eliminate the need for another repository to accommodate anticipated future decommissioning wastes.

This document presents the outcomes of studies considering where on the site any additional vaults might best be developed, and how the pre- and post-closure engineering for the facility could be optimised should the Extended Disposal Area be implemented. The siting and design optimisation outcomes are preliminary in nature, but sufficiently robust to meet their intended purpose. Alternative designs are presented, matched to alternative scenarios for potential future LLW arisings.

The pre- and post-closure aspects of the reference design have been the subject of a significant optimisation study (LLWR, 2011c; Paulley and Egan, 2011). That study set out a range of principles and assumptions that led to the derivation of an overall strategy for engineering design, underpinned by assessments of the anticipated performance of the facility as a whole, and the functions of individual components. Many of the principles, assumptions, and indeed design assessments and decisions remain valid for the current work. The approach taken is therefore to consider which of the previous outcomes need to be changed as a result of the potential implementation of additional vaults, and how the design might be modified to optimise performance given those differences.

The report is structured as follows.

- ▲ Section 2 describes key objectives and assumptions for the study, and the process that was implemented to achieve those objectives.
- ▲ Section 3 presents the outcomes of an examination of alternative possible locations for development of additional Vaults on the LLWR site.
- ▲ Section 4 outlines the requirements and evidence considered in determining an optimised pre- and post-closure engineering design for the Extended Disposal Area.

2 Approach

2.1 Scope

The context for the study, and the scope and objectives of the optimisation work, were discussed at a workshop held in June 2010. The workshop involved participants from the LLWR ESC team and supporting contractor organisations. The agreed objectives, and other considerations relevant to framing the examination of alternatives, are presented below.

2.1.1 Objectives

The main objectives for the study were agreed as being:

- To identify the most suitable location on the LLWR site for the development of any additional vaults beyond those included in the reference design for the 2011 ESC.
- Given a preferred location and the volumes and characteristics of wastes likely to be disposed to such additional vaults, to identify a preferred, optimised design.

The siting and design assumptions determined in this way are intended to provide the basis for quantitative assessment calculations and other relevant analyses, examining whether such additional disposals could be shown to be achievable safely.

2.1.2 Additional Inventory

Assumptions regarding the additional volumetric disposal capacity likely to be required for the Extended Disposal Area are fundamental to the present study. The main ESC assessment calculations consider four main 'cases' of projected future waste arisings as the basis for determining the assumed disposed inventory (LLWR, 2011b). A summary of these cases is provided below.

- Case A (the reference case): projected LLW waste arisings are defined by the UK Radioactive Waste Inventory and WIDRAM'09 database, excluding those waste streams with identified alternative disposal routes and certain high-volume, low activity waste streams including Sellafield contaminated land.
- Case B: as for Case A, but including additional volumes according to representative estimates of wastes that might arise as a result of a future new build programme.

- Case C: examining the implications of introducing additional sorting and segregation measures, leading to disposal of the same radioactive inventory within reduced waste volumes (e.g. through more waste treatment or additional diversion of VLLW).
- Case D: taking into account the possibility that no wastes arising from the management of contaminated land are routed to LLWR.

The same cases also apply for the Extended Disposal Area. However, whereas in the main ESC assessment the disposed inventory was truncated by including only the proportion that could be accommodated up to Vault 14, the inventory assigned to the Extended Disposal Area corresponds to the total amount identified in the WIDRAM'09 database as being destined for LLWR, 'LLWR 2' or the deep geological disposal facility, but not included in the Reference Disposal Area inventory. Thus, for the Extended Disposal Area assessment it is assumed that the entire inventory associated with each case is considered for eventual disposal to the LLWR, not just that component that can be accommodated up to Vault 14.

For Case A, the total waste volume, a considerable fraction of which is from Stage 3 reactor decommissioning, could amount to an additional 294,000 m^3 beyond that defined for the Reference Disposal Area (requiring an additional 573,000 m^3 of total disposal volume once packing ratios and related factors are considered). Taking into account potential arisings from new build (Case B), the additional waste volume could rise to 374,000 m^3 (730,000 m^3 total disposal volume) beyond that assumed in the current reference development plan.

Performance assessment calculations for the main ESC examine the implications of all four inventory cases. In providing illustrative assessments of impacts that might arise from disposals to an Extended Disposal Area, it is considered that investigation of Cases A and B (assuming complete disposal of all relevant waste streams) is sufficient.

2.1.3 Location

One of the main framing assumptions for this work is the expectation that, if an appropriate case can be made, the disposal of future UK LLW arisings to an extended LLWR would be preferred over the development of a new repository at a different site. Examining the option of extending the operational life of the LLWR is also consistent with the objective defined in NDA's UK LLW Strategy to make 'best use of existing infrastructure'.

Consistent with that assumption, the current study is constrained to identification of a preferred location within the boundary of the LLWR licensed site. It is also assumed that the construction of additional near-surface disposal facilities would represent a natural extension of the LLWR's present mode of operation, and that optimisation of the pre- and post-closure design engineering design should be determined within such a context.

2.1.4 Required Footprint

An important component of the decision regarding a preferred location for possible future vaults is an understanding of the plan area likely to be required. This in turn requires judgements to be made regarding the likely stack heights of disposal containers, the depths of the vault bases and the profile of the final cap. The underpinning rationale for decisions made in the current study is reported in Section 3.

2.1.5 Design Constraints

A fundamental assumption underlying the identification of an optimised design for the facility incorporating an Extended Disposal Area is that the starting point should be the strategy developed for the reference development plan (LLWR, 2011a). Radical departures from the current design basis for disposal operations (e.g. alternatives to near-surface vault disposal) are therefore excluded, but the possibility is allowed that differences in site characteristics associated with alternative locations for new Vaults (e.g. topography and geology) may require modifications to be made. The question that frames the design optimisation aspect of the study is therefore:

> *What changes to the baseline design, if any, are necessary if further disposal vaults are to be developed at the chosen location?*

2.1.6 Assessment Requirements

The evaluation of alternatives for both the siting and design optimisation elements of the study is carried out in a manner consistent with the principles followed in the pre- and post-closure engineering optimisation study (Paulley and Egan, 2011). Thus, the aim is to explore whether significant benefits can be achieved in terms of confidence in the protection afforded against the main 'threats' to long-term isolation and containment of the hazards associated with the wastes (from coastal erosion, groundwater, gas, and human intrusion), balanced against practicalities, including cost.

In order to avoid decisions being biased towards more conservative engineering solutions, the comparison of alternative locations and designs needs to be based on 'realistic' (i.e. not pessimistic) assumptions, as in the analyses undertaken to support the optimisation study for the reference design. This requires high-level qualitative analyses of potential threats and their impacts, underpinned by appropriate quantitative studies to examine more detailed issues (e.g. based on existing or updated hydrogeological model calculations).

2.1.7 Engagement

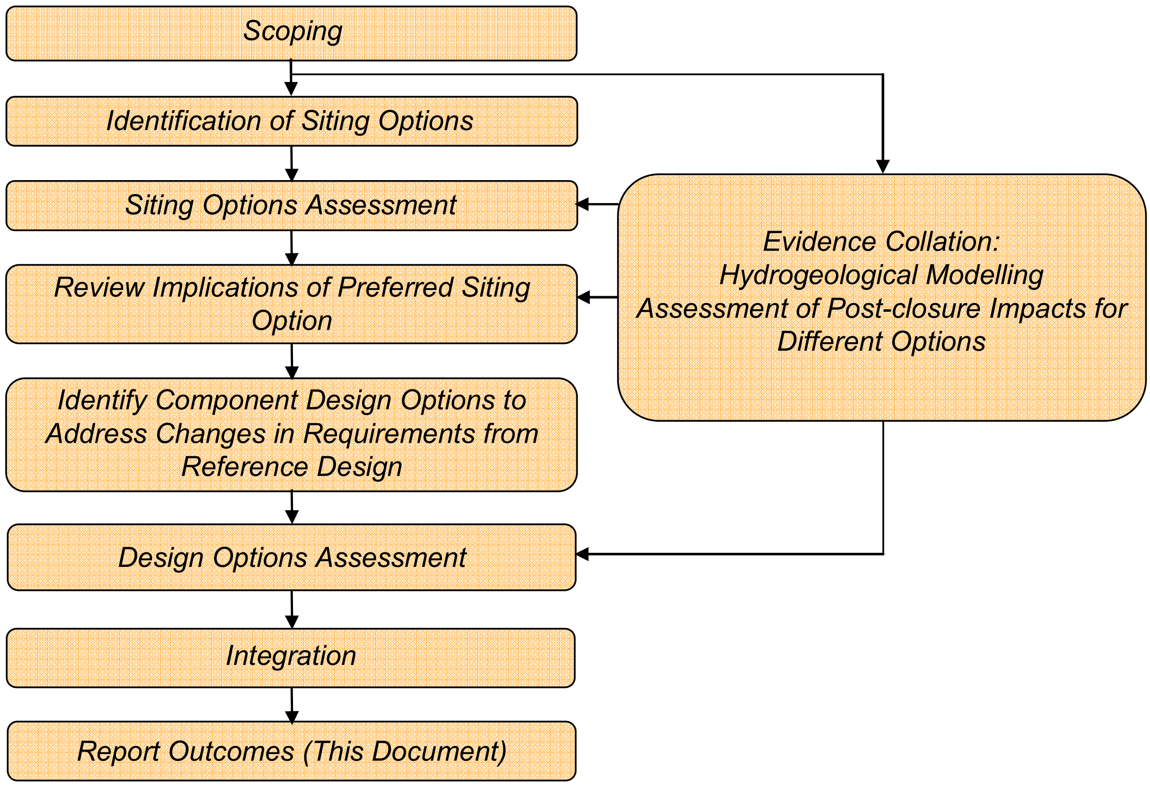
The engineering optimisation programme for the reference design incorporated a number of steps in which the views of various stakeholders were sought (Paulley and Egan, 2010). For the present study, it was agreed that no additional engagement activities would be required. This is because:

- The purpose of the variant case is to explore feasibility and guide strategic planning.
- The engagements undertaken for the main engineering optimisation programme included a particular focus on scoping and process. The principles agreed during these engagements are considered to be equally applicable to the current study, even though some of the framing considerations are different.
- Should it be decided to pursue further the possibility of extending the size of the facility beyond that defined in the reference design, a formal programme of design optimisation and engagement would be undertaken at the appropriate time.

2.2 Process

The process developed to address the above objectives and constraints is illustrated in Figure 1.

Figure 1: Evaluation Process Implemented for the Extended Disposal Area Optimisation Study



The main elements of the process are outlined below.

Scoping

This phase concerned the identification and agreement of the main objectives, requirements, assumptions and constraints that apply to the study, and the process required to address them (as summarised here).

Identification of Siting Options, and Siting Options Assessment

The next step involves identifying a preferred location on the LLWR site for developing the additional disposal capacity required for the extended inventory. Process requirements include:

- Identification of potential alternative locations for new vaults within the LLWR licensed site boundary.
- Evaluation of the potential footprint of the vaults against the identified alternative locations, taking into account the plan area and possible implications for design.
- Assessment of whether there are likely to be any significant differentiators between siting options from the perspective of providing confidence in the effective isolation and containment of the hazards associated with the wastes.
- Assessment of whether there are any potential differentiators between siting options from the perspective of other evaluation criteria (health and safety, technical feasibility, community and socio-economic factors, cost).
- Consideration of the relative advantages and disadvantages of alternative siting options to inform the choice of a preferred location.

Review Implications of Preferred Siting Option, Identify Component Design Options to Address Changes in Requirements from the Reference Design, Design Options Assessment

The next steps are concerned with design optimisation, taking into account any significant characteristics of the preferred location and other requirements associated with developing additional disposal vaults. This includes:

- Identification of any deviations from the reference design strategy adopted for the ESC that might be required due to the characteristics of the chosen location (topography, water table height, groundwater flows, required cap profiles etc).
- Development of a clear rationale for any required changes to the design. If more than one option is identified for how a particular component of the pre- or post-closure engineering might be implemented, the advantages and disadvantages of different options need to be considered against the principles discussed above (i.e. consideration of any differentiators associated with providing isolation and containment, balanced against any practicability-related differentiators).

Integration, Report Outcomes

Finally a clear justification of the preferred design needs to be produced, reviewed and agreed as being appropriate to the overall purpose of the Extended Disposal Area environmental safety assessment. The outcomes and underpinning rationale then need to be reported (as presented in this document).

3 Identification of Preferred Location for Additional Vaults

3.1 Potential Footprint of the Additional Vaults

The estimated footprint required for developing any additional vaults needs to be defined in order to guide the identification and assessment of alternative location options. A number of factors inform this requirement:

- The required disposal volumes of the additional waste streams under consideration.
- Consideration of whether any of the additional wastes could be accommodated by higher stacking on top of existing wastes, above and beyond the approach to stacking adopted for the 2011 ESC reference design.
- The depth of the bases of any additional vaults, and whether they could be set at a level that might facilitate higher stacking without increasing the overall elevation of the final cap.
- Consideration of alternative options for the cap profile that could be implemented.

These issues were discussed in detail at a workshop held in June 2010 involving LLWR staff and contractors. The following outcomes were agreed.

Cap height

The pre- and post-closure engineering optimisation study to support the reference design for the 2011 ESC (Paulley and Egan, 2011) made the assumption that the cap would be designed to have the minimum height required consistent with the profile needed to ensure long-term effective water-shedding. The study also concluded that wastes could potentially be stacked greater than four containers high within the profile beneath the engineered cap, provided that this did not compromise environmental safety performance. However, sensitivity to the visual impact presented by the closure engineering requires that the overall cap height should not be raised in order to accommodate more wastes.

It was agreed that the current study should draw on the same principles as those adopted in defining the reference design. This excludes the option of raising the proposed cap height and undertaking additional higher stacking in order to reduce the footprint of the Extended Disposal Area.

However, if the Extended Disposal Area were to be developed contiguously with the existing reference design, at the southern end of the trenches and planned future vaults, the associated extension to the planned cap profile would enable additional higher stacking of waste containers within the currently planned Vaults. Some of the additional inventory could therefore be disposed of within the Reference Disposal Area, rather than to the additional vaults, thereby reducing the required footprint. The precise proportion of the additional inventory that could be accommodated in this way will vary according to the detailed cap profiles associated with different inventory cases.

Depth of vault bases

The possibility of implementing significantly deeper bases for future Vaults 10-14 was considered in the main pre- and post-closure engineering optimisation study (Paulley and Egan, 2011). This was rejected as having disadvantages that outweighed any benefits that might be achieved, for reasons including those listed below.

- ▲ The base of the vaults and the underlying drainage layer would be much closer to, or even potentially within, the regional groundwater table, and thus it would be difficult to establish the desired 2 to 3m depth of unsaturated zone beneath the facility.
- ▲ The primary aim of developing a deeper vault base would be to facilitate very high stacking within an acceptable final cap profile. This could present significant concerns regarding operational stability, and would be likely to enhance the degree of settlement occurring post-emplacement.
- ▲ Inter-vault and operational drainage might also be adversely affected.

It was agreed that these conclusions were equally appropriate to the current study, and that the option of accommodating the additional wastes within a smaller footprint by creating deeper additional vaults with higher stacking should be excluded.

Stacking of containerised waste above the Trenches

A further option, involving the development of a loading platform on top of the trenches and then stacking disposal containers on top of that platform within the cap profile, was also considered in the optimisation study for the reference engineering design. However, the option was rejected as it was considered that the associated effects of additional loading on the trenches would be unclear. For example, enhanced settlement could occur, potentially leading to a lack of stability within the containerised waste stack, or threats to the slope and integrity of the cap. In addition, the drainage arrangements associated with two separate levels of waste disposal could prove to be complex.

It was agreed that these conclusions were equally relevant to the present study and that the possibility of accommodating the additional wastes within a smaller footprint through stacking of containerised wastes on top of the trenches should be excluded.

Summary

The above arguments indicate that the vault base depth and cap profile for the extended facility should be consistent with the principles utilised to determine the design strategy for the Reference Disposal Area. In addition, the possibility of disposing containerised waste to a loading platform built over the trenches is excluded.

3.2 Identification of Siting Options

For the two indicative inventory cases explored in the current study, the total required disposal volume associated with developing an Extended Disposal Area is estimated to be 573,000 m^3 (Inventory Case A) and 730,000 m^3 (Inventory Case B) (see subsection 2.1.2 above). The plan area of the additional vaults required to accommodate such volumes, given the assumptions on cap profile and base depth defined above, is sufficiently large to limit significantly the number of siting options on the LLWR site.

Figure 2 shows a plan view of the LLWR nuclear licensed site, showing two areas that present the most obvious alternative locations for the development of additional vaults. The plan shows estimated disposal facility and associated cap footprint areas for these two alternative locations (based upon detailed considerations of required volumes, base depths, cap profiles etc), for the Case A inventory.

The rationale for these two siting options identified is as follows.

Although it is possible to re-route surface water features (e.g. the Drigg stream has been re-routed in the past, and it is planned that its course should be further altered when the Vaults 10-14 are built and the final cap emplaced (LLWR, 2011a)), it does not seem credible to consider developing any new vaults directly over the area through which the East-west stream currently runs. The stream follows a line through the middle of a shallow natural valley and provides an outflow for the Drigg stream. Substantial re-routing to avoid interaction with any engineered facility developed on this area would require extensive alteration to the site landscape.

There is no obvious rationale to suggest that siting options involving re-routing the East-west stream would have advantages over alternative siting options from the perspective of providing assurance in long-term isolation and containment. Indeed, it is likely that vaults founded on the lowest part of the site would be more vulnerable than other locations to inundation by flooding resulting from changes to surface hydrology and regional groundwater levels associated with global sea-level rise. Given its other disadvantages (in terms of requirements for landscape engineering) it is therefore considered appropriate to screen out such a location from further consideration. The locations available for additional vaults are therefore reduced to two main options: on land to the north-west or south-east of the East-west stream.

A location to the north-west of the East-west stream would place the new facility to the immediate south-east of the trenches and the proposed location of future Vaults 10-14. There is no obvious advantage to be gained from implementing an independent structure in this area, as it would entail additional cost (compared with a contiguous development) with no clear technical benefit. For example, a 'detached' disposal area would effectively require the creation of a two-dome 'gull-wing' design for the overall facility, with less scope for using the profiling volume under the cap to accommodate waste disposal. It is therefore reasonable to assume that any further vaults to be built in the general area to the north-west of the East-west stream would be constructed such that they were contiguous with the reference design, both in order to simplify capping arrangements and to take advantage of commonalities in requirements for drainage etc. This option is marked as S1 on the schematic plan in Figure 2.

In order to accommodate the footprint of the Extended Disposal Area on land to the south-east of the East-west stream, consideration has to be given to development constraints associated with other site features (in particular the boundary of the licensed site, the railway sidings and the course of the East-west stream). Indeed, if such features (alongside other constraints on vault depth and cap height) are taken to provide rigid restrictions on development, the maximum disposal volume that could be accommodated (within the plan area indicated by S2 in Figure 2) would be only 430,000 m^3, compared with the 573,000 m^3 required for Inventory Case A. Figure 3 therefore shows an alternative footprint, illustrating what would be required in order for S2 (i.e. a system of disposal vaults to the south-east of the East-west stream) to accept all of the required Case A wastes.[1]

Figure 4 illustrates the increase in the S1 and S2 footprints associated with planning to accommodate waste disposals for Inventory Case B. In the case of S1, the plan area changes very little as most of the additional volume can be accounted for via adjustments to waste stacking profiles. Engineering constraints governing the stability (and therefore gradient) of the cap profile then result in a slightly larger cap footprint.

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[1] The schematic illustration shows the toe of the cap extending beyond the existing licensed site boundary to the south of the site. Alternatively, a more irregular shape of footprint could potentially be accommodated by extending into the south-eastern corner of the site. For simplicity, such an option has not been considered here – it does not affect the broad conclusions of the study.

Figure 2: Map of the LLWR, showing the licensed site boundary and topography (after BNFL, 2002; original reproduced from the Ordnance Survey map by permission of the Ordnance Survey), with the potential locations and geometries for additional vaults marked as S1 and S2. Geometries correspond to that required for Inventory Case A, except for S2, for which the footprint is allowed to be constrained by site features.

Figure 3: As for Figure 2, except that S2 dimensions are increased to indicate required footprint to accommodate all Case A inventory wastes

Figure 4: As for Figure 2, except that S1 and S2 dimensions are both increased to indicate required footprint to accommodate all Case B inventory wastes

3.3 Comparison of Siting Options

A systematic assessment of the advantages and disadvantages of the alternative siting options for an Extended Disposal Area was undertaken. The criteria were chosen to be consistent with those used to support assessments of component options for the main pre- and post-closure engineering design optimisation study (Paulley and Egan, 2011).

- Health and safety-related criteria (Worker Safety, Public Safety).
- Impact on the Environment (Habitats/Construction, Authorised Discharges, Operational Environmental Impact, Post-closure Impacts, Non-LLW Waste Volumes, Resource Use).
- Technical Factors (Ease of Implementation, Confidence in Performance, Timescales for Implementation, Impact on Operations, Flexibility, Impacts on Existing Engineered Features, Capacity).
- Community and Socio-economic Factors (Impacts on Local Community, Support for Local Community).
- Cost (Total Implementation Cost, Affordability).

The evaluation was undertaken through two workshops involving LLWR staff and contractors during the summer of 2011, in which participants considered the extent to which such criteria represented potentially significant differentiating factors between the two locations. The agreed outcomes are presented in Table 1 and Table 2.

Table 1: Identification of differentiating factors between alternative locations

Criteria Group	Notes on Option Differentiation
Health and Safety	The siting options both involve the same volumes of wastes and similar scales of operation, but the extent of construction activities and the material volumes involved would tend to be larger for the S2 location. Nevertheless, good construction and operations practices should mean that conventional health and safety considerations would not be significant at either location, and this should not therefore represent a significant differentiating factor between options.
Impact on the Environment	*Operational and post-closure impacts are discussed separately in the specific discussion presented in Table* 2. There should be little differentiation between options from the perspective of operational discharges, as both would involve similar volumes of wastes and would involve similar engineering measures that would influence discharges. A potential concern in relation to location S1 is that the relevant area is typically used as a nesting site by great crested newts. Relocation of the population to another favourable area could be considered, as happens with other types of construction project; nevertheless, this represents a potential disadvantage of S1. The likelihood of impact from construction on other species at either location is considered to be very low. The option involving extension of the Reference Disposal Area footprint, with a contiguous cap and cut-off wall (S1), could be expected to require less material resource than the alternative (S2), which would not share any engineering features with the existing facilities. The overall footprint for location S1 is also likely to be smaller (see Section 3.1). From this perspective, therefore, the assessment slightly favours option S1. It is conceivable that contaminated land might be encountered when developing new vaults at either location, due to the industrial history of the site. However, it is considered more likely to affect the S2 location, due to its larger footprint and because of the ROF operations known to have been undertaken in that vicinity in the past. Assessment against this sub-criterion therefore also slightly favours S1.
Technical Factors	This group of criteria considers factors relevant to confidence in implementation and performance of the disposal facility, its engineering, and its operations. Analysis of the two siting options against most of the sub-criteria in this group does not reveal any clear differentiation. However, an important consideration is that it would be very difficult to provide the required capacity at S2 without extending the required cap footprint over the East-west Stream or the railway sidings, unless a significantly deeper excavated construction were developed (see Figures 2 to 4). ▲ The East-west stream is a more significant landscape feature than the Drigg Stream, which by comparison is effectively a minor drain. Re-rerouting the East-west stream would introduce additional technical complexity, with a risk that the changed course may not prove stable to long-term meander, thereby reducing confidence in system performance. Moving the railway sidings from their current location in order to accommodate the Extended Disposal Facility would also potentially represent a significant inconvenience and expense. ▲ Creation of a much deeper base structure would also be problematic. In particular, it would be likely to violate the design aim of keeping the wastes unsaturated and maintaining an unsaturated zone beneath the vault base for as long as practicable (see Section 3.1).

	Such arguments represent a clear differentiation in favour of S1, which would not require any disturbance of the East-west Stream or the railway sidings, or necessitate substantially deeper construction to accommodate the required waste volumes under a suitable cap profile. As noted in Section 3.1, the S1 location would also enable the efficient exploitation of disposal volume in the profile of the final cap. The profile gradient for the 2011 ESC reference design extends significantly beyond the currently planned vaults. With a comparatively small change in final gradient, this would allow vaults to be constructed underneath the cap that would be sufficiently large to accommodate all the Extended Disposal Area wastes. A number of detailed design issues were identified that would need to be resolved in relation to development of the S1 site. In particular, there might be a requirement for a deeper cut-off wall in the vicinity of the additional vaults given the relatively low elevation of the vault bases and proximity to the water table. Overall, however, participants felt that these technical issues would present less of a technical challenge than the creation of a 'separate' facility at location S2, for the reasons outlined above. Furthermore, the creation of a separate facility could potentially have implications for timescales. For example, the development of a facility with a separate engineered cap, rather than just an extension of a structure already scheduled for construction, might lead to extended timescales for final closure. However, as the final wastes are scheduled to be disposed beyond 2100 (i.e. tens of decades after disposals to earlier vaults have been completed), such a difference in timescales may not be significant. The above arguments are based on comparisons of facility footprint requirements for Inventory Case 'A'. The same arguments apply to other inventory cases, but the differences between locations would be magnified where higher disposal volumes are involved.
Community and Socio-economic Factors	In terms of visual impact, the differentiation between options is that between an 'extended' version of the cap planned for the Reference Disposal Area and a separate new dome elsewhere on the site. It is considered that extension of the planned cap for the 2011 reference design would probably represent a lower intrusion than the creation of an entirely new dome, therefore favouring the S1 location. Most of the factors associated with potential impacts on, and support for, the local community would be an important element in any construction and operational planning, but do not appear to provide strong discriminating arguments between siting options. Both options involve a similar level of construction and would occur for a broadly similar length of time. Materials imported to the site would be primarily transported by rail. The main differentiating factor is that extension of the existing footprint (S1) may involve reduced material usage and hence fewer transports.
Cost	The above discussions suggest that the cost of developing S1 as the Extended Disposal Area would be less than that for S2. S1 would involve a contiguous development of the existing facility, whereas S2 requires a separate facility to be constructed, involving greater material volumes and the potential need to re-route or otherwise engineer around the East-west Stream and railway siding.

Table 2: Operational and post-closure environmental impact differentiators between alternative locations

Threat	Notes on Option Differentiation
Impacts from the Groundwater pathway	As it was considered that caps can be constructed for either option that would meet performance objectives (i.e. to minimise infiltration and hence waste saturation) in tandem with the cut-off wall or any equivalent structure required for 'detached' vaults, there should be no major differentiation in terms of impacts associated with the groundwater pathway for the period during which there is confidence in engineering performance. However, an analysis of the local hydrogeological conditions (Hartley, 2010) suggests that there are some advantages associated with the S1 location in terms of receptors for contaminants transported via groundwater. In particular, although groundwater pathways to the sea are likely to be similar for both S1 and S2, there is an indication (based on the observation of lower heads at the south of the site) that a pathway may also exist from S2 to the Irt Estuary.
Impacts via the Gas Evolution pathway	For both siting options, the inventory would be geochemically isolated from other disposals. The only differentiation here therefore concerns the pathlength and release profile for any evolved gases from the combined inventory. ▲ Assuming that the cap can be engineered to ensure a sufficient (similar) Rn-222 diffusion length for both options, assessments for this component of the inventory are unlikely to differentiate between S1 and S2. ▲ For C-14, assuming that diffusion is the main gas transport/exposure mechanism of interest and that the cap design for each location is similar in terms of layers and thicknesses, the only difference is that the 'detached' (S2) option would tend to involve a greater surface area for release. The extent to which this could be considered a differentiating factor depends on the precise approach taken to estimating doses and comparing with regulatory risk guidance criteria. Overall, this is expected to be a minor issue compared with other potential differentiating factors.
Impacts via Human Intrusion	Provided that engineering can be designed and implemented at either location sufficient to ensure a suitable distance between the cap surface and the surface of the waste, the human intrusion pathway is unlikely to offer a differentiating argument. However the cost implications of achieving this requirement may differ between siting options.
Impacts via Coastal Erosion	There are some differences between siting options for this potential exposure pathway. ▲ The S2 option would involve a higher proportion of engineered material to waste, which will tend to affect erosion and dispersion processes. ▲ The S2 option is further from the current shoreline, which may have implications for the mode of disruption. ▲ Distance from the shoreline could also influence the timing of disruption, but this has only a limited effect on calculated peak impacts, as the difference in distance is not very large (equivalent to a difference in timing of perhaps a hundred years or so) and the contaminants of interest tend to be very long-lived (e.g. C-14). Overall there is no clear argument for substantive differentiation in performance from the perspective of coastal erosion.

3.4 Preferred Siting Option

The main outcomes of the siting analysis were agreed as follows.

- Other than the potential requirement to re-locate a nesting site for great crested newts, no advantages of the S2 option over S1 were identified.
- A number of potential disadvantages of the S2 site compared with S1 were noted, some of which (particularly in relation to technical feasibility) were judged to be significant.

The analyses reported here are high-level in nature and are not supported by detailed cost engineering studies or comparative assessments of potential radiological impact. Nevertheless, workshop participants concluded that the outcomes were sufficiently robust to underpin a firm conclusion.

Participants therefore agreed that, for the purposes of the current study, siting option S1 (development contiguous with the southern end of the trenches and the vaults planned in the existing reference design) should be taken forward as the assumed preferred location for any additional vaults.

4 Pre- and Post-closure Engineering Design Optimisation

4.1 Key Differences in Design Requirements for the Extended Disposal Area

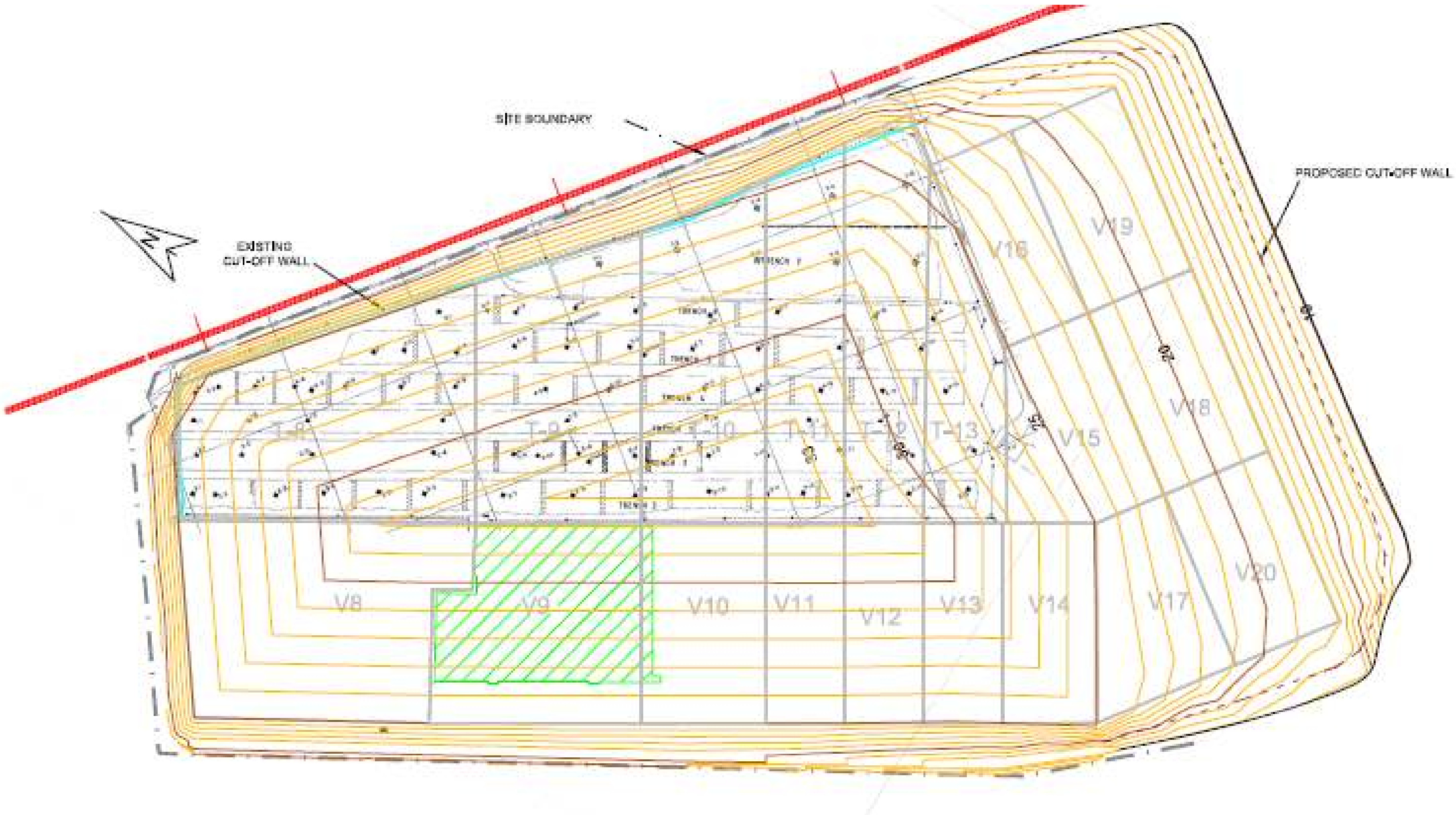
Given the identification of location S1 as the likely preferred option for developing an Extended Disposal Area, the next stage in the study was to examine design optimisation considerations for any further vaults that might be developed.

The first step in that process is to consider the basic vault layout, illustrated in Figure 5. This illustrates a compartmental system based on six additional vaults (Vaults 15 to 20), adjoining the southern end of the trenches and the proposed future Vault 14. The total plan area is consistent with that required to accommodate the additional wastes from inventory Case A within a suitable final cap profile. Engineering estimates (Tonks, 2010) indicated that only minor changes to the footprint would be required to accommodate Case B wastes (involving lateral extension by up to a few tens of metres and/or comparatively minor changes to the cap profile) and so this basic layout was used to underpin all the main design optimisation judgements.

As noted in Section 2.1.5, the approach taken in examining design optimisation considerations for the Extended Disposal Area is to identify what changes to the baseline design strategy may be necessary for the additional vaults in order to account for changes in site characteristics at the preferred location (e.g. topography and underlying geology). Having considered the wider implications of any such differences, an updated, optimised pre- and post-closure engineering design can then be identified. In assessing alternative to the reference design, options need to be assessed against the same principles and criteria used in the previous optimisation study (Paulley and Egan, 2011), with a particular focus on the threats to environmental safety performance associated with potential future release and exposure pathways.

A number of potential requirements for changes to the reference design were noted and mapped against differences in site characteristics associated with Extended Disposal Area. Key considerations are listed below.

Figure 5: Schematic layout showing potential additional vaults and the possible cap profile for inventory Case A



- **Surface topography.** The LLWR site slopes downwards towards the south, where the local topographic low is defined by the course of East-west stream (Figure 3). The design of any additional vaults (e.g. in terms of their base level, as well as active and passive drainage systems) will need to take into account differences in surface topography compared with that in the reference design.

- **Underlying geology, including the effective drainage capacity underlying the additional vaults, and the height of the vaults above the water table.** It is important to consider whether the strategy of achieving essentially unsaturated conditions in the waste column for as long as possible, coupled with the under-slab drainage blanket concept, associated with the 2011 ESC reference design (LLWR, 2011a) will be appropriate given differences in the underlying geology and the elevation of the vault bases above the regional water table.

- **Interactions between the southern end of the trenches and the additional vaults.** Developing the Extended Disposal Area as a contiguous extension of the existing facility means that the additional vaults would interface with structures at the southern end of the trenches. The southern end of the trenches may need additional stabilisation, for example with a secant pile wall (as constructed to the west of Trench 3 in the reference design), to support the integrity of the trenches during excavation and construction of additional vaults. There might also be the potential for flows from the south of the trenches into the new vaults (e.g. prior to construction of the final cap), the management of which would need to be considered in detailed design.

- **Operational leachate management requirements for the trenches.** Operational leachate from the trenches is currently drained at the southern end of the facility for routing to the marine holding tank. Additional vaults would be constructed at this location, and their design would therefore need to facilitate the continued management of trench leachate, as well as supporting any decommissioning requirements for the operational leachate management system at final closure.

- **Operational and passive leachate management requirements for the vaults.** The design of future vaults associated with an Extended Disposal Area would need to incorporate a suitable approach to operational leachate management and passive post-closure leachate management, without breaching the principles and overall design philosophy associated with the 2011 ESC reference design. Put another way, an optimised design for leachate management within the Extended Disposal Area needs to be effectively integrated with that defined for the Reference Disposal Area.

4.2 Evidence Sources

Two key evidence sources were used in order to explore the potential implications of each the above issues for design optimisation. These were:

- A range of **detailed design drawings** showing alternative approaches for the design of additional vaults within the Extended Disposal Area (Tonks, 2010; 2011).
- A number of detailed **hydrogeological model calculations**, exploring potential engineering design issues and solutions from a water management perspective (Couch and Hartley, 2010).

4.3 Assessment Outcomes

The key design considerations identified above and the outputs of the design and hydrogeological modelling analyses were systematically considered through a series of expert workshops held during the summer of 2010. Participants were drawn from the core LLWR team and supporting contractor organisations. The process concluded with a 'decision workshop' held on 13th September 2010. Through these meetings, participants considered whether the evidence base relating to a hypothetical Extended Disposal Area indicated whether or not modifications would need to be made to the strategy underlying the 2011 ESC reference design. Participants then sought to identify the best practicable option for resolving each issue, by systematically considering the advantages and disadvantages of each identified option.

Key outcomes from the assessment are summarised below.

Vault layout and geometries

It was agreed that the vault layout illustrated in Figure 5 should be taken forward as the basis for design optimisation, based on the outcomes of the siting study (Section 3) and to assist in assuring consistency of approach with the reference design. In addition, the basic design characteristics of the additional vaults (base and wall construction methods and materials, wall heights, passive drainage system etc) should be as defined for the reference design.

The elevation of additional vault bases with respect to ground level will need to be consistent with surface topography in S1, which means that they will be installed to the same base level as Vault 14). The under-slab passive drainage system will mirror the surface topography. Apart from these changes, the vault base and passive leachate management features should be consistent with the strategy adopted in the reference design.

The vault identification numbers shown in Figure 5 for the Extended Disposal Area present the likely order of construction and operation, and are used in the safety assessment as a reference point for estimating potential inventory distributions, etc. However, the overall layout offers a degree of flexibility to vary the sequence in which the facility might be developed, if that subsequently proves to be beneficial.

Cap profile

It was agreed that the most appropriate approach to defining the cap profile would be to extend the single dome defined in the 2011 ESC reference design (LLWR, 2011a) over the additional vaults, effectively by adopting a more gentle gradient towards the southern end of the facility (Tonks, 2010; 2011). The additional volume that would be required to accommodate inventory Case B could be accommodated within the same Extended Disposal Area by slightly higher profiling and associated higher stacking. Engineering constraints governing the stability (and hence the gradient) of the cap profile would then mean that the 'toe' of the cap would necessarily extend further towards the south beyond the additional vaults.

Stabilising wall at the southern end of the trenches

It was agreed that there would be a need for a stabilising wall to be implemented at the southern end of the trenches, along the line of excavation required to develop the additional vaults. A secant pile wall (similar to the wall that separates the Trench 3 from the ESC vaults in the 2011 ESC reference design) would be likely to be appropriate for this purpose. The wall would be designed with a structural function only, i.e. it would probably not include an impermeable liner.

Active leachate management arrangements

The basic approach to active leachate management for the additional vaults would be similar to that for the reference design. Thus it is assumed that there will be small north-to-south and west-to-east falls associated with the vault base slabs, in order to direct run-off collected during operations towards pumped leachate sumps at the outer perimeter walls of the Extended Disposal Area. Specific arrangements would need to be made for Vault 15, which would have no perimeter wall by the time that disposal operations were completed (see Tonks, 2010, 2011).

Leachate from the trench gravity drainage system could be connected to sumps adjacent to the stabilising secant pile wall, and pumped from there directly to the marine holding tank. An alternative approach was also identified whereby trench leachate could be collected via the vault drainage system, where it would mix with the vault leachate and be managed accordingly. No significant differentiation was drawn between the two options from an overall performance perspective, but the former approach was considered to be preferred as it facilitates ongoing separate monitoring of leachate from the trenches and the vaults systems.

It is assumed that leachate pumping will continue during post-closure management of the facility, but will eventually cease at an agreed time. The system would then be sealed and any subsequent infiltration of water into the vaults will be controlled by the engineered passive leachate management system.

Cut-off wall

Options for the cut-off wall were the subject of particularly detailed discussion and analysis, supported by the outcomes of hydrogeological modelling exercises exploring the potential benefits and disadvantages of different approaches.

The optimisation study for the reference design (Paulley and Egan, 2011) examined whether a complete encircling cut-off wall is required, and the implications of extending such a wall to different depths. The primary function of such a cut-off wall was identified as being to prevent the lateral infiltration of water (including water shed by the cap) into the vault and trench wastes around the edges of the repository. It also has a contingency role in providing reassurance against the possibility of near-surface release close to the facility in the unlikely event of early cap failure (leading to possible saturation of the waste column), or as a result of preferential pathways for leachate that might arise as a result of higher waste stacking. The cut-off wall will be keyed into the perimeter of the cap, to preclude the possibility of over-topping in the event of saturated conditions within the wastes.

Expert elicitation and hydrogeological modelling undertaken for the reference design suggested that there is advantage to be gained from installing a cut-off wall, in terms of the confidence it provides in environmental safety performance of the disposal system. However, such studies also showed that there were no significant benefits to be gained from taking the wall to a depth greater than 2m below the underside of the composite basal liner to the vaults, or from including a geomembrane within the wall. Such a design is consistent with the existing cut-off wall, constructed in the 1990s along the northern and eastern perimeter of the trenches. Subject to ongoing monitoring showing no grounds for concern in the performance of this feature, it is expected that the existing cut-off wall can be incorporated into the overall perimeter barrier for the reference design.

For the Extended Disposal Area, analyses focused on whether the geometry and construction method proposed for the reference design would need to be modified in order to ensure that the cut-off-wall continued to provide the required functions in the light of the layout and geometries proposed for possible additional vaults.

In discussion, it was noted that the geology underlying the Extended Disposal Area implies that the natural drainage capacity of the system in this area will be broadly similar to that for the reference area, owing to the relative thickness of the B2 and B3 layers. The natural geology associated with S1 will therefore tend to act to support the roles of the passive drainage and cut-off wall features in the vault design. The main issue for consideration in design optimisation relates to the anticipated proximity to the water table of the vault bases (and hence the passive drainage system) that would be constructed in this area, as the additional vaults would be implemented to a lower base level than for the Reference Disposal Area (excepting Vault 14). This proximity and the influence of topography means there is also an enhanced potential for lateral inflows into the lower part of the repository. In the hydrogeological model runs for central estimate parameters (Couch and Hartley, 2010), this resulted in a much reduced thickness of unsaturated zone under the Extended Disposal Area vaults.

It was agreed, therefore, that the reference cut-off wall design gives less confidence that the Extended Disposal Area vaults will remain substantially unsaturated for a prolonged period of time post-closure than is the case for the Reference Disposal Area. For example, if the actual rates of infiltration (or other parameter values) proved to be 'worse' than the elicited central estimates, there might be no unsaturated area at all underneath the vaults, the drainage blanket could cease to function as designed and the Vaults may become saturated to above the 1m level.

Alternative hydrogeological model calculations incorporating a deeper cut-off-wall (Couch and Hartley, 2010) were also discussed. In these runs of the model, the cut-off wall was extended by an additional two metres in depth (i.e. to 4 metres below the basal liner). These calculations indicated that such a deeper construction would be sufficient to substantially reduce lateral infiltration from the south and east into the area immediately underneath the Extended Disposal Area. It would therefore enable the sub-base drainage blanket to perform its designated function and thereby offer an increased level of assurance regarding the prolonged maintenance of unsaturated conditions within the waste column.

More detailed analysis was then undertaken to examine whether it would be necessary to implement the cut-off wall to this additional depth along the entire perimeter of the

Extended Disposal Area in order to achieve this level of confidence. This is because the main concern relates to the potential for lateral infiltration due to topographical differences in certain areas of land adjacent to the Extended Disposal Area. Analysis of the additional hydrogeological modelling results indicated that an increase in the depth of the cut-off wall to the south and east sides of the Extended Disposal Area would be sufficient to achieve this. No such protection is required for the Reference Disposal Area, as the vault bases and drainage blankets are generally at a higher elevation.

At later times post-closure, when it is assumed that sea-level could rise significantly above current levels, with associated impacts on regional groundwater levels and coastal erosion in the vicinity of the facility, the Extended Disposal Area vaults (and subsequently the Reference Area equivalents) may become saturated (Couch and Hartley, 2010). However, given the timescales involved, and the expectation that the disposal vaults will begin to be eroded on a timescale of a few hundred to a few thousand years (with consequent disruption of the repository), it was judged that no changes to the design of the cut-off wall would realistically be merited with the aim of preventing such saturation from occurring.

As a result of this analysis it was agreed that the basic design for the cut-off-wall should be carried forward in the safety assessment, but that it should be assumed to be constructed 2 metres deeper than as defined for the 2011 ESC reference design around the south and east sides of the Extended Disposal Area (i.e. to 4 metres below the depth of the basal liner). This was considered sufficient to provide confidence for a suitable period of time that the additional vaults will be protected from lateral inflows.

4.4 Summary

In summary, the following outcomes were agreed.

- The basic features of the design for any additional vaults should be essentially the same as in the 2011 ESC reference design.
- The vault bases and underlying passive drainage features could be developed at the same base level as Vault 14, in a manner consistent with site topography.
- The vault bases should be appropriately sloped to facilitate active leachate management via a system of sumps. Operational leachate from the southern end of the trenches should be collected separately and pumped directly to the marine holding tank.

- The maximum cap dome height for the reference design should be retained, with the profile of the cap extended to the south to accommodate any additional vaults. The different disposal volumes required for different inventory cases (with and without new nuclear build) can be addressed by minor changes to the profile slope with a broadly similar overall footprint.

- The cut-off wall should be implemented to a depth of four metres below the vault base slab (i.e. two metres deeper than in the reference design) around the south and east perimeters of the additional vaults, in order to provide confidence in containment against lateral inflows.

Tonks (2011) presents engineering drawings as detailed illustrations of the optimised designs corresponding to the two inventory cases. Appendix A provides a summary of the total volumetric capacities of any additional vaults given specified layouts.

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Appendix A: Potential Future Vault Capacities

Table A1 below provides a summary of the total disposal ('air space') capacities of the additional vaults, mapped against the two inventory cases of relevance (Tonks, 2010 and 2011). The vault numbers correspond to the layout presented in Figure 5 in the main text.

Table A1: Potential air space capacities of additional vaults (m^3)

	Inventory Case A	Inventory Case B
Vault 15	153000	202000
Vault 16	98000	148000
Vault 17	122000	136000
Vault 18	72000	83000
Vault 19	67000	83000
Vault 20	61000	78000
Total	***573000***	***730000***