# Optimising the Performance of the Low Level Waste Repository - 12144

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## ABSTRACT

The Low Level Waste Repository (LLWR) is the United Kingdom's principal facility for the disposal of low-level waste (LLW). The LLWR made a major submission to its environmental regulator (the Environment Agency) on 1st May 2011, the LLWR's 2011 Environmental Safety Case (ESC). One of the key regulatory requirements is that all aspects of the construction, operation and closure of the disposal facility should be optimised.

An optimised Site Development Plan for the repository was developed and produced as part of the ESC. The Site Development Plan covers all aspects of the construction, operation and closure of the disposal facility. This includes the management of past and future disposals, emplacement strategies, design of the disposal vaults, and the closure engineering for the site. The Site Development Plan also covers the period of active institutional control, when disposals at the site have ceased, but it is still under active management, and plans for the long-term sustainable use of the site. We have a practical approach to optimisation based on recorded judgements and realistic assessments of practicable options framed within the demands of UK policy for LLW management and the characteristics the LLWR site and existing elements of the facility.

The final performance assessments undertaken for the ESC were based on the Site Development Plan. The ESC will be used as a tool to inform future decision-making concerning the repository design, operation and the acceptance of wastes, as set out in the evolving Site Development Plan. Maintaining the ESC is thus essential to ensure that the Site Development Plan takes account of an up-to-date understanding and analysis of environmental performance, and that the Plan continues to be optimised.

## INTRODUCTION

The Low Level Waste Repository (LLWR) is the United Kingdom's principal facility for the disposal of LLW. It operates under a Permit issued by the Environment Agency under the Environmental Permitting Regulations (EPR) [1].

The LLWR made a major submission to the Environment Agency on 1st May 2011, the 2011 Environmental Safety Case (ESC) [2]. The 2011 ESC is the first full environmental safety case to be submitted for the facility since 2002 and its submission was required under the terms of our current Permit. The ESC presents a number of significant, necessary improvements on the earlier safety cases. One of these improvements is that the ESC fully addresses the optimisation of the facility. Optimisation is a key regulatory principle and it is an explicit requirement in the UK environmental regulators guidance [3] that all aspects of the design, operation and closure of the repository relevant to radiological safety are optimised. The requirement states that:

> '*The choice of waste acceptance criteria, how the selected site is used and the design, construction, operation, closure and post-closure management of the disposal facility should*

*ensure that the radiological risks to members of the public, both during the period of authorisation and afterwards, are as low as reasonably achievable (ALARA), taking into account economic and social factors.* '

The ESC will direct and inform the future use of the LLWR and has implications for the success of the UK's strategy for managing LLW from nuclear operations and decommissioning programmes in the UK. A more complete overview of the 2011 ESC and its importance is given in another paper at this conference [4].

## DESCRIPTION OF THE SITE

The LLWR is located in the north-west of England, situated on the West Cumbrian coastal plain. It is close to the small village of Drigg and is approximately five kilometres south-east of the Sellafield reprocessing plant. The LLWR site has an area of about 1.0 square kilometres, with disposals being located in the northern part of the site and the rest of the site brown field land. At its nearest point, the LLWR site is only about 400 m from the high water mark, so that in the long term the site is vulnerable to coastal erosion. Taking account of predicted sea level rise, it is expected that the facility will be eroded by the sea within a few hundreds to thousands of years. The local area is predominantly rural with small villages and towns. The site itself is mainly surrounded by grazing land. The area along the coast adjacent to the west of the site is designated as a Site of Special Scientific Interest (SSSI), known as the Drigg Coast SSSI. The area is also a Special Area of Conservation (SAC) under the European Habitats Directive.

## SITE HISTORY

The LLWR site was first developed as a Royal Ordnance Factory (ROF) in 1940 for the production of TNT. After the 2$^{nd}$ World War, ownership passed to United Kingdom Atomic Energy Authority, which was granted planning consent for the disposal of waste in 1957. Disposal operations started in 1959. Ownership and responsibility for the site was transferred to British Nuclear Fuels Ltd (BNFL) when the company was formed in 1971, and the site became a part of the Nuclear Decommissioning Agency's (NDA) estate when that body was established in 2005. The site is currently operated on behalf of the NDA by a Site Licence Company (SLC) – LLW Repository Limited. 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-six years of operation, drummed, bagged and loose wastes were tumble tipped into disposal trenches. The first trench was an old railway cutting through the northern part of the site that was built as part of the ROF. Subsequently, five wider and deeper 'purpose built' trenches were excavated on either side of Trench 1. The bases of these trenches were constructed so that their bases lie within low-permeability clay layer 5 to 8 m below ground level. In the case of the later trenches at least, if the natural clay was not present, bentonite clay was rotovated into the bases to reduce the permeability in those areas. A final trench, Trench 7, of irregular shape was excavated to use the remaining area. This trench was closed in 1995. The trenches are all now covered with a temporary cap to reduce water infiltration into the wastes and thus minimise leachate.

In 1987 a decision was made to move away from loose waste disposal in trenches to a more engineered solution. Remedial work was carried out on the trenches; a low-permeability cut-off wall (COW) was constructed (to limit lateral movements of groundwater and radionuclides) and the leachate drainage system was upgraded.

Vault 8 started to receive waste in 1988. The waste emplaced in Vault 8 is grouted into half-height ISO (International Organization for Standardization) containers. Vault 8 is permitted to accept waste stacked to four containers high and is now almost full to its originally planned capacity. As a result of the Agency review of the 2002 submission [5], LLWR are permitted to dispose of waste in Vault 8 but only store wastes in Vault 9 pending the issue of a new Permit. Construction of Vault 9 was completed in December 2010 and now contains stored ISO containers. Larger items that will not fit into an ISO container are grouted directly into Vault 8 within specific areas of the vault.

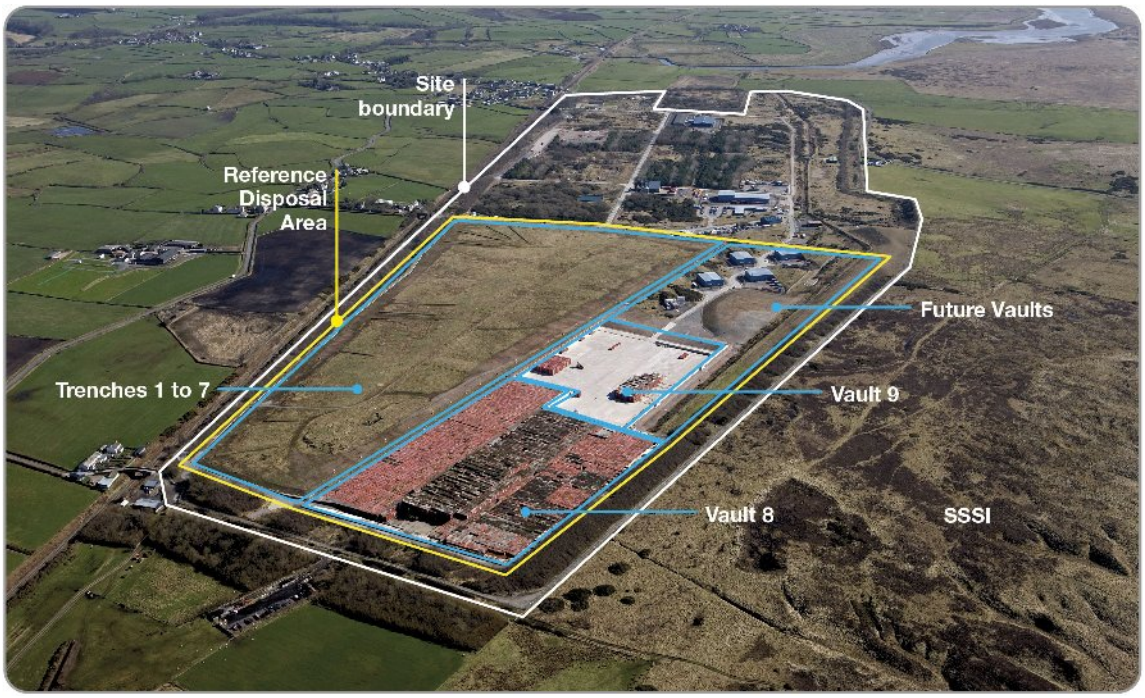


Figure 1 Aerial photograph of the LLWR site 2011 (viewed from north-west to south-east)

## OPTIMISATION CONTEXT

The role of the LLWR is defined within the NDA UK Strategy for LLW, consistent with Government Policy. The Strategy is to make '*best use of existing LLW management assets*' for the management of LLW. This means maximising the capacity to accept wastes at LLWR that requires the protection provided by disposal in vaults. This involves developing, and implementing, plans for the safe and optimised use of the LLWR for LLW disposals, subject to necessary planning approvals and regulatory permissions. This is covered in more detail in [4].

A key aspect of optimising the use of the LLWR is supporting the NDA in the application of the waste hierarchy, see Figure 2, to minimise the volume of LLW that needs to be disposed at the LLWR. The waste hierarchy seeks to reduce the amount of waste being produced but where wastes already exist or cannot be prevented from arising, the strategy seeks to increase opportunities for reuse and recycling of waste materials. Better characterisation and segregation of wastes, such as Very Low Level Waste (VLLW) that can be disposed in certain licensed landfill sites, is increasing in the UK. This, and the increased availability of options for treating wastes, through metal smelting/cleaning, incineration of organic wastes and compaction, are already reducing the volumes of LLW requiring disposal in the vaults at the LLWR.

The Strategy recognises that the LLWR can only continue to be used to dispose of LLW if we can demonstrate that the facility is safe using an environmental safety case.

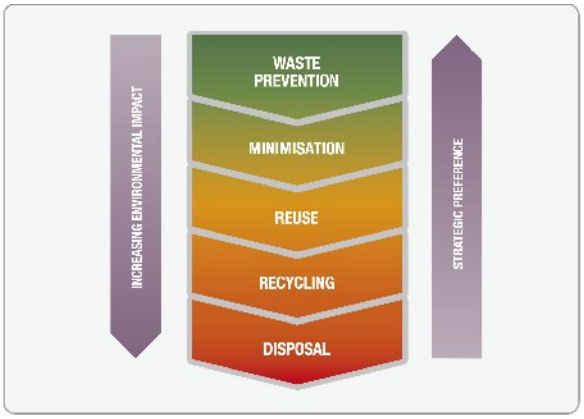


Figure 2 Waste Hierarchy

The environmental safety case for the LLWR, submitted by the previous operator in 2002, is in two parts: an '*Operational Environmental Safety Case*' [6] and a '*Post-closure Safety Case*' [7]. Following its submission, the Environment Agency undertook a thorough review of the cases [5] and concluded that these reviews were deficient in a number of respects and had failed to make '*an adequate or robust argument for continued disposals of LLW*' [5]. In particular, stating: '*The 2002 safety cases include insufficient consideration of optimisation and risk management, to demonstrate that impacts will be as low as reasonably achievable (ALARA)'.*
The 2011 ESC addresses the shortcomings identified by the regulator, in particular for this paper, the need to optimise all aspects of the facility.

**APPROACH**

For the 2011 ESC a range of optimisation studies were undertaken looking at various aspects of the site and waste disposals. These studies considered:

- Remediation of historical, trench disposals
- Waste management treatment strategies for future wastes
- Waste emplacement strategies
- Leachate and run-off management
- Future vault design and closure engineering
- Post-closure management plans.

A range of optimisation approaches, such as multi-attribute analysis, development of alternative strategies, expert meetings and stakeholder consultation have been used in the optimisation studies relevant to each aspect being considered. However, the main focus of the optimisation process was to provide a technical, quantative justification for all the decisions made. This meant the optimisation process was iterative and involved utilising modelling results to provide insight and underpinning to decisions. For example, our hydrogeological model [8] was used to analyse barrier performance and to inform the selection of our approach to site engineering. This has led to a more visible presentation of key underpinning evidence and logic that has led us to put forward the proposed set of controls for future management of the LLWR.

Through the process of optimisation we have developed our plan for the future management of the site – our Site Development Plan (SDP) and also our Environmental Safety Strategy (ESS). Our SDP is our plan for implementing our ESS to ensure continuing environmental protection as the site is used and developed. Our SDP also takes into account a wider set of considerations that do not directly affect radiological risk, such as the scheduling of new vaults, closure engineering and the need to protect workers during the operational period.

The ESS is the complete strategy by which an ESC is developed. This includes developing the management framework under which all work related to the ESC is carried out, as well as specific engineering measures. Our SDP describes how we will implement our overall ESS and forms the basis of our safety assessments carried out for the ESC. Optimisation is the process we have used to determine a preferred set of control measures that are consistent with the goal of achieving radiation doses and risks that are ALARA.

## OPTIMISATION ARGUMENTS

At a high level, the ESC case for optimisation is that we have carried out a comprehensive evaluation of options, underpinned by quantative evidence, to arrive at an optimised SDP for the LLWR. Because the LLWR is an operating facility with a substantial history, decisions regarding its future management, design and operation are framed, and to a certain extent also constrained, by past actions. The logic and evidence developed in support of decisions regarding the future of the facility therefore start from an understanding of decisions that were taken in the past and the considerations that related to those decisions when they were taken. Development of the optimised ESC was an iterative process, and will remain so through the life of the facility. It involves progressive development with focused improvement of data, understanding, design options and assessments. Decisions taken regarding the development and operation of the LLWR to meet environmental safety objectives are captured in the Site Development Plan (SDP).

The SDP forms the basis of the future management of the site and a means for assessing proposed changes. The SDP presents an appropriate combination of implementable options for the future development of the site.

### Remediation of past waste disposals

As discussed above, one of the main conclusions of the Environment Agency's review of the 2002 safety case was the insufficient consideration of optimisation and risk management to demonstrate that impacts would be ALARA. This was due in part to the high calculated doses and risks from existing disposals in the trenches that significantly exceeded regulatory guidance levels of risks of $10^{-6}$ per year. As a result of the work for the present ESC, to improve and refine our assessment methods and models and to reduce uncertainties, calculated doses and risks from the trench disposals are now consistent with regulatory guidance levels. Although assessed risks are consistent with guidance, we have undertaken work to consider the ways that we could further reduce the environmental impact associated with past disposals. These studies were underpinned by analysis of the inventory and also the understanding gained from the assessments. Remediation options, such as removing selected wastes or treating wastes in-situ, have been assessed in terms of the potential reductions in risk they would deliver. Consideration has also been given to the wider implications that remediation activities would have. These include doses to workers carrying out the remediation work and impacts that undertaking the work would have on the local community.

Our options assessments demonstrate that while reductions in peak doses and risks would be achievable, the benefits are small compared with the costs and disruption associated with retrieval or remediation. The cost and detriment that these actions would have is large compared with the reduction in doses that are already below the regulatory guidance level. Therefore, we do not include any such activities in our forward plan for the future management the facility and the ESC assumption is that the past disposals will be left in situ.

**Optimisation of future waste disposals**

The LLWR is working closely with the NDA to implement the waste hierarchy strategy. We currently provide framework contracts that allow our customers to access treatment services and have recently facilitated the treatment of five redundant boilers allowing 95% of the metal to be recycled and free-released.

Implementation of the UK Strategy will lead to a change in the nature of some of the wastes as a result of the treatments. LLWR has started to receive shot blast residues as secondary waste, for example. The ESC assessments take account of the implementation of the UK Strategy in the inventory data used. The disposal inventory is calculated based on assumptions about the fraction of waste segregation and the timings of implementation. Our assessments show that the resulting wastes can be safely disposed at the LLWR.

Disposal container designs will be optimised using the ESC and any proposals to change the disposal operations will be assessed against the ESC using our change control process. As the ESC is based on assumptions around waste types, packaging efficiency and inventory, we will monitor the wastes being disposed to LLWR and review changes to ensure the assumptions of the ESC remain valid.

**Site Engineering**

When Vault 9 was commissioned it was based on the principle that the preferred design was to contain leachate for as long as practicable. Thus Vault 9 was designed with an impermeable base and walls and so that any infiltrating water would be contained in the vault. Optimisation work carried out in the ESC has led to a change in design philosophy for the future vaults, away from saturated waste conditions towards undersaturated or ‘dry’ wastes. Future vaults will be designed without containing side walls. This will minimise the potential for buildup of water in the vaults and thus minimise the interaction between infiltrating water and the wastes, which may both reduce the concentrations of contaminants in leachate and limit the degradation of the wastes. The concept of maintaining unsaturated conditions also minimises the potential for contaminated leachate to be released to near-surface pathways. The results of the hydrogeological model were used to explore the saturation profile of the repository at different times due to varying permeability of the engineered and site features, see Figure 3. This allowed quantitatively-informed decision to be made on the function and required characteristics of key engineered features, e.g. the cut-off wall.

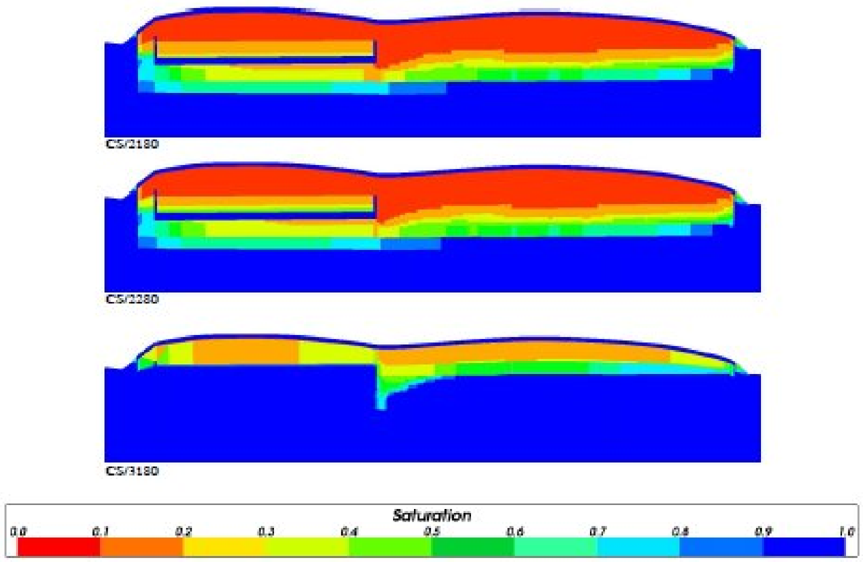


Figure 3 Calculated saturation profile from 100 to 1100 years after closure

There are uncertainties associated with providing definitive estimates of long-term engineering performance due to uncertainties in future climate conditions etc., so the main emphasis in comparing engineering options was on establishing confidence in demonstrating environmental safety. After reviewing the components and making such a comparison, we then assessed each option against a wider set of considerations.

Our overall conclusions, on which our SDP for the LLWR is based are that:

- The future vault design will be based on the principle of providing comprehensive capture and control of leachate during operations and the active control period.
- The final site cap is a major component of the overall engineering design for the closure of the LLWR. The component layers of the engineered cap have been optimised over several design cycles for performance as a hydraulic barrier. It also provides effective protection against intrusion by humans, deep rooting plants and burrowing animals. It will be implemented progressively, as disposals to each vault are completed, so as to minimise infiltration to the closed vaults.
- The gradient of the cap profile has been minimised to reduce visual impact, but only to a level that will ensure that its water-shedding and drainage function will persist over the long term under expected rates of natural settlement. The cap will have a single-dome profile over the whole disposal area, capable of providing the required structural stability to assure long-term performance. The profiling volume potentially provides additional capacity for waste emplacement (consistent with making optimal use of the available disposal volume). We have assumed higher stacking in vaults using this profiling space and our assessments have shown that this will be safe.
- A low permeability cut-off wall (COW) will be constructed around the whole facility, to a depth of approximately 2 m below the underside of the vault bases. The primary function of the COW will be to prevent lateral movement of shallow ground water into the facility. This

COW will be keyed into the final cap and provide reassurance against the possibility of near-surface release of leachate.
- A passive gas venting system is included in the cap design to prevent pressurisation of the system by bulk gas production or atmospheric pressure changes. The vent will also allow confirmatory monitoring of bulk gas and radioactive gas production during post-operational control of the site. A decision will be made before the end of active control on whether to close the vent prior to final site closure.

**Waste emplacement strategies**

We have considered a wide range of options in our approach to waste emplacement within future disposal vaults. In general, our conclusions are that disadvantages associated with implementation of such strategies (for example, in terms of cost and complexity, and impacts on efficient operation of the facility) would significantly outweigh any advantages they might offer in terms of risk reduction. In most cases, the potential benefits are assessed to be marginal. We have, however, identified a number of strategies that offer sufficient benefit to be implemented. Two such strategies are the emplacement of disposal packages such that the impacts that might result from human intrusion or coastal erosion are minimised. Emplacement strategies to limit loads on packages containing absorbed liquids and to reduce the effects of settlement on the cap are also planned.

**Management of run-off and leachate**

During operations, rainwater run-off from the open vaults and leachate from the trenches and closed vaults will continue to be managed as now. Currently this is carried out by the collection, monitoring and controlled discharge to sea, subject to the terms of our Permit. We plan to construct the final cap over the disposal area progressively in strips, which will reduce infiltration to the trenches and closed vaults. This will ensure that the current leachate management systems remains capable of handling run-off from most storm events.

The assumption in our SDP is that leachate will continue to be actively managed while waste emplacement continues and also up until final site closure. The assumption of continued active management and monitoring is consistent with established practice for landfill operations. Based on current understanding of cap performance, however, we expect that the vaults and trenches will be effectively de-saturated within two decades after the completion of final waste emplacement resulting in minimal leachate generation.

Monitoring will continue into the post-operational period with the objective of confirming performance in relation to leachate management.

**Management during closure**

After the completion of the final cap a period of institutional control will follow in which the facility will continue to be monitored and managed until it is finally closed.

It is not appropriate at this stage to define detailed, or to conduct a detailed optimisation of, arrangements for management during the closure period. Our ESC presents the case that the LLWR can continue to safely dispose of LLW for many decades. It is important, however, to provide assurance that the facility can be safely closed and released from control, and to understand what actions need to be undertaken now, such as records retention, to help in the future. Hence, our SDP outlines arrangements for the closure period, covering aspects such as leachate management, monitoring and preparations for final facility closure and release of the site from control.

Our assessment in the ESC suggests that the site could be safely released from control after 100 years. We consider that the best way of reducing the likelihood of damage or inadvertent intrusion into the facility in the future is to ensure that knowledge of the site is retained. This includes information about the nature of site and wastes, and the hazards that the wastes present. This could be achieved in many ways, but we believe involvement of the local community in making decisions on the future of the site is vital.

## FUTURE PLANS

The ESC will now be implemented at the LLWR and the SDP used as a tool to manage the site. The ESC and SDP will continue to develop and evolve to account for new information, e.g. on waste arisings, and new proposals to improve performance. The ESC will be used as a basis to optimise and assess proposed changes to the SDP, and then the ESC and SDP will be amended to account for adopted changes using our formal change control procedure. The ESC will also be used in decisions about future waste acceptance, including those related to making optimal use of the radiological capacity of the repository. Use of a maintained ESC will continue to ensure that the SDP evolves taking account of environmental performance, and that the Plan continues to be optimised.

The 2011 ESC has assumed the use of containers similar to the half-height ISO containers that have been used in Vault 8 since 1988. An optimisation study is underway to develop a new waste disposal container to improve the efficiency of waste packaging. Currently we achieve about 60% packing efficiency in a container and we are also looking at ways to improve this. These activities will improve the efficiency of the use of the space in our vaults and reduce the quantity of non-waste materials disposed. The design of the new waste container will be optimised having taken account of environmental considerations on the basis of the ESC. The final proposed design will also be assessed against the requirements of the ESC, using LLWR's change control process.

We are continuing to evaluate the performance of the interim cap over the trenches and are expecting sufficient data to be available in 2012 to support an optimisation study to consider the best strategy for managing the interim cap, prior the installation of the final cap.

We will consider further the role and design of the gas vent in the cap, and whether it should be left open or closed before the end of active institutional control.

In addition, the ESC may be used as an input to optimisation studies at the national level, for example, in relation to the management of reactor graphite, LLW destined for disposal to the Geological Disposal Facility and orphan wastes.

## SUMMARY AND CONCLUSIONS

The LLWR submitted its ESC to the environmental regulator on 1$^{st}$ May 2011. The safety case presents a number of improvements on the earlier safety cases. One of these improvements is that the ESC fully addresses optimisation of the facility. The ESC will now be implemented at the LLWR and the SDP used as a tool to manage the site. The ESC will be used as a basis to optimise and assess proposed changes to the SDP. The ESC will also be used in decisions about future waste acceptance, including those related to making optimal use of the radiological capacity of the repository. Use of a maintained ESC will continue to ensure that the SDP evolves taking account of environmental performance, and that the Plan continues to be optimised.

## References

1 The Environmental Permitting (England and Wales) Regulations 2010, Permit, Permit number EPR/YP3293SA, 21 December 2010.

2 LLWR, *The 2011 Environmental Safety Case*, LLWR/ESC/R(11)10016, May 2011.

3 Environment Agency, Northern Ireland Environment Agency and Scottish Environment Protection Agency, Near-surface Disposal Facilities on Land for Solid Radioactive Wastes: Guidance on Requirements for Authorisation, February 2009.

4 Cummings, R., Baker, A., Huntington, A., Shevelan, J. and Sumerling, T., *The LLWR's 2011 Environmental Safety Case*, WM Paper 12143, Dec 2011

5 Environment Agency, *The Environment Agency's Assessment of BNFL's 2002 Environmental Safety Cases for the Low-Level Radioactive Waste Repository at Drigg*, NWAT/Drigg/05/001, June 2005.

6 BNFL, *Drigg Operational Environmental Safety Case.* 2002.

7 BNFL, *Drigg Post-closure Safety Case*, September 2002.

8 Hartley L, Applegate D, Couch M, Hoek J, Jackson CP and James M, *Hydrogeological Modelling for LLWR 2011 ESC*, Serco Report No. SERCO/TCS/E003632/007 Issue 3, April 2011