LLW Repository Ltd

LLWR Environmental Safety Case

Development of the Disposal Inventory – Review of Non-Radiological Inventory Data

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

SERCO/TAS/E003756/001 **Issue 2** **Date: April 2011**

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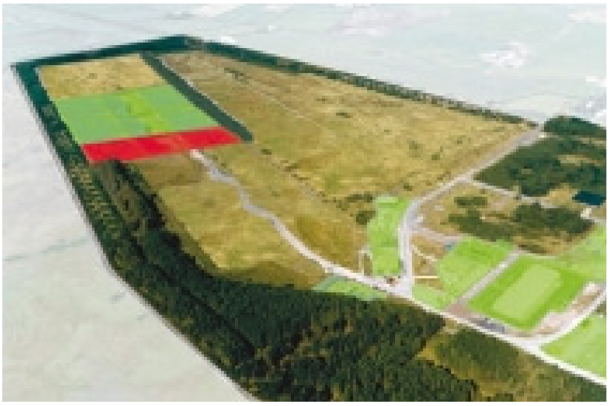

Development of the Disposal Inventory

Review of Non-radiological Inventory Data

Your Reference: LLWRP1106

Our Reference: SERCO/TAS/E003756/001 Issue 2

Date: April 2011

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Customer	LLW Repository Ltd
Customer reference	LLWRP1106
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Our Reference	SERCO/TAS/E003756/001 Issue 2

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List of Acronyms/Abbreviations

Acronym/Abbreviation	Meaning
ALARP	As Low As Reasonably Practicable
BNFL	British Nuclear Fuels Ltd
Defra	Department of Environment, Food and Rural Affairs
DWS	Drinking Water Standards
EA	Environment Agency
EPA	Environmental Protection Agency Ireland
EPR	Environmental Permitting Regulations
EQS	Environmental Quality Standards
ESC	Environmental Safety Case
GWD	Groundwater Directive
HPA	Health Protection Agency
JAGDAG	Joint Agencies Groundwater Directive Advisory Group
LLW	Low-Level Radioactive Waste
LLWR	Low Level Waste Repository (near Drigg in Cumbria)
LOD	Limit of Detection
MCL	Maximum Contaminant Loading
MHT	Marine Holding Tank
NIEA	Northern Ireland Environment Agency
PCB	Polychlorinated biphenyls
SEPA	Scottish Environment Protection Agency
TCE	Trichloroethylene
TOC	Total Organic Carbon
UK	United Kingdom
UKRWI	United Kingdom Radioactive Waste Inventory
US EPA	United States Environmental Protection Agency
VOC	Volatile Organic Carbon
WAG	Welsh Assembly Government
WFD	Water Framework Directive
WHO	World Heath Organisation

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Executive Summary

The Low Level Waste Repository (LLWR) is undertaking a programme of work to underpin the assessments made as part of an Environmental Safety Case (ESC) for submission to the Environment Agency (EA) in 2011. Part of this programme of work is the production of a robust and defensible inventory of past and future waste disposals.

This study, undertaken in late 2009, evaluates the information available on those components of LLW defined as hazardous and non-hazardous in the Groundwater Directive. The study considers material already disposed of to the trenches and Vault 8 at LLWR in addition to future arisings. Suggestions are made for the improvement of the non-radiological inventory of materials expected to be disposed to the LLWR.

Literature describing the results from previous site monitoring assessments was reviewed in order to identify which hazardous and non-hazardous contaminants are currently characterised. Analysis of the leachate from trench probes, the marine holding tanks and the surface and/or drain run-off water were all considered in view of whether the data reported were sufficiently robust and/or extensive to gain an understanding of each contaminant's concentration in, and movement from, the LLWR trenches/Vault 8. Contaminant concentrations were compared to appropriate drinking water standards, where available, as these define the safe contaminant concentration limits in relation to human health.

Suggestions are made for any supplementary studies that could be undertaken in order to improve the quality of the inventory of non-radiological materials disposed at the LLWR. Suggestions relating to individual substances, or groups of substances, are provided. Our conclusions are also relevant to deciding what environmental monitoring should be performed at the LLWR site.

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1 Introduction

The Low Level Waste Repository (LLWR) is undertaking a programme of work to underpin the assessments made as part of an Environmental Safety Case (ESC) for submission to the Environment Agency (EA) in 2011. Part of this programme of work is the production of a robust and defensible inventory of past and future waste disposals.

In 2006, the Environment Agency (EA) issued a new Authorisation for operations at the Low-Level Waste Repository (LLWR) near the village of Drigg, Cumbria. One of the requirements of the authorisation (Schedule 9, Requirement 13) was to undertake a review and assessment of the non-radiological components of the inventory at the LLWR, and hence to identify potential health hazards that could arise from those components of the inventory.

In 2008, an assessment of the environmental and health hazards arising from the non-radioactive components of the LLWR inventory was performed [1], in accordance with Requirement 13. This assessment used a methodology that was very similar to that employed in the radiological assessments [2], and was based on an inventory developed on the basis of examining historical and other records of waste disposals at the LLWR [3].

The non-radiological assessment indicated that a number of non-radiological contaminants could, in the period following repository closure, enter the accessible environment at levels that would be considered unacceptable. This conclusion can be traced, in part, to a number of cautious assumptions that were made in the non-radiological assessment [1]. However, since the inventory of contaminants is key to determining the magnitude of the environmental hazards, it follows that the numerical inventory used in the assessment calculations needs to provide the best estimate of the contents of the trenches and vaults at the LLWR, in so far as uncertainties over disposals at the LLWR permit.

This study, undertaken in late 2009 and updated in 2011, evaluates the information available on those components of LLW defined as hazardous and non-hazardous in the Groundwater Directive. The study considers material already disposed of to the trenches and Vault 8 at LLWR in addition to future arisings. Suggestions are made for the improvement of the non-radiological inventory of materials expected to be disposed of to LLWR.

The structure of this report is as follows. Section 2 discusses the expectations of the Environment Agency (EA) in the context of assessments of landfill sites. Sections 3 and 4 then describe the contaminants identified as hazardous and non-hazardous in the Groundwater Directive and discuss some of the specific issues with the Requirement 13 inventory with potential approaches for improvement described in Appendices 1 and 2. Section 5 describes the approach adopted in this review. Section 6, in conjunction with Appendices 3 and 4, discusses the information available on the inventory and from environmental monitoring data. The outcomes of the review are presented and suggestions are made for work in relation to future national inventories and focussed studies relating to the current trench and Vault 8 inventories that could be undertaken.

There have been a range of developments in monitoring since this review was initially conducted. The LLWR have carried out a review of non-radiological monitoring data [4], and concluded that LLWR activities have not resulted in significant non-radiological contamination of groundwater or surface water. The monitoring programme for non radiological contaminants has also been revised [5]. Based on the limited impact, it was decided to reduce the number of measurements for non-radiological contaminants. Recently, the LLWR have undertaken a comprehensive measurement of leachate from the Marine Holding Tanks (MHT) with a view to identifying those contaminants that might need to be included in the detailed monitoring programme. No additional contaminants were identified. However, it is understood that the LLWR are currently considering whether similar measurements are required on less diluted samples from trench probes or end of trench samples..

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2 Hydrogeological Risk Assessments for Conventional Landfills

In its guidance on hydrogeological risk assessments for landfills [6], the EA notes a number of requirements and expectations of assessors with respect to the inventory of materials disposed, and the use of that inventory in landfill assessments. While the LLWR is not a landfill, the landfill guidance in [6] sets out certain expectations of a facility that will be used to dispose of non-radiological materials. It is therefore important to review the guidance of the EA, to ensure that non-radiological assessments of the LLWR are as consistent as is feasible with the EA guidance on landfill assessment. In this report, attention is focussed on requirements and guidance in the development of the source term components of the assessment.

A key theme of the EA guidance is that landfill assessments can be undertaken at various levels of complexity, depending on the nature of the landfill system and the expected hazards that could arise. However, characterisation of leachate is a requirement of all levels of assessment. Possible sources of information on leachate quality are provided in Appendix 3 of [6]. These are summarised below.

For new landfills, no leachate information will be available, so information is to be gained from either reviews of the literature, similar landfills owned by the operator of the new landfill, or existing landfills that accept similar waste streams to those that will be accepted by the new landfill. Reference [6] notes that this information should then be used to calculate the source term of wastes to be disposed in the new landfill. This contrasts with the usual procedure for assessing near-surface repositories such as the LLWR, where the source term is used initially to estimate leachate quality.

For an existing landfill, the EA notes that leachate quality data may already be available. However, these data may need to be supplemented by additional programmes of sampling, literature reviews, knowledge of similar landfills owned by the operator of the existing landfill, or other existing landfills that accept similar waste streams.

The guidance for an existing landfill refers to situations where a waste stream is to be evaluated to determine suitability for disposal, or consideration of an extension or modification to an existing landfill. The guidance notes that even though existing information is being used, it is still necessary to go through the steps of computing the source term to determine the applicability of the data. The guidance also notes that the alteration of leachate quality with time needs to be taken into account.

In the context of the LLWR, the trenches could be thought of as analogous to an existing landfill, and the vaults as analogous to a new landfill. For the trenches, previous and ongoing work [5] is concerned with developing a source term that makes best use of available leachate data. This work seeks to establish whether there is consistency between the inventory of non-radioactive contaminants, estimates obtained from assessment models of contaminant concentrations, and leachate quality. This approach is consistent with the guidance expressed above.

It should be noted that the EA have developed new draft guidance regarding the performance of landfills [7]. This is intended to update the guidance issued in 2003, reference [6], in respect to the legislative context only. This has not yet been issued for use, but this review has considered the new guidance where appropriate.

3 Groundwater Regulations

The European Union (EU) Water Framework Directive (WFD) [8] sets out general provisions for the protection and conservation of groundwater. It sets objectives for groundwater quality, including an objective to meet "good chemical status" by 2015, an objective on pollution trends, and an objective to prevent or limit the input of pollutants to groundwater. The EU 2006 Groundwater Directive [9] clarifies these objectives and sets out specific measures to prevent and control groundwater pollution. The new groundwater regime (consisting of both the WFD and the 2006 Groundwater Directive) are implemented in the Groundwater (England and Wales) Regulations 2009 [10] (the "2009 Regulations").

The 2009 Regulations have been superseded by the Groundwater provisions of the Environmental Permitting (England and Wales) Regulations 2010 [11] (EPR 10), in particular Schedule 22 of EPR10; however, with regard to groundwater protection, the EPR 2010 achieves the same effect as the 2009 Regulations.

In England this legislation provides for protection of groundwater. It distinguishes between hazardous substances and non-hazardous pollutants. The Department for Environment, Food and Rural Affairs (Defra) guidance on the 2009 Regulations [12] notes that the hazardous substances broadly equate to the former List I under the now-superseded 1980 Groundwater Directive [13] as implemented by the Groundwater Regulations 1998 [14], and that the non-hazardous pollutants are analogous to the former List II, but potentially apply to all other pollutants.

The definitions of hazardous and non-hazardous pollutants and the substances contained within each category are outlined in the following sections. Thus, as LLWR aims to meet requirements comparable to those set out for non-radiological landfill it will be the contaminants within these two categories that will require further assessment and/or characterisation.

3.1 Hazardous Pollutants

A hazardous substance is defined as "*any substance or group of substances that are toxic, persistent and liable to bio-accumulate*" and "*in particular includes the following when they are toxic, persistent and liable to bioaccumulate –*

- *organohalogen compounds and substances which may form such compounds in the aquatic environment;*
- *organophosphorous compounds;*
- *organotin compounds;*
- *substances and preparations, or the breakdown products of such, which have been proved to possess carcinogenic or mutagenic properties or properties which may affect steroidogenic, thyroid, reproduction or other endocrine-related functions in or via the aquatic environment;*
- *persistent hydrocarbons and persistent and bioaccumulable organic toxic substances;*
- *cyanides;*
- *metals (in particular cadmium and mercury) and their compounds;*
- *arsenic and its compounds;*
- *biocides and plant protection products."*

3.2 Non-hazardous Pollutants

A non-hazardous pollutant is defined as "*any pollutant other than a hazardous substance.*"

The 2009 Regulations specify that the Environment Agency may provide an exemption from the requirement for a permit, a discharge or an activity that would result in an input of pollutants to groundwater in circumstances when:

- the quality of groundwater would to all intents and purposes be unaffected;
- the measures needed to protect groundwater would cause greater harm to human health or wider environmental needs; or
- the measures to remove quantities of pollutants from, or otherwise control their percolation in, contaminated land or subsoil would be disproportionately costly.

3.3 Determined Substances

The hazardous and non-hazardous substances are defined in terms of broad groups and there is no definitive list of individual species in the Directive. The 1980 Groundwater Directive (80/68/EEC) required Member States and competent authorities to determine which substances or compounds could be removed from List I in the light of the risks posed by their intrinsic properties. The 2006 Groundwater Directive (2006/118/EC) requires a different approach by which Member States or their competent authorities determine which substances should be determined as hazardous on the basis of their toxicity, persistence and capacity to bio-accumulate – i.e. positive determination rather than removal from a pre-determined list. This provides a more transparent process based on current scientific evidence to include substances within, or alternatively exclude them from, the 'hazardous' category. In practice substances which have been determined as List I will continue to be regarded as hazardous and will only be reviewed if new evidence becomes available.

The Joint Agencies Groundwater Directive Advisory Group[1] (JAGDAG) was set up to determine which substances were within List I and II within the UK. The current list of substances determined [15], the substances still under review [16] and the process for determination are available on the JAGDAG website [17].

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[1] JAGDAG is a body comprising the Environment Agency (EA), the Scottish Environment Protection Agency (SEPA) and the Northern Ireland Environment Agency (NIEA) ('the Agencies'), together with the Department of Environment, Food and Rural Affairs (Defra), Welsh Assembly Government (WAG), the Environmental Protection Agency Ireland (EPA), Health Protection Agency (HPA) and industry representatives.

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4 Inventory Data

The inventory used in the Requirement 13 Submission [3] builds on inventory studies undertaken for the 2002 Post-closure Safety Case (PCSC) for Drigg [18]. However, it is noted in [3] that the EA made various comments regarding the inventory used in the 2002 PCSC. These included the need for a more detailed consideration of the non-radiological components of the inventory.

In response, an inventory was developed by Wareing [3] which aimed to produce a revised inventory that addressed this issue, together with other comments raised by the EA.

Wareing's inventory [3] was derived using the following data sources:

Trenches: Paper disposal records that were made at the time of disposals;

Vault 8: Contents of the Waste Tracking System Database

Future vaults: The 2004 UK Radioactive Waste Inventory [19].

Evaluating the inventories of the trenches and of future disposals presented significant difficulties. In the case of the trenches, over 100,000 individual disposal records are available; the majority of these do not provide the necessary data relating to the type and amount of radioactive and non-radioactive contaminants disposed. In order to provide a plausible estimate of disposals in the trenches, a back-fitting approach was applied. The basis of this approach is the assumption that historical disposals have broadly similar characteristics to contemporary disposals. The outcome of the study for the trenches is an inventory of radioactive and non-radioactive materials in the trenches at LLWR. However, the inventory of non-radiological contaminants presented in [3] can not be considered to be complete or definitive, for several reasons:

1. A number of contaminants are detected in trench porewater, for which no data are recorded in the inventory although they are known to have been, or might have been, disposed (e.g. arsenic)[2].
2. A significant component of the inventory is recorded as being of unknown composition.
3. The physical form of the wastes is often not clear from the available information.

Therefore, while the reliability of the disposed inventory presented in [3] is substantially greater than that presented in the 2002 PCSC [18], the inventory of non-radiological contaminants remains less than ideal. Studies to improve the non-radiological inventory by assessment of contaminants measured in site waters have been undertaken by Lean et al. [20] and Kelly and Jackson [21], examples of the approaches are described in Appendices 1 and 2. However, it is clear that substantive improvements require better input data. We have not reviewed the information that the LLWR requires from consignors in relation to hazardous and non-hazardous pollutants. However, we recommend that LLWR reviews the extent of this information to confirm that it will meet the needs of future non-radiological assessments. In addition, consideration should be given, in conjunction with other end users of the data, as to whether any enhancements to the national inventory should be requested.

The non-radiological inventory of projected disposals to LLWR described in reference [3] is derived from information held in the 2004 UKRWI [19]. This information is necessarily speculative in a number of areas, but it is clear that the methodology for gathering the data does not ensure that adequate information on the nature and quantity hazardous and non-hazardous materials is obtained.

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[2] It should be noted that substances detected in the groundwater might be present as background (rather than having originated from the trenches) and their concentrations may not necessarily be above the local baseline concentration.

5 Approach to Assessment

5.1 Methodology

The numerical inventory used in the assessment calculations needs to provide the best estimate of the contents of the trenches and vaults at the LLWR, in so far as uncertainties over disposals at the LLWR permit. In order to consider the potential enhancements to the inventory of non-radioactive materials, the methodology outlined in the following steps was utilised:

1) The Drigg Non-Radioactive Contaminant Assessment [20] was examined to determine whether the hazardous and non-hazardous contaminants of concern are recorded and/or quantified in the inventory. In the case of non-hazardous substances, where no categories/families of substances are defined, the Groundwater Directive [13] List II families of substances have been used as a framework against which to perform the current review. The Trench, Vault 8 and Forward inventories were considered separately.

2) Literature describing the results from previous site monitoring assessments was reviewed in order to identify which contaminants are currently characterised [1, 20]. Analysis of the leachate from trench probes, the marine holding tanks and the surface and/or drain run-off water were all considered to determine whether the data reported were sufficiently robust and/or extensive to gain an understanding of each contaminant's concentration in, and movement from, the LLWR trenches/Vault 8, although it should be noted that substances detected in the groundwater might be present as background, rather than having originated from the trenches. Contaminant concentrations were compared to appropriate drinking water standards, where available, as these define the safe contaminant concentration limits in relation to human health.

3) Suggestions are made for any supplementary studies that could be undertaken in order to improve the quality of the inventory of non-radiological materials disposed at the LLWR where this could materially improve the quality of the 2011 ESC. These studies may be either practical or desk based and suggestions may cover either short-term or more long-term actions. The former includes focussed studies that could be completed as part of the work to support the 2011 ESC whilst the latter are presented in relation to future UK Radioactive Waste Inventories. Suggestions relating to individual substances, or groups of substances, are offered and are discussed in Section 6 and were arrived at via an internal (Serco) workshop in which the assessment method previously outlined was followed.

5.2 Data Sources

Prior to 2008, environmental monitoring at the LLWR was undertaken on a project basis where objectives were tailored to the needs of individual issues or specific statutory requirements. The monitoring programme was not integrated or co-ordinated as a single project and was not sufficiently optimised. The LLWR monitoring requirements [22] were compiled and a more consistent approach to data access and processing, management, quality control issues and programme definition was established in 2008 [23] and continued through 2009 [24] and 2010 [25].

However, the main sources of information available for this 2009 review were the Inventory of Past and Future Disposals at the LLWR [3] previously described; the Drigg Non-Radioactive Contaminant Assessment [20] and the Assessment of Human Health and Environmental Impacts Associated with the Non-radioactive Component of Disposals to the LLWR at Drigg [1].

The Lean, Lennon and Galais [20] 2004 assessment of non-radioactive contaminants derived the non-radioactive component of the inventory from the 2002 Drigg PCSC inventory of disposals [18]. Many of the hazardous and non-hazardous contaminants were quantified in this study and so this study is also referenced as the evidence for their presence in the inventory.

The study by Barber and Henderson [1] is an assessment of the human health and environmental impacts associated with the non-radioactive component of disposals to the LLWR. The report contains data from an environmental monitoring programme instigated in 2005 to provide a comprehensive non-radiological dataset for the LLWR. Data include contaminant concentrations within the main leachate drains, surface waters, other drains discharging to the site streams and groundwater monitoring cluster boreholes. The study also incorporates data derived from statutory monitoring of locations not sampled by the environmental monitoring programme, such as the marine holding tanks. Leachate from the trench probes was not routinely sampled but analyses performed in 2002 and 2004 are also summarised and utilised by Barber and Henderson [1]. However, monitoring of the leachate drains from the trenches and Vault 8 is undertaken but it is important to note that the leachate contained within these drains is diluted by surface run-off, as occurs for streams and drains.

Where available, the leachate monitoring data are compared against UK Drinking Water Standards (UK DWS), as defined in the Water Supply (Water Quality) Regulations 2000 (as amended) [26]. Where UK DWS are defined for a particular hazardous or non-hazardous contaminant, other limits and/or guidelines are quoted for comparison. In order of preference are the UK freshwater EQS [27], the World Heath Organisation water limits/guidelines [28] and the US EPA maximum contaminant level [29]. Although there are no legal requirements to meet these limits, they serve as a useful indicator for assessing whether the levels detected in leachate monitoring procedures warrant concern and aid the formulation of suggestions for further action.

It should be noted that since this review was carried out in 2009, a subsequent review of non-radiological data has been performed by LLWR, see Section 1. A description of the current monitoring programme of LLWR is provided in reference [5].

6 Outcome of Review

6.1 Introduction

The outcomes of the internal (Serco) assessment workshop are presented and discussed in this section. The inventory of the trenches and Vault 8 are first assessed in Section 6.2. The future inventory is considered separately in Section 6.3. For each of these inventories, hazardous and non-hazardous substances (or groups of substances), as outlined in Section 3, are assessed.

Quantitative information and references relating to the individual assessments of specific contaminants are provided in Appendices 3 and 4, respectively, alongside the justifications and/or the reasoning logic behind each suggestion. The suggestions are then summarised in Section 6.4 in relation to the broad categories previously outlined.

It is important to note that substances detected in the groundwater local to the LLWR might represent local background concentrations, rather than having originated from the trenches. It is, however, outside the scope of this review to determine for which contaminants this may be the case; consideration of the baseline contaminant concentrations forms part of the review reported in reference [4].

6.2 Trenches and Vault 8 Inventories

6.2.1 Hazardous pollutants

A number of hazardous materials are known to be in the disposed inventory and have been the subject of analysis in ground and surface waters and in trench leachate. A brief discussion is provided below, noting that the focus here is not on assessing impacts to the environment, but on identifying substances that might require monitoring or additional inventory data. Some of the identified substances have only been detected in a limited number of analyses.

Organohalogen compounds and substances which may form such compounds in the aquatic environment

Organohalogens are known to be present in the inventory and have been measured in water samples taken at the LLWR site. Trichloroethene and similar compounds are known to be present in the inventory, and have been detected in trench leachate at concentrations in excess of the UK DWS (10 $\mu g l^{-1}$ for sum of tetrachloroethene and trichloroethene) and other compounds (dichloroethane and dichloroethylene) have been detected at levels greater than the World Health Organisations limits. In the short-term it might be useful to undertake a desk-based study to evaluate the likely relationship between the concentrations in trench leachate and those in groundwaters or surface waters. Should such a study indicate a significant chance that these concentrations may approach drinking water limits a programme of monitoring may be advisable.

Organophosphorus compounds

Tributyl phosphate is a known component in the disposed inventory. The available analytical data suggest transfer of this material from the trenches to the stream running E/W through the site, although the data are sparse, and it is difficult to assess the true environmental significance of any releases. Given the quality of the available data, it is not clear that a simple assessment programme would illuminate this issue significantly, and a more comprehensive campaign of environmental monitoring for this material might be appropriate.

Organotin compounds

Organotin compounds are not explicitly reported as part of the inventory, although they are widely used as stabilisers in the manufacture of PVC, which forms a significant proportion of the existing materials inventory of the site. The release of these materials from disposed PVC to the environment is a known phenomenon, although its significance in the context of LLWR is far from clear, and no analytical data for such species are reported.

An assessment of the importance of these materials for the non-radiological environmental impact of these materials could usefully begin by a review of the available data on the release of these materials form PVC under the conditions pertaining in LLWR and their stability in the LLWR environment. Should such an assessment indicate the possibility for a significant impact, a campaign of environmental monitoring would be appropriate.

Substances and preparations, or the breakdown products of such, which have been proved to possess carcinogenic or mutagenic properties or properties which may affect steroidogenic, thyroid, reproduction or other endocrine-related functions in or via the aquatic environment

No substances with these properties were identified as known components of the inventory other than substances already contained within other groups of hazardous substances (e.g. certain metals). Such contaminants are assessed in the relevant section in relation to the appropriate drinking water standards which are assumed to have covered the carcinogenic, mutagenic and teratogenic properties as appropriate.

Persistent hydrocarbons and persistent and bioaccumulable organic toxic substances

Hydrocarbons are known to be in the disposed inventory and are routinely detected in surface waters and reported in terms of total organic carbon (TOC) (mean value of 10 μgl^{-1}) but not volatile organic carbon (VOC). Combination of VOC and TOC data can be useful in determining the speciation of hydrocarbon components. It is not clear whether analysis as VOC is not undertaken or whether the data are merely not reported in [1]. The determination of VOCs is routine in water analysis, and data of this sort may be of value.

Cyanides

Cyanides are also recorded in the current inventory, and have been detected in surface waters and site drains at average concentration being well below UK drinking water standards (50 μgl^{-1}). In view of the low concentrations, it seems inappropriate to mount a more extensive monitoring campaign.

Metals (in particular cadmium and mercury) and their compounds

Cadmium and its compounds

Cadmium is reported as part of the disposed inventory. Analysis of Vault 8 leachates indicate concentrations at or about the limit of detection, and well below the UK drinking water standards. No data are available for trench leachates. Analysis of water from site streams and drains has not revealed concentrations above the limits of detection. Unless assessments of the environmental impact of cadmium based on stream data or other information suggest a significant issue, no programme of targeted monitoring seems necessary.

Mercury and its compounds

Mercury is recorded in the current inventory and quantification has been attempted within leachates and surface waters. The data indicate that the concentrations in groundwater are at or about the UK drinking water standard (1 μgl^{-1}), but this seems to represent the limit of detection for the analytical methods used. Continued monitoring is recommended here. Analytical techniques with better sensitivity than those currently used might be an advantage, but only if readily available.

Arsenic and its compounds

Arsenic is not currently known to exist in the inventory. Analysis shows that small quantities are found in both trenches and surface waters, but at concentrations well below drinking water standards. Whilst the environmental impact of this material is likely to be very small, a desk-based assessment of the available data in terms of a potential inventory for trenches and Vault 8 might be of value.

Biocides and plant protection products

The trench leachate and surfaces waters were reportedly tested for pesticides in the extensive monitoring carried out in February and March 2005 [30]. Although no details relating to the compounds analysed nor the experimental data are presented, the levels are reported to be below the limit of detection. The environmental impact of this material is likely to be very small, and there seems little merit in measurement beyond the minimum required to demonstrate compliance with environmental legislation. The need to monitor for biocides should be reviewed.

6.2.2 Non-hazardous pollutants

A non-hazardous pollutant is defined as "*any pollutant other than a hazardous substance.*" The determined substances on the current list [15] that have been brought across from the 1980 Groundwater Directive [13] List II families of substances have been used to bound the current review.

Other metals and metalloids and their compounds

Of the 20 metals and metalloids previously included in List II, arsenic has been determined as hazardous and only Zn and Cu-soluble compounds have been included by JAGDAG in the current list of non-hazardous substances [15]. The remaining 17 are still to be determined by JAGDAG as either hazardous or non-hazardous [16][3]. The expectation would be that these metals would mostly be determined as non-hazardous, consistent with their inclusion on the previous List II. The information available indicates that Zn, Cu and twelve of the metals pending determination (Ni, Cr, Pb, Sb, Mo, Ti, Sn, Ba, B, U, V and Co) are well characterised in terms of inventory entries and measurement. The distribution of most of these substances within the site leachates and drains seems to be well characterised. Although in many cases the values in the surface waters are significantly lower than the Drinking Water Standards, the measurements are consistent with the contaminants leaching into the trench water. It will therefore be appropriate to continue monitoring these materials. The degree of monitoring of the remainder may depend on whether they are determined as hazardous in future reviews of the list in reference [16].

Data for selenium and beryllium (previously List II but not currently determined) suggest a slightly more complicated picture. In the case of selenium, the concentrations found in trench leachate and in surface waters are about the same, and at a similar level to the drinking water standard. Although beryllium has not been reported in leachate or surface waters at levels greater than the limit of detection (LOD) the LOD quoted for this material is similar to the drinking water standard. In neither of these cases is there a clear-cut need to recommend further work at this stage. However, the available data will be used as part of a formal assessment of the environmental impacts of releases of these materials. The position should be reviewed when these assessments are available, with a view to determining the need for further measurements if the assessments suggest that they are warranted. The degree of monitoring may depend whether these substances are determined as hazardous in future reviews of the list in reference [16].

Thallium, tellurium and silver (also List II but not currently determined) are not currently known to form part of the LLWR inventory, and have hence been the subject of only limited analysis. The presence in the inventory of these materials, at least in small quantities, cannot be excluded as LLWR is known to have accepted wastes from research facilities such as Harwell and Windscale where these materials may have been handled. The data

[3] It should also be noted that certain determined hazardous substances (e.g. Copper hydroxide, Copper sulphate) are currently categorised as biocide/metal. For the sake of this review, these will be considered under the category of '*biocides and plant protection products'.*

currently available are judged to be too sparse to eliminate the possibility of their presence. If determined as hazardous in future reviews of the list in reference [16], it may therefore become appropriate to mount a monitoring campaign to establish whether these materials can be found at significant levels in trench leachate or other waters from the LLWR site and thus to establish firmly whether or not they are present at non-trivial levels in the inventory.

Substances which have a deleterious effect on the taste and/or odour of groundwater

It is known that putrescible wastes and detergents are amongst such substances present in the inventory and there are a number of other substances which would have this effect on groundwater if present at high enough concentrations. However, various harmful substances and/or groups of compounds that fall into this category are potentially already being measured against DWS and so are being assessed as to whether they are safe. No suggestions specific to this category of non-hazardous substances are deemed appropriate.

Toxic or persistent organic silicon compounds

No such compounds were identified in the inventory and there is no evidence in references [1] or [20] to suggest that attempts have been made to measure them in trench leachate or groundwater. As for the metals thallium, tellurium and silver previously discussed, the presence in the inventory of these materials cannot be excluded due to the acceptance of wastes from research facilities, although the credible quantities are very small. It may therefore be appropriate to mount a monitoring campaign to establish whether these materials can be found at significant levels in trench leachate or other waters from the LLWR site and thus to confirm that they form at most only a trivial part of the inventory. In developing any monitoring regime the limit of detection of readily available techniques should be assessed against the potential releases from small quantities of material.

Inorganic compounds of phosphorous and elemental phosphorus

The only determined former-List II substance from this category is phosphoric acid. Although phosphorus and phosphate are quantified in the inventory and phosphate has been detected in the trench leachates and surface waters, there are no standards or guidelines relating to its concentration in drinking waters. As such, no programme of targeted monitoring seems necessary.

Fluorides

Fluoride is currently on the list of substances still to be determined [16] but is, however, quantified within the inventory and its distribution within the trench leachates and site drains seems to be well characterised. Although the fluoride concentration in the trench leachate is in excess of the DWS (1.5 mgl^{-1}), the values in the surface waters are significantly lower than the Drinking Water Standards. No programme of targeted monitoring seems necessary.

Ammonia and nitrites

The only determined former-List II substance from this category is ammonia whilst nitrites are currently on the list of substances still to be determined [16]. Ammonia is not known to exist in the inventory but ammonium compounds and nitrites are quantified, and both are significantly below their respective DWS (0.5 mgl^{-1} for both). No programme of targeted monitoring seems necessary

6.3 Future Inventory

Many of the hazardous and non-hazardous contaminants are already quantified in the future inventory, although other hazardous and non-hazardous contaminants do not currently appear to be accounted for, including arsenic. However, the CfA currently relies on the ability of the waste stream compiler/characteriser to correctly identify hazardous and non hazardous substances. The UK RWI does not allow for the capture of the level of detail required to show this association and thus identify the hazardous materials, either with a positive statement of the non-inclusion of these materials or with a comments field sufficient to capture the identity of the materials present.

It would be useful to ensure that the system of waste stream compilation/characterisation be reviewed so ensure that information regarding the inclusion and the quantity of all listed contaminants can be readily included in the disposal records of future waste consignments. Consideration should also be given to any improvements to the national inventory that might be requested.

6.4 Summary

An overview of the suggestions relating to the hazardous and non-hazardous groups of substances is provided in the following table. The nuances of the individual suggestions are not indicated and the table is intended to serve only as a simple summary of the outcomes of the assessment.

Suggestion	Hazardous Pollutants	Non-hazardous Pollutants
A. Sufficient monitoring data appears to be available; further action not felt necessary.	Cyanides Cadmium and its compounds Biocides and plant protection products	Deleterious on odour/taste Inorganic compounds of phosphorus and elemental phosphorus Fluorides Ammonia and Nitrites
B. Recommend that (further) desk-based assessment/evaluation should be performed in order to determine whether further monitoring is required.	Organohalogen compounds… Organotin compounds Arsenic and its compounds	
C. Review whether sufficient monitoring data have been acquired.	Organophosphorus compounds… Persistent hydrocarbons… *(unclear from data reviewed)* Mercury and its compounds	Toxic or persistent organic silicon compounds Copper Zinc [Other metals (if determined as hazardous): Antimony, Barium, Beryllium, Boron, Chromium, Cobalt, Lead, Molybdenum, Nickel, Selenium, Silver, Tellurium, Thallium, Tin, Titanium, Uranium & Vanadium]
D. Ensure hazardous materials are explicitly declared and quantified as well as practicably achievable in the future inventory.	All	All

Summary of the suggestions for hazardous and non-hazardous pollutants

7 Conclusion

The assessment of the inclusion of hazardous and non-hazardous pollutants in the inventory of disposals at LLWR has led to tailored suggestions for improvement of the characterisation of individual elements/compounds or groups of substances.

Suggestions have been made for any supplementary studies that could be undertaken in order to improve the quality of the inventory of non-radiological materials disposed at the LLWR where these could materially improve the quality of the 2011 ESC. Suggestions relating to individual substances, or groups of substances, are provided.

In conclusion, it is recommended that LLWR should consider the outcome of this review as part of the decision as to what environmental monitoring should be performed.

8 References

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Appendices

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Appendix 1 - Inventory Approaches for Missing Contaminants

One of the most significant difficulties of the inventory reported in [1] is that it fails to take account of at least one significant contaminant – cadmium – that is known to be present in trench porewater. This failing has almost certainly arisen because the presence of cadmium is not recorded in any of the available disposal records. Cadmium is a carcinogen, and as such could present a health hazard to future populations if it enters the accessible environment at significant levels.

For contaminants that are missing from the current inventory two approaches could be adopted to quantify the amounts present, if the available information permits this.

<u>Approach 1</u>

The first stage of this approach would be to analyse carefully the available monitoring data for non-radioactive contaminants in the trenches, to identify a complete list of contaminants that are known to be present in trench porewater. This list could then be compared with the contaminants declared in the inventory in [1] to identify the missing contaminants.

In previous work undertaken by Kelly [2] and ongoing work for the 2011 ESC, an approach has been developed in which trench leachate concentrations are related to waste concentrations through the use of "release coefficients". These are defined as follows:

$$RC = \frac{C_L}{C_W}$$

where RC is the release coefficient for a particular radionuclide or chemotoxic contaminant in the repository,

C_L (Bq m^{-3} or kg m^{-3}) is the concentration of the radionuclide or contaminant in leachate, and

C_W (Bq m^{-3} or kg m^{-3}) is the volumetric concentration of the radionuclide or contaminant in the wastes.

In the work undertaken in [2], the leachate concentrations C_L are obtained from the known monitoring data, and the release coefficients RC are then obtained by computing C_W and using the above equation. The release coefficients can then be used to define effective sorption coefficients, which then ensure that the computed leachate concentrations in assessment models are consistent with measured leachate concentrations.

In [2], the release coefficients and effective sorption coefficients were computed for the known components of the inventory (both radiological and non-radiological). The problem to be addressed here is how the release coefficient approach can be used to assist in quantifying the amounts of "unknown" contaminants in the repository.

Earlier work by NRPB [3] included the derivation of a set of release coefficients on the basis of leachate measurements available in the 1980s and earlier. For the missing contaminants that have release coefficients in [3], it would be possible to use the release coefficients in [3] along with the C_L values (obtained from contemporary monitoring data) to provide an estimate of C_W, and hence an estimate of the mass of the contaminants present in the trenches. Contaminant masses in the vaults could be obtained in a similar way, under the assumption that trench leachate concentration data apply also to the vaults.

Unfortunately, cadmium is not among the contaminants considered in [3]. However, zinc would provide a suitable chemical analogue, and this is covered in [3]. Indeed, the work reported in [4] made use of contemporary monitoring data to obtain a release coefficient for zinc, and this could be adopted for cadmium on the basis of chemical analogy.

Approach 2

Approach 2 would make use of assessment models to provide estimates of inventory. The aim would be to estimate leachate concentrations for unit disposals of the missing contaminants. In the absence of solubility limitation, the leachate concentrations are directly proportional to the disposed inventory. Thus, the actual leachate concentrations (as obtained from contemporary monitoring data) could be compared with the predicted concentrations for unit disposals to obtain estimates of the inventory of missing contaminants.

In general, assessment models provide cautious estimates of leachate concentration. This is because they usually incorporate simplifying, but cautious, assumptions about the representation of the disposal system under consideration. Therefore the inventory estimates obtained by this method would be lower bounds on the quantities present.

With this in mind, while Approach 2 is a plausible method for obtaining inventory estimates, Approach 1 is preferred because it is simpler and is likely to yield the best quality information about the inventory of missing contaminants, including uncertainty bounds. In particular, it makes best use of actual data that describe what is observed in the trenches, whereas approaches based on the use of assessment models will be subject to all the simplifications and uncertainties inherent in such models.

References

[1] A.S. Wareing, L. Eden, A. Jones and M. Ball, *LLWR Lifetime Project: The Inventory of Past and Future Disposals at the LLWR*, Nexia Solutions (07) 9124 issue 3, April 2008.

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Appendix 2 - Unknown Inventory

A significant component of the inventory provided in [1] is listed as “unknown”. This means that the material composition is unknown, though estimates have been provided for the mass of unknown contaminants.

In the Requirement 13 assessment [2], the unknown component of the inventory was treated by assuming that it was thallium. The rationale for this assumption is that thallium and its compounds are extremely toxic, and as such assuming that unknown materials are thallium will lead to cautious estimates of hazards to the human population. However, since thallium is not recorded in its own right in the inventory, and is not detected in trench porewater, the assumption has no logical foundation in the context of the LLWR.

An alternative approach is required. One such approach [3] could be to assume the total inventory (i.e. the sum of the known and unknown components) is taken to be composed of the same materials as the known inventory, and that materials are assumed to be present in the total inventory in the same relative proportions as they are in the known inventory.

To put this on a quantitative footing, let $M_{K,i}$ denote the known inventory of the i^{th} contaminant and let $M_{U,i}$ denote the unknown component, to be determined. The condition set out in the previous paragraph then becomes:

$$\frac{M_{K,i}}{M_{K,T}} = \frac{M_{K,i} + M_{U,i}}{M_{K,T} + M_{U,T}}$$

where

$$M_{K,T} = \sum_i M_{K,i}$$
$$M_{U,T} = \sum_i M_{U,i}$$

Simple rearranging then leads to:

$$M_{U,i} = M_{K,i} \frac{M_{U,T}}{M_{K,T}}$$

This scaling procedure would need to be undertaken following the application of procedures described in the previous section, to estimate the inventories of contaminants that are missing from the current inventory.

References

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Appendix 3 - Review of hazardous pollutants

Hazardous Material	Known in Inventory?	Measured?	Detail(s) and Reference(s)[iv]	Credible in Inventory	Comments	Suggestions for further assessment?
Organohalogen compounds and substances that may form such compounds in the aquatic environment	Yes	Yes (significant quantities detected)	Trichloroethane known to be present in inventory [Table 12, Lean et al. 2004] although it is not quantified. Trichloroethylene (TCE) and similar compounds quantified in trench probes to levels significantly >LOD and some measurements >DWS. A couple of compounds are >WHO drinking water limit. [Table 27, Barber and Henderson, 2008]. Polychlorinated biphenyls (PCBs) measured in stream and drain samples <LOD. [Table 20, Lean et al. 2004].	-	DWS for trichloroethene and tetrachloroethene is 10 $\mu g l^{-1}$ (sum of compounds). Soluble to some extent and so a comparison of their movement from the trenches is required.	Short-term: are there data available for a desk-based study? Perform a series of leachate measurements. Long-term: further measurements may be advisable.
Organophosphorus compounds	Yes	Yes (1 non-zero measurement)	Tributyl phosphate known to be present in inventory [Table 12, Lean et al. 2004] although it is not quantified. Tributyl phosphate measured in East-West stream. [Table 20, Lean et al. 2004].	-	Not clear what the LOD is and insubstantial data. Credible in the inventory although no reason to expect any other compounds in significant quantities.	Analyse trench leachate for tributyl phosphate and further E-W stream measurements required. Long-term: may be appropriate to monitor.
Organotin compounds	No	No	No evidence in data available.	Yes, used to stabilise PVC.	Probably has not been looked for.	Short-term: review available data. Long-term actions may include environmental monitoring.

[iv] References are to be found in the main reference list, Section 8 of report.

Hazardous Material	Known in Inventory?	Measured?	Detail(s) and Reference(s)[iv]	Credible in Inventory	Comments	Suggestions for further assessment?
Substances and preparations, or the breakdown products of such, which have been proved to possess carcinogenic or mutagenic properties or properties which may affect steroidogenic, thyroid, reproduction or other endocrine-related functions in or via the aquatic environment	-	-	Hazardous substances with these properties are discussed in relevant field of table. No additional materials identified in the inventory or monitoring data.	-	-	-
Persistent hydrocarbons and persistent and bioaccumulable organic toxic substances	Yes	Yes	Known to be present and quantified in inventory [Table 10, Wareing et al. 2008 and Table 5, Lean et al. 2004]. TOC (which will include, but not exclusively, breakdown products) detected up to max. levels of 57, 20 and 21 $\mu g l^{-1}$ in trench probe leachates, Vault 8 leachates and surface waters, respectively [Tables 26, 28 and 31 Barber and Henderson, 2008]. Odourless kerosene was analysed but not found (if data are credible); toluene <LOD and phenol >LOD in limited analysis [Table 20, Lean et al. 2004].	-	Dissolution of e.g. benzene and toluene will occur at low levels.	Perform VOC testing to align with landfill practice.

Hazardous Material	Known in Inventory?	Measured?	Detail(s) and Reference(s)[iv]	Credible in Inventory	Comments	Suggestions for further assessment?
Cyanides	Yes	Yes	Known to be present in inventory [Table 12, Lean et al. 2004] although not quantified. It does not appear to have been monitored in the trench probe leachate [Table 6, Barber and Henderson, 2008] and results not clear for Vault 8 leachate. In stream/drain samples <LOD (10 μgl^{-1}) [Table 20, Lean et al. 2004]. For surface water/drain sampling 4 of 20 samples >DWS but average is well below limits [Table 31, Barber and Henderson, 2008].	-	DWS 50 μgl^{-1} so no cause for concern over leachate levels outside of trenches. Effects on human health have not been assessed in Barber and Henderson, 2008.	More extensive monitoring seems unecessary.
Metals (in particular cadmium and mercury) and their compounds						
Cadmium and its compounds	Yes	Yes (significant	Cadmium is known and quantified in the inventory [Table 5, Lean et al. 2004]. Not clear if trench leachate was analysed for Cd but Vault 8 leachate at/around LOD and <DWS [Tables 26 and 28, Barber and Henderson, 2008]. Stream/drain concentrations<LOD and <DWS [Table 20, Lean et al. 2004].	-	Effects on human health have not been assessed in Barber and Henderson, 2008.	Assessment could be performed on the human health impacts using data from streams/drains. No targeted monitoring programme required unless the human health assessment indicates otherwise.

Hazardous Material	Known in Inventory?	Measured?	Detail(s) and Reference(s)[iv]	Credible in Inventory	Comments	Suggestions for further assessment?
Mercury and its compounds	Yes	Yes (all positive measurements outside trenches are at/around LOD)	Known and quantified in Inventory [Table 5, Lean et al. 2004]. Max. 0.3 μgl^{-1} in leachate/Vault 8 drain sample [Table 28, Barber and Henderson, 2008]. LOD (2 μgl^{-1}) for mercury in surface water/drains >DWS. [Table 31, Barber and Henderson, 2008]. Stream and drain samples <LOD (8.5 μgl^{-1}) [Table 20, Lean et al. 2004].	-	DWS 1 μgl^{-1}. A significant number of samples analysed but different LOD quoted implies different methods used. LODs imply that measurements are difficult.	Unless the LOD can be improved then no suggestions for a targeted monitoring programme.
Arsenic and its compounds	No	Yes	Not known to exist in the inventory. Trench leachate ~0.0034 mgl^{-1}; leachate/Vault 8 ~0.0013 mgl^{-1}; surface waters ~0.001 mgl^{-1} [Tables 26, 28, 31, Barber and Henderson, 2008].	-	DWS 0.01 mgl^{-1} so no cause for concern over leachate levels outside of trenches.	Review whether to estimate an inventory from the assessment. May be appropriate to monitor.
Biocides and plant protection products	No	Yes	Leachate was tested for pesticides in Feb and March 2005 and was <LOD. [Barber and Henderson, 2008, p46]. Contamination arising from herbicide application is covered in [Fowler and Barber, 2006].	No	Probably not an inventory related issue.	Review the need to monitor.

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Appendix 4 - Review of non-hazardous pollutants

Non-hazardous Material	Known in Inventory?	Measured?	Detail(s) and Reference(s)	Credible in Inventory	Comments	Suggestions for further assessment?
Other metals						
Zinc	Yes	Yes	Known and quantified in Inventory [Table 10, Wareing et al. 2008 and Table 5, Lean et al. 2004]. Trench leachate ~23 mgl^{-1}; leachate/Vault 8 ~55 μgl^{-1}; surface waters ~39 μgl^{-1} [Tables 26, 28, 31, Barber and Henderson, 2008].	-	DWS 5 mgl^{-1} so no cause for concern over leachate levels outside of trenches.	May be appropriate to continue monitoring.
Copper	Yes	Yes	Known and quantified in Inventory [Table 10, Wareing et al. 2008 and Table 5, Lean et al. 2004]. Trench leachate ~0.05 mgl^{-1}; leachate/Vault 8 ~0.03 mgl^{-1}; surface waters ~0.01 mgl^{-1} [Tables 26, 28, 31, Barber and Henderson, 2008].	-	DWS 2 mgl^{-1} so no cause for concern over leachate levels outside of trenches.	May be appropriate to continue monitoring.
Nickel	Yes	Yes	Known and quantified in Inventory [Table 10, Wareing et al. 2008 and Table 5, Lean et al. 2004]. Trench leachate ~0.1 mgl^{-1}; leachate/Vault 8 ~0.1 mgl^{-1}; surface waters ~0.007 mgl^{-1} [Tables 26, 28, 31, Barber and Henderson, 2008].	-	DWS 0.02 mgl^{-1} so no cause for concern over leachate levels outside of trenches.	May be appropriate to continue monitoring. Degree of monitoring may depend whether determined as hazardous/non-hazardous.
Chrome	Yes	Yes	Known in Inventory although not quantified [Table 12, Lean et al. 2004]. Trench leachate ~0.03 mgl^{-1}; leachate/Vault 8 ~0.006 mgl^{-1}; surface waters ~0.006 mgl^{-1} [Tables 26, 28, 31, Barber and Henderson, 2008].	-	DWS 0.05 mgl^{-1} so no cause for concern over leachate levels outside of trenches.	May be appropriate to continue monitoring. Degree of monitoring may depend whether determined as hazardous/non-hazardous.

Non-hazardous Material	Known in Inventory?	Measured?	Detail(s) and Reference(s)	Credible in Inventory	Comments	Suggestions for further assessment?
Lead	Yes	Yes	Known and quantified in Inventory [Table 10, Wareing et al. 2008 and Table 5, Lean et al. 2004]. Trench leachate ~0.026 mgl^{-1}; leachate/Vault 8 ~0.001 mgl^{-1}; surface waters ~0.001 mgl^{-1} [Tables 26, 28, 31, Barber and Henderson, 2008].	-	DWS 0.01 mgl^{-1} so no cause for concern over leachate levels outside of trenches.	May be appropriate to continue monitoring. Degree of monitoring may depend whether determined as hazardous/non-hazardous.
Selenium	Yes	Yes	Known and quantified in Inventory [Table 5, Lean et al. 2004]. Trench leachate ~0.006 mgl^{-1}; leachate/Vault 8 ~0.005 mgl^{-1}; surface waters ~0.01 mgl^{-1} [Tables 26, 28, 31, Barber and Henderson, 2008].	-	DWS 0.01 mgl^{-1} so some cause for concern as the surface water concentration is at/around the DWS. Has not been assessed for human health impact [Barber and Henderson, 2008].	Wait for assessment of impacts to human health to determine whether further studies are required. Degree of monitoring may depend whether determined as hazardous/non-hazardous.
Antimony	No	Yes	Not known to exist in the inventory. Trench leachate ~0.0007 mgl^{-1}; no evidence for analysis in leachate/Vault 8 or surface waters [Tables 26, 28, 31, Barber and Henderson, 2008].	-	DWS 0.005 mgl^{-1} so probably no cause for concern over leachate levels outside of trenches.	Review whether to estimate an inventory from the assessment. May be appropriate to continue monitoring. Degree of monitoring may depend whether determined as hazardous/non-hazardous.
Molybdenum	Yes	Yes	Known and quantified in Inventory [Table 10, Wareing et al. 2008 and Table 5, Lean et al. 2004]. Trench leachate ~0.04 mgl^{-1} (with max. 0.07 mgl^{-1}); no evidence for analysis in leachate/Vault 8 or surface waters [Tables 26, 28, 31, Barber and Henderson, 2008].	-	WHO 0.07 mgl^{-1}. Maximum concentration in trench leachate is approaching WHO limits. Assessed for human health impact [Barber and Henderson, 2008].	May be appropriate to continue monitoring. Degree of monitoring may depend whether determined as hazardous/non-hazardous.

Non-hazardous Material	Known in Inventory?	Measured?	Detail(s) and Reference(s)	Credible in Inventory	Comments	Suggestions for further assessment?
Titanium	No	Yes	Not known to exist in the inventory. In limited trench probe leachate analysis Ti was <LOD in 2 [Table 18, Lean et al. 2004]. No evidence for analysis in leachate/Vault 8 or surface waters [Tables 26, 28, 31, Barber and Henderson, 2008]	-	No DWS or WHO guidelines regarding Ti.	May be appropriate to continue monitoring. Degree of monitoring may depend whether determined as hazardous/non-hazardous.
Tin	Yes	Yes	Known and quantified in Inventory [Table 5, Lean et al. 2004]. Trench leachate ~0.04 mgl^{-1}; leachate/Vault 8 ~0.0004 mgl^{-1}; surface waters ~0.0003 mgl^{-1} [Tables 26, 28, 31, Barber and Henderson, 2008].	-	Fresh Water EQS 0.025 mgl^{-1} so no cause for concern over leachate levels outside of trenches.	May be appropriate to continue monitoring. Degree of monitoring may depend whether determined as hazardous/non-hazardous.
Barium	Yes	Yes	Known in Inventory although not quantified [Table 12, Lean et al. 2004]. Trench leachate 1.6 mgl^{-1}; leachate/Vault 8 ~0.18 mgl^{-1}; surface waters ~0.05 mgl^{-1} [Tables 26, 28, 31, Barber and Henderson, 2008].	-	DWS 1 mgl^{-1} so no cause for concern over leachate levels outside of trenches.	May be appropriate to continue monitoring. Degree of monitoring may depend whether determined as hazardous/non-hazardous.
Beryllium	Yes	Yes	Known and quantified in Inventory [Table 5, Lean et al. 2004]. Trench leachate <0.005 mgl^{-1}; no evidence for analysis in leachate/Vault 8 or surface waters [Tables 26, 28, 31, Barber and Henderson, 2008].	-	USEPA maximum contaminant level (MCL) in drinking water is 0.004 mgl^{-1}.	Wait for assessment of impacts to human health to determine whether further monitoring is required. Degree of monitoring may depend whether determined as hazardous/non-hazardous.

Non-hazardous Material	Known in Inventory?	Measured?	Detail(s) and Reference(s)	Credible in Inventory	Comments	Suggestions for further assessment?
Boron	Yes	Yes	Known in Inventory although not quantified [Table 12, Lean et al. 2004]. Trench leachate 0.5 mgl^{-1}; leachate/Vault 8 ~0.26 mgl^{-1}; surface waters ~0.2 mgl^{-1} [Tables 26, 28, 31, Barber and Henderson, 2008].	-	Issue regarding detectability of B as min, mean and max of surface water are all at/around LOD. DWS 1 mgl^{-1} so no cause for concern over leachate levels outside of trenches.	May be appropriate to continue monitoring. Degree of monitoring may depend whether determined as hazardous/non-hazardous.
Uranium	Yes	Yes	Known and quantified in Inventory [Table 10, Wareing et al. 2008 and Table 5, Lean et al. 2004]. U-238: Trench leachate 0.5 mgl^{-1}; no evidence for analysis in leachate/Vault 8 or surface waters [Tables 26, 28, 31, Barber and Henderson, 2008].	-	WHO guideline limit is 15 μgl^{-1}. More detailed analysis will be available in radiological assessments. Assessed for human health impact [Barber and Henderson, 2008].	May be appropriate to continue monitoring. Degree of monitoring likely to depend on monitoring for radioactivity assessments rather than chemotoxicological.
Vanadium	Yes	Yes	Known in Inventory although not quantified [Table 12, Lean et al. 2004]. Trench leachate 0.04 mgl^{-1}; leachate/Vault 8 ~0.0049 mgl^{-1}; surface waters ~0.0034 mgl^{-1} [Tables 26, 28, 31, Barber and Henderson, 2008].	-	Fresh Water EQS 0.02-0.06 mgl^{-1} so no cause for concern over leachate levels outside of trenches.	May be appropriate to continue monitoring. Degree of monitoring may depend whether determined as hazardous/non-hazardous.
Cobalt	Yes	Yes	Known in Inventory although not quantified [Table 12, Lean et al. 2004]. Trench leachate 0.04 mgl^{-1}; no evidence for analysis in leachate/Vault 8 or surface waters [Tables 26, 28, 31, Barber and Henderson, 2008].	-	No guidelines.	May be appropriate to continue monitoring. Degree of monitoring may depend whether determined as hazardous/non-hazardous.

Non-hazardous Material	Known in Inventory?	Measured?	Detail(s) and Reference(s)	Credible in Inventory	Comments	Suggestions for further assessment?
Thallium	No	Yes	Thallium is used in the inventory to represent all "unknown metals" but it is actually unrecorded itself in the inventory. [Barber and Henderson, 2008] Limited analysis of stream and drain leachate showed levels <LOD. [Table 20, Lean et al. 2004]. No evidence that it has been analysed in trench probe leachate	No	USEPA maximum contaminant level (MCL) in drinking water is 0.002 mgl^{-1}. Potential small-scale arisings from consignments from research labs.	May be appropriate to mount a monitoring campaign. Degree of monitoring may depend whether determined as hazardous/non-hazardous.
Tellurium	No	Yes	Not known to exist in the inventory. Limited analysis of stream and drain leachate showed levels <LOD. [Table 20, Lean et al. 2004]. No evidence that it has been analysed in trench probe leachate.	No	No guidelines. Potential small-scale arisings from consignments from research labs.	May be appropriate to mount a monitoring campaign. Degree of monitoring may depend whether determined as hazardous/non-hazardous.
Silver	No	No	Not known to exist in the inventory. No evidence that it has been analysed anywhere.	No	No guidelines. Potential small-scale arisings from consignments from research labs.	May be appropriate to mount a monitoring campaign. Degree of monitoring may depend whether determined as hazardous/non-hazardous.

Non-hazardous Material	Known in Inventory?	Measured?	Detail(s) and Reference(s)	Credible in Inventory	Comments	Suggestions for further assessment?
Substances that have a deleterious effect on the taste and/or odour of groundwater…	Some	Yes	Putrescible wastes and detergents are known to be in the inventory. [Tables 5 and 12, Lean et al. 2004].		There are a number of substances which would have this effect on groundwater if present at high enough concentrations. However, substances/groups of compounds are already being measured against DWS and so are being assessed as to whether they are safe.	No suggestions for further action.
Toxic or persistent organic compounds of silicon	No	No	None identified in inventory and no evidence that any have been looked for in analysis of trench probe leachate.	No	No materials credibly present at significant concentrations can be identified. Potential small-scale arisings from consignments from research labs.	Review the need to monitor.
Inorganic compounds of phosphorus and elemental phosphorus	Yes	Yes	Phosphorus and phosphate are quantified in the inventory [Table 5, Lean et al. 2004]. Phosphate in trench leachate 0.1 mgl^{-1}; leachate/Vault 8 ~0.0005 mgl^{-1}; surface waters ~0.0005 mgl^{-1} [Tables 26, 28, 31, Barber and Henderson, 2008].	-	No guidelines.	No programme of targeted monitoring seems necessary

Non-hazardous Material	Known in Inventory?	Measured?	Detail(s) and Reference(s)	Credible in Inventory	Comments	Suggestions for further assessment?
Fluorides	Yes	Yes	Known and quantified in Inventory [Table 5, Lean et al. 2004]. Trench leachate 3.5 mgl^{-1}; leachate/Vault 8 ~0.0005 mgl^{-1}; surface waters ~0.0017 mgl^{-1} [Tables 26, 28, 31, Barber and Henderson, 2008].	-	DWS 1.5 mgl^{-1} so no cause for concern over leachate levels outside of trenches.	No programme of targeted monitoring seems necessary
Ammonia and nitrites	No	Yes	Not known to exist in inventory. Ammonia is not measured but ammonium is: Trench leachate 56 mgl^{-1}; leachate/Vault 8 ~0.0007 mgl^{-1}; surface waters ~0.0004 mgl^{-1} [Tables 26, 28, 31, Barber and Henderson, 2008]. Nitrite: leachate/Vault 8 ~0.0001 mgl^{-1}; surface waters ~0.0002 mgl^{-1} [Tables 26, 28, 31, Barber and Henderson, 2008].	-	No DWS for ammonia but ammonium DWS 0.5 mgl^{-1} so no cause for concern over leachate levels outside of trenches. Nitrite DWS 0.5 mgl^{-1} so no cause for concern over leachate levels outside of trenches.	No programme of targeted monitoring seems necessary