LLW Repository Ltd

Low Level Waste Repository

Environmental Safety Case

Assessment of Uncertainty in the LLWR Inventory for Key Radionuclides

This report was prepared by the National Nuclear Laboratory for and on behalf of the Low Level Waste Repository Site Licence Company.

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National Nuclear Laboratory

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Issue 1

A report prepared for and on behalf of
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EXECUTIVE SUMMARY

The Low Level Waste Repository (LLWR) is undertaking a programme of work leading to the production of an Environmental Safety Case by May 2011 (2011 ESC). The 2011 ESC will be submitted to the Environment Agency (EA) in order to satisfy a Requirement in the LLWR's current authorisation.

In developing the 2011 ESC LLWR would like to improve their knowledge of the inventory of key radionuclides in more detail, covering ^{234}U, ^{238}U, ^{36}Cl, ^{99}Tc, ^{226}Ra and ^{129}I, and considering waste streams contributing greater than 1% each of total activity for these radionuclides. The assessment presented in this report supports an improved and more realistic consideration of the impact of ^{234}U, ^{238}U, ^{36}Cl, ^{99}Tc, ^{226}Ra and ^{129}I.

Analysis of the 2007 UK National Inventory has shown increases in future forecast activity compared to those presented in the 2004 UK National Inventory for ^{234}U, ^{99}Tc, ^{226}Ra and ^{129}I designated for LLWR disposal, whilst forecast activities for ^{238}U and ^{36}Cl have decreased by around 50%. Increases in activity for ^{99}Tc, ^{226}Ra and ^{129}I are up to three orders of magnitude and are each attributed to activity contributed by a single key waste stream. It is noted that the observed increases are attributed to waste streams for which the fingerprints are likely to undergo significant revision downwards or, in the case of ^{226}Ra, to a waste stream for which LLWR disposal is unlikely to be viable.

Assessment of the estimated inventory for waste stream 2B03 (empty hexafluoride cylinders at Capenhurst), the principal source of activity for uranium and ^{99}Tc, has shown that it is likely to be conservative, with the 2007 UK National Inventory fingerprint being for the waste prior to potential treatment which may remove or reduce the activity content.

Assessment of waste stream 7S01 (Defence estates contaminated soil & rubble), the principal source of activity for ^{226}Ra has shown that its activity content would breach current annual and site limits for $^{226}Ra/^{232}Th$, were it to be disposed to the LLWR.

Errors arising in the estimation of the fingerprint for Sellafield waste streams have been shown to account for activity overestimates of up to three orders of magnitude for ^{129}I (in waste stream 2X71). Sellafield Ltd are continuing to review data on their waste streams in the light of these errors.

Investigation of the material content of waste streams destined for the LLWR has shown that the majority of future forecast activity for all the radionuclides of interest is contained within metals or soil and rubble. Upper estimate activity levels in specific material types were calculated by assuming, for each material type within a waste stream, that all the waste stream activity for a radionuclide is in that material. Examination of these upper estimate specific activities showed that, typically, large deviations from the best estimate across the whole of the waste were only observed for materials with very small volumes, such as complexants; whilst deviations in specific activity for materials with large volumes, such as metals, were not significant.

Magnox future decommissioning wastes, a significant source of ^{36}Cl activity, are to be reviewed by Magnox, with potentially a large proportion of the volume being reclassified as VLLW.

An assessment of historical GE Healthcare disposals has highlighted larger quantities of ^{36}Cl, ^{99}Tc and ^{226}Ra in the trenches than in future forecasts. It is recommended that further data should be sought from GE Healthcare.

Pending confirmation of initial findings, the future forecast activities of ^{234}U, ^{238}U, ^{36}Cl, ^{99}Tc, ^{226}Ra and ^{129}I calculated in 2008 are unlikely to change substantially. Increases in the ^{234}U, ^{99}Tc, ^{226}Ra and ^{129}I inventories for the 2007 UK National Inventory are attributed either to waste streams for which radionuclide fingerprints are likely to undergo significant revision downwards or, in the case of ^{226}Ra, to a waste stream for which LLWR disposal is unlikely to be viable. Future forecasts for both ^{234}U and ^{238}U may

be reduced following potential revision of the 2B03 fingerprint, since activity from the top-contributing waste stream in the 2004 UK National Inventory, 2E101, has been removed in the 2007 UK National Inventory. However, if total alpha activity in 2E101 were to be assigned to ^{234}U and/or ^{238}U then future forecasts for these radionuclides could increase by up to 55%.

It is recognised that uncertainties in the waste streams contributing less than 1% of future forecast activity may contribute additional activity, if the upper band limits given in the 2007 UK National Inventory were to apply.

VERIFICATION STATEMENT

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

- The document meets the requirements as defined in the task specification/scope statement
- The constraints are valid
- The assumptions are reasonable
- The document demonstrates that the project is using the latest company approved data
- The document is internally self consistent

HISTORY SHEET

Issue Number	Date	Comments
Issue 0.1	30/03/09	Issue for customer comment
Issue 1	18/06/09	Issue addressing customer comments

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The Low Level Waste Repository (LLWR) is undertaking a programme of work leading to the production of an Environmental Safety Case by May 2011 (2011 ESC). The 2011 ESC will be submitted to the Environment Agency (EA) in order to satisfy a Requirement in the LLWR's current authorisation.

In developing the 2011 ESC, the LLWR would like to improve their knowledge of the inventory of ^{234}U, ^{238}U, ^{36}Cl, ^{99}Tc, ^{226}Ra and ^{129}I in more detail and considering waste streams contributing greater than 1% each of total activity for these radionuclides. As part of work to support a submission to the Environment Agency on 1st May 2008, assessments of the inventory and its spatial variation were undertaken (Wareing *et al.*, 2008; Lennon *et al*., 2008). This work was directed at getting a better understanding of the quantity and distribution of certain key radionuclides.

The assessment presented in this report supports an improved and more realistic consideration of the inventories of ^{234}U, ^{238}U, ^{36}Cl, ^{99}Tc, ^{226}Ra and ^{129}I.

A review of work undertaken to date is given in Section 2, with current inventory data sources discussed in Section 3. Section 4 presents the assessment of uncertainty in the LLWR future inventory for these radionuclides.

It is noted that, in the process of reviewing the 2007 UK National Inventory source data with the Sellafield consignor, a number of errors were discovered, which reveal a significant overestimate in the forecast inventory for particular waste streams. Corrected data were supplied by Sellafield Ltd for some waste streams, but it should be recognised that investigations are ongoing, and the findings of this report may need to be reviewed once the complete set of revised data is available. Sections 2 and 3 discuss the inventory data as presented in the 2007 UK National Inventory, whilst Section 4 utilises the corrected data.

2. Review of work to date

The inventory of past and potential future disposals at the LLWR (Wareing *et al.,* 2008) was calculated both as part of the LLWR's response to the EA's requirements under Schedule 9 of the Authorisation and as part of the preparation for the 2011 ESC.

The following subsections summarise the key findings in previous work, covering the LLWR inventory of disposals for ^{234}U, ^{238}U, ^{36}Cl, ^{99}Tc, ^{226}Ra and ^{129}I.

2.1. LLWR radionuclide inventory

The derivation of the LLWR inventory (Wareing *et al*., 2008) was carried out in the 2007/08 financial year, prior to the publication of the 2007 UK National Inventory. Three components of the inventory were considered:

1. The Trench inventory, representing the inventory disposed to the trenches from the start of LLW operations in 1959 up to the date when trench disposals were first recorded on the waste tracking system in July 1993.
2. The Vault 8 inventory, based on the contents of the waste tracking system database, and covering the period from the start of Vault 8 operations until the present day. For this analysis the system database was frozen at April 2007.
3. The future vaults inventory, based on the 2004 UK National Inventory (Electrowatt-Ekono, 2005).

The LLWR's waste tracking system database is currently used to track and locate disposals in Vault 8. The waste tracking system database contains the full inventory of disposals to Vault 8 and the latter portion of Trench 7 extracted directly from the disposal records, as well as additional useful information from WAMAC and LLWR operations. Information stored in the waste tracking system database has proven to be useful but is limited in describing disposals over the period 1988 to 2007. It does not contain the full data-set for historic consignments to the trenches, thereby requiring some conceptual modelling to complete the inventory determination.

The 2004 UK National Inventory represented the most up-to-date public domain data source at the time of calculating the inventory, providing information on radioactive waste streams with the potential to be consigned to the LLWR, both from within and without the nuclear industry.

^{234}U and ^{238}U are both naturally-occurring isotopes of uranium present in nuclear fuel, with over 99% by mass of natural uranium comprising ^{238}U. Uranium isotopes are present in UK LLW as a direct result of fuel manufacture and reprocessing operations. In the 2002 Safety Cases, disposals to the trenches from Springfields accounted for around 90% of the total derived site activity for ^{234}U and ^{238}U at the time of closure. Subsequent work carried out (Lennon, 2007) using the paper-based disposals records resulted in a fully mapped trench uranium inventory with a uranium content approximately half that calculated for the 2002 Safety Cases. An increase in the calculated future forecast inventory for ^{234}U and ^{238}U, with over 90% from a single Springfields decommissioning waste stream, has led to the current LLWR inventory of disposals being more evenly distributed across the trenches and vaults.

^{36}Cl is an activation product generated within the core fuel of nuclear reactors. It arises predominantly as secondary contamination in the structural steel and concrete and in the graphite moderator following operations such as defuelling. Much of the ^{36}Cl-bearing decommissioning wastes will not arise until after 2040. As such, over 60% of ^{36}Cl in the

LLWR inventory of disposals calculated in Wareing *et al*. (2008) is in the future vaults, with an activity 50 times greater than in the trenches.

^{99}Tc is a fission product that is commonly found in wastes arising from the nuclear fuel cycle. There is significant weighting of the LLWR site ^{99}Tc inventory towards Vault 8, the inventory of which was derived from actual electronically-stored disposal records.

The derived ^{226}Ra activity is distributed approximately equally between the trenches and the vaults. The majority of radium activity in the trenches is due to specific disposals of process residues from Thorium Ltd. ^{226}Ra activity in the vaults will arise mainly from waste generated during land remediation.

^{129}I is evenly distributed across the trench and vault disposal areas. This is a fission product found in a range of routine operational and decommissioning waste streams. Around 40% of ^{129}I activity in the future vaults inventory is contributed by a single operational waste stream covering routine operations across the Sellafield site: 2D53, Site Services LLW. This waste stream has also contributed significantly to the derived historical trench inventory, which has been estimated by backfitting.

The total inventories of ^{234}U, ^{238}U, ^{36}Cl, ^{99}Tc, ^{226}Ra and ^{129}I calculated in Wareing *et al*. (2008) for the trenches and vaults are as given in Table 1.

Table 1 Total activity contents of LLWR inventory for ^{234}U, ^{238}U, ^{36}Cl, ^{99}Tc, ^{226}Ra and ^{129}I, derived in Wareing *et al*. (2008), by disposal area

Radionuclide	Disposal Area	Total activity (TBq)	% of LLWR total for radionuclide
^{234}U	Trenches	5.80E+00	67.9
	Vault 8	3.58E-01	4.1
	Future Vaults	2.43E+00	28.0
^{238}U	Trenches	6.70E+00	50.8
	Vault 8	4.16E-01	3.2
	Future Vaults	6.07E+00	46.0
^{99}Tc	Trenches	2.05E-01	6.2
	Vault 8	2.64E+00	79.9
	Future Vaults	4.58E-01	13.9
^{36}Cl	Trenches	1.85E-02	1.2
	Vault 8	5.58E-01	36.7
	Future Vaults	9.45E-01	62.1
^{226}Ra	Trenches	2.90E-01	36.2
	Vault 8	4.76E-02	5.9
	Future Vaults	4.65E-01	57.9
^{129}I	Trenches	2.95E-03	38.1
	Vault 8	2.41E-03	31.2
	Future Vaults	2.38E-03	30.7

Trench inventories of ^{36}Cl, ^{99}Tc, and ^{129}I were calculated from the backfitting of Vault 8 disposal records and present-day or future forecast waste streams in the 2004 UK National Inventory considered representative of historical disposals. ^{36}Cl activity was predominantly derived from Amersham and Sellafield waste streams, ^{99}Tc from Sellafield and Capenhurst waste streams (uranium hexafluoride cylinders), and ^{129}I predominantly from Sellafield waste streams.

Trench inventories of ^{238}U, ^{234}U and ^{226}Ra have been derived largely from the historical disposal records for specific disposals; the uranium activity comprising Springfields uranic residues and the ^{226}Ra originating from the disposal of thorite residues from the chemical extraction industry.

The Vault 8 inventory was derived predominantly from actual disposal data, occasionally augmented with information from the 2004 UK National Inventory for disposal records where detailed radionuclide activity or materials data were not available. The waste tracking system database was assessed to identify the majority contributors of the activity declared as disposed to Vault 8 for the radionuclides of interest, as shown in Table 2.

Table 2 Majority contributors of activity disposed to Vault 8, extracted from the waste tracking system database.

Radionuclide	Consignor	Associated waste volume (m^3)	Percentage of total volume (%)	Waste activity (TBq)	Percentage of declared V8 activity (%)
^{234}U	Sellafield	68232	28.7	1.63E-01	69.2
	Capenhurst	4381	1.8	3.15E-02	13.4
	Aldermaston	4678	1.9	1.26E-02	5.4
^{238}U	Sellafield	72890	30.7	1.52E-01	53.4
	Capenhurst	4381	1.8	2.72E-02	9.5
	Eskmeals	30	0.01	2.46E-02	8.6
^{99}Tc	Capenhurst	4381	1.8	2.45E+00	94.5
	Sellafield	70195	29.5	1.00E-01	3.9
	Amersham	597	0.25	2.05E-02	0.8
^{36}Cl	Amersham	1133	0.5	3.26E-01	85.2
	Heysham 1	991	0.4	1.24E-02	3.2
	Hartlepool	340	0.14	8.90E-03	2.3
^{226}Ra	Amersham	3979	1.7	1.23E-02	25.8
	RAF Carlisle	377	0.16	8.75E-03	18.4
	Harwell	4558	1.9	7.38E-03	15.5
^{129}I	Sellafield	41343	17.4	2.17E-03	82.7
	Amersham	384	0.16	2.66E-04	10.1
	Winfrith	1558	0.65	1.28E-04	4.9

It can be seen in Table 2 that the majority of the activity for the radionuclides of interest in the Vault 8 inventory has been provided by a small number of consignors and, with the exception of ^{226}Ra, can in each case be mostly accounted for by just one significant consignor.

The future vaults inventory was calculated from the waste stream arisings data provided in the 2004 UK National Inventory. This information concerns waste stream stock and forecast arising volumes, radionuclide fingerprint activities per unit volume and material contents. Table 3 shows those waste streams that will, if consigned, contribute the majority of the total disposed activity for each of the radionuclides of interest.

Table 3 Majority contributors of key radionuclide activity to the Future Vaults Inventory (based on 2004 UK Radioactive Waste Inventory).

Radio-nuclide	Waste Stream	Waste Stream Description	Waste volume (m^3)	% of total volume	Activity (TBq)	% of total Activity
^{234}U	2E101	Decommissioning LLW	3,647	0.45	2.21E+00	90.9
	7A114	Decommissioning LLW Suitable for Disposal at Drigg - Enriched Uranium	1,982	0.24	1.23E-01	5.1
	2D53	Site Services LLW	111,905	13.83	3.18E-02	1.3
	2F23	Low Level Waste	22,627	2.80	1.53E-02	0.6
	2D49	High Active Waste Plants LLW	13,459	1.66	1.27E-02	0.5
	8A03	Contaminated Combustible Waste	1,733	0.21	8.67E-03	0.4
	5C309	Decommissioning: Other Facilities LLW	5,141	0.64	6.17E-03	0.3
^{238}U	2E101	Decommissioning LLW	3,647	0.45	5.69E+00	93.7
	7A33	Radioactive Contaminated Land	197,065	24.36	2.01E-01	3.3
	2D53	Site Services LLW	117,906	14.57	1.24E-01	2.0
	5C309	Decommissioning: Other Facilities LLW	5,141	0.64	1.23E-02	0.2
	8A03	Contaminated Combustible Waste	1,733	0.21	8.67E-03	0.1
	6H02	LLW (Minor Users)	8,600	1.06	8.60E-03	0.1
	2F23	Low Level Waste	22,627	2.80	6.45E-03	0.1
^{99}Tc	2E101	Decommissioning LLW	3,647	0.45	3.42E-01	74.7
	2D53	Site Services LLW	117,906	14.57	6.12E-02	13.4
	5G301	SGHWR Decommissioning LLW	8,604	1.06	2.24E-02	4.9
	2D47	Magnox LLW	7,580	0.94	1.27E-02	2.8
	2D109	Miscellaneous Plants Initial/Interim Decommissioning: Processing Plants, Tanks, Silos etc.	62,104	7.68	8.63E-03	1.9
	2F23	Low Level Waste	2,627	0.32	6.13E-03	1.3
	2D49	High Active Waste Plants LLW	13,459	1.66	4.98E-03	1.1
^{36}Cl	1A02	LLW Non-Compactable Drummable	4,650	0.57	3.06E-01	32.4
	1A03	LLW Non-Compactable Non-Drummable	4,650	0.57	3.06E-01	32.4
	1A01	LLW Compactable Drummable	990	0.12	6.50E-02	6.9
	5F303	Windscale Pile 2 LLW	2,429	0.30	6.07E-02	6.4
	9E951	Care & Maintenance Preparation : Mild Steel (Non-Reactor) LLW	467	0.06	4.67E-02	4.9
	5G303	Dragon Reactor Decommissioning LLW	1,792	0.22	3.58E-02	3.8
	9C941	Care & Maintenance Preparation : Mild Steel (Non-Reactor) LLW	2,464	0.30	1.72E-02	1.8
^{226}Ra	7A33	Radioactive Contaminated Land	197,065	24.36	2.62E-01	56.3
	5C309	Decommissioning: Other Facilities LLW	5,141	0.64	7.20E-02	15.5
	1A02	LLW Non-Compactable Drummable	4,650	0.57	4.70E-02	10.1
	1A03	LLW Non-Compactable Non-Drummable	4,650	0.57	4.70E-02	10.1
	1A04	LLW Non-Compactable Drummable (Spoil)	2,475	0.31	1.88E-02	4.0
	1A01	LLW Compactable Drummable	990	0.12	1.00E-02	2.2
	6H02	LLW (Minor Users)	8,600	1.06	4.30E-03	0.9
^{129}I	2D53	Site Services LLW	117,906	14.57	9.81E-04	41.2
	2F23	Low Level Waste	22,627	2.80	5.14E-04	21.6
	2A910	Care and Maintenance Preparation (Reactor LLW)	4,811	0.59	4.81E-04	20.2
	5C309	Decommissioning: Other Facilities LLW	5,141	0.64	3.50E-04	14.7
	7D26/C	Conditioned Low Level Ion Exchange Resin (excl. Plant Decontamination)	167	0.02	1.27E-05	0.5
	2D109	Miscellaneous Plants Initial/Interim Decommissioning: Processing Plants, Tanks, Silos etc.	62,104	7.68	9.81E-06	0.4
	5C303	Development Laboratory LLW	2,356	0.29	9.19E-06	0.4

Forecast information provided for waste streams by the waste producers is subject to potential uncertainties or inaccuracies. These are discussed in more detail in Section 4.

2.2. *Groundwater pathway assessment*

An interim safety assessment for the groundwater pathway was undertaken (Paksy and Henderson, 2008) for the LLWR to support a submission to the Environment Agency against Requirement 2 of Schedule 9 of the Authorisation.

The safety assessment was undertaken using a model implemented in the GoldSim software tool and was based on the calculated LLWR inventory discussed in Section 2.1 (Wareing *et al*., 2008). This GoldSim model was used to calculate the activity concentrations of radionuclides in groundwater, fluxes of radionuclides to the biosphere and hence radiation doses to members of potentially exposed groups.

Calculations were undertaken to assess radiological impacts as a result of:

- the discharge of contaminated groundwater to the marine environment;
- the abstraction of contaminated water from a hypothetical well located at the western site boundary; and
- the potential discharge of contaminated groundwater to surface water receptors in the vicinity of the LLWR.

The assessment was undertaken for the period starting from 2150, the time at which the withdrawal of controls is assumed to occur, until 2500 years After Present, which is determined by the expected disruption of the facility by coastal erosion.

Risks associated with potential future releases from the LLWR via the Regional groundwater pathway to the coast and via potential near-surface pathways to surface water receptors are below the 1E-06 y^{-1} regulatory risk target by about two orders of magnitude. On the basis of a preliminary and cautious model, conditional risks from the potential future use of well water from the Regional groundwater have been calculated above the 1E-06 y^{-1} risk target for the vaults and slightly below the risk target for the trenches. The highest conditional risks were estimated as:

- 5.8E-09 y^{-1} for the Regional groundwater pathway to the coast, for the Future vaults;
- 1.9E-08 y^{-1} for near-surface pathways to surface waters, from Vault 8; and
- 2.1E-05 y^{-1} for water abstraction from the Regional groundwater, for the Future vaults.

Given the relatively short timescale of the assessment, the significance of short lived and/or mobile radionuclides (^{36}Cl, ^{14}C, ^{99}Tc) was shown to have increased and the significance of long-lived radionuclides (e.g. uranium) decreased compared with the findings of the 2002 Post-Closure Safety Case (PCSC).

The main radionuclides contributing to the highest estimated risks, which are associated with water abstraction, were found to be:

- ^{36}Cl (for all source areas);
- ^{237}Np (Vault 9 and Future vaults);
- ^{14}C (Vault 9 and Future vaults); and
- ^{99}Tc (Vault 8).

Whilst of lower impact than the radionuclides listed above, significant potential doses were also calculated for ^{129}I (Trenches), ^{234}U (Vault 8, Vault 9 and Future Vaults) and ^{238}U (for all source areas).

Peak risks for ^{14}C, ^{36}Cl and ^{99}Tc were estimated to occur within about 100 years from the start of the assessment (2150) whilst peak risks for ^{237}Np were estimated to occur at about 1500 to 2000 years after this time. These estimations were, in the absence of detailed information, based on conservative assumptions for the mechanisms of radionuclide release and transportation; e.g. that all ^{14}C is associated with cellulose, etc.

It is noted that 99.7% of the ^{237}Np activity calculated for the LLWR future vaults inventory (Wareing *et al*., 2008) is contributed by one waste stream, 2E101 – Springfields Decommissioning LLW, as given in the 2004 UK National Inventory. As a result of the findings of the radiological safety assessment regarding the potential impact of ^{237}Np and uranium isotopes, an investigation into the data underpinning the 2E101 inventory was undertaken. The investigation led to a revision of the radionuclide fingerprint for 2E101 for the 2007 UK National Inventory, in which the uranium concentration was reduced from 2.23E-03 TBq/m^3 to 3.85E-04 TBq/m^3 and the ^{237}Np activity was removed completely from the waste stream. The activity associated with the remaining ^{237}Np in the future vaults inventory is not expected to be of significance. Further discussion of the impact of the changes to 2E101 on the activity of uranium in the LLWR forecast inventory can be found in Section 4.

An assessment of uncertainty in the LLWR ^{14}C inventory has been undertaken separately from the work described in this report. This work is described in Wareing (2009).

2.3. Gas pathway assessment

A review of previous information and some updated calculations were undertaken to assess the significance of advective transport of ^{222}Rn by other gases, such as CO_2 and CH_4, produced in the near-field (Ball *et al*., 2008).

The ^{222}Rn study examined site monitoring data, inventory mapping data, previous results from the 2002 PCSC DRINK near-field biogeochemical model and new calculations of ^{222}Rn ingrowth from the inventory of disposed ^{238}U and daughter radionuclides.

Due to the long half lifes of the isotopes above ^{226}Ra in the decay chain, it is unlikely that their decay will contribute to the formation of significant ^{222}Rn concentrations during the time periods of interest to the analysis of ^{222}Rn entrainment (~2,500 years). However, due to the very short half life of ^{222}Rn (3.8 days) in relation to its parent ^{226}Ra (~1600 years), ^{222}Rn will reach secular equilibrium very quickly. Therefore, assuming there is no loss of ^{222}Rn from the system, the activity levels of ^{222}Rn within the trenches and vaults will mimic the decay of ^{226}Ra. The inventory of ^{226}Ra within the trenches and vaults is therefore of significance when assessing not only the overall generation of ^{222}Rn but also the likely regions or potential areas of ^{222}Rn generation.

Recent site monitoring data indicates regions of ^{222}Rn associated with the location of the principal ^{226}Ra disposals, and another region of lower magnitude associated with the main region of CH_4 generation. During the 2,500 year period of interest, ^{222}Rn generation is limited by being in secular equilibrium with ^{226}Ra. From the inventory of radium disposals, radon generation will be at a maximum at present and its spatial distribution will be influenced by the location of the parent radium. Only over very long (100,000 years) timescales will ^{222}Rn generation rates increase due to disposed uranium, by which time methane generation will have ceased. Overall, considering the timing of the various processes, any effect of advective transport of ^{222}Rn, if significant, is likely to be manifest during the operational phase of the site and will be dominated by those disposal areas likely to produce higher levels of CO_2 and CH_4.

With this in mind, it is important to understand the potential distribution of gas-generating materials in the future forecast waste disposals and how these are likely to be associated with the key radionuclides. In particular, it will be of interest to identify cellulosic-bearing wastes containing significant ^{226}Ra or ^{14}C. A study of the ^{14}C content of future LLWR disposals and how this is distributed across the material types has been undertaken separately from the work described in this report, and is presented in Wareing (2009).

3. Current inventory data sources

The future vaults inventory calculated by Wareing *et al*. (2008) was, as discussed above, based on the 2004 UK National Inventory, which was the most up-to-date information at the time. However, the 2007 UK National Inventory (Pöyry, 2008) is now available for review. This more-recent information may post-date the previous LLWR inventory data by up to three years and therefore may influence and change the prioritised list of waste streams for further investigation. Previous comparative studies of National Inventories have shown some significant differences in waste stream data between successive publications.

For waste streams currently disposed to the LLWR, additional detailed inventory data may be available within the LLWR Waste Stream Characterisation Documents (WSCDs); documentation required to be provided by the waste producers to the LLWR prior to agreement that waste will be accepted for disposal. This information should align with and corroborate that given in the National Inventory.

Other information may be sought directly from the waste producers to develop confidence in the National Inventory estimates.

The following subsections discuss these data sources in more detail.

3.1. 2007 UK National Inventory

The 2007 UK National Inventory is the latest in a series of publicly-available National Inventory reports commissioned by the UK Government, providing comprehensive and transparent information on UK radioactive wastes.

The National Inventory is a snapshot of radioactive waste and other radioactive materials in the UK as at 1st April 2007. It is based on a single scenario for the production of radioactive waste in the UK. This scenario reflects the status of UK nuclear industry and Government policies at that date. For example, the inventory assumes that no new nuclear power stations will be built in the future in the UK and that radioactive materials such as spent nuclear fuels are not classified as waste, as they could be reused in the future.

Raw arising and packaged volumes are given for the UK as a whole, for each type of waste-producing activity and for each of the main waste-producing organisations. The report also presents information on the radioactivity and the material content of the wastes.

The report includes high, intermediate and low level wastes produced from uranium enrichment, nuclear fuel manufacture, nuclear power production, spent fuel reprocessing, research and development, medical and industrial sources and defence activities.

The radionuclide fingerprint tables provided in the 2007 UK National Inventory give specific activities in terabequerels per cubic metre. Codes are associated with each radionuclide activity to show the upper and lower uncertainty bands and to indicate how activities have been derived.

Future waste stream radionuclide fingerprints and volumetric estimates submitted to the UK National Inventory are derived using a variety of methods, dependent on the information available to the waste producer at the time of submission. Activities and volumes for current wastes may be directly measured whereas, for wastes arising in the future, estimates may be provided. This has a direct influence on the confidence in radionuclide activity data, with measured values liable to have greater accuracy than estimated values.

Similar to the activity data, the volumetric data provided in the National Inventory are subject to differing derivation methods, dependent on whether waste is currently stored or arising, or is forecast to arise at a future date. Typically, volumes may be derived through direct measurement, calculated from process flow-sheets, or for decommissioning wastes, estimated from building dimensions and/or observation.

Comments are provided occasionally by the waste producers in reference to confidence in future forecast volumes and the method of derivation, but uncertainty bands are not assigned to the volumetric data.

Material compositions are given in the National Inventory as percentage weights or volumes for each waste stream. Data quality is highly variable. Addition of the given material contents for a waste stream may result in totals equal to, less than or greater than 100%. Totals greater than 100% are obtained where there is uncertainty in the material composition and a number of materials are assigned values with a 'less than' prefix.

As has been observed in the past with successive National Inventories, a high level comparison of the 2004 and 2007 UK National Inventories shows a number of differences. Specifically for the radionuclides of interest to this study:

^{234}U

- The total inventory of ^{234}U in LLW in the 2004 UK National Inventory was 3.3 TBq, compared with 4.6 TBq in the 2007 UK National Inventory (of which 4.1 TBq is designated for consignment to the LLWR);
- Activities for specific radionuclides in the waste stream 2E101 (Springfields decommissioning), which contributed over 90% of LLWR future forecast ^{234}U activity in the 2004 UK National Inventory, have been removed in the 2007 UK National inventory, therefore this waste stream no longer contributes to the ^{234}U inventory. It is noted, however, that the fingerprint for 2E101 still includes total activities not assigned to any specific radionuclide. These could, potentially, be attributed to uranium, therefore further investigation may be required;
- The waste stream 2B03 (Empty uranium hexafluoride containers at Capenhurst), which had no post-2007 volume in the 2004 UK National Inventory, has a volume of over 57,000 m^3 in the 2007 UK National Inventory and a significant ^{234}U specific activity. This waste stream contributes 59.2% of future forecast ^{234}U activity for LLWR disposal in the 2007 UK National Inventory; and
- 30% of future forecast ^{234}U activity for LLWR disposal is contributed by the newly-added waste stream 2X31 (Oxide Ponds LLW) in the 2007 UK National Inventory. This waste stream was part of 2F23 in the 2004 UK National Inventory, which contributed only around 0.6% of forecast ^{234}U activity.

^{238}U

- The total inventory of ^{238}U in LLW in the 2004 UK National Inventory was 6.9 TBq, compared with 3.2 TBq in the 2007 UK National Inventory (of which 3 TBq is designated for consignment to the LLWR);
- Activities for specific radionuclides in the waste stream 2E101 (Springfields decommissioning), which contributed over 90% of LLWR future forecast ^{238}U activity in the 2004 UK National Inventory, have been removed in the 2007 UK National inventory, therefore this waste stream no longer contributes to the ^{238}U inventory; and

- The waste stream 2B03 (Empty uranium hexafluoride containers at Capenhurst), which had no post-2007 volume in the 2004 UK National Inventory, has a volume of over 57,000 m^3 in the 2007 UK National Inventory and a significant ^{238}U specific activity. This waste stream contributes 77.5% of future forecast ^{238}U activity for LLWR disposal in the 2007 UK National Inventory.

^{36}Cl

- The total inventory of ^{36}Cl in LLW in the 2004 UK National Inventory was 3.4 TBq, compared with 1.8 TBq in the 2007 UK National Inventory (of which 0.16 TBq is designated for consignment to the LLWR); and
- 1A02 and 1A03 (Non-compactable LLW from GE Healthcare) each contained 0.3 TBq of ^{36}Cl in the 2004 UK National Inventory and together contributed around two-thirds of the total forecast ^{36}Cl activity for LLWR disposal. These waste streams contain zero quantified activity in the 2007 UK National Inventory.

^{99}Tc

- The total inventory of ^{99}Tc in LLW in the 2004 UK National Inventory was 1.6 TBq, compared with 14.7 TBq in the 2007 UK National Inventory (of which 12.3 TBq is designated for consignment to the LLWR);
- Activities for specific radionuclides in the waste stream 2E101 (Springfields decommissioning) have been removed in the 2007 UK National Inventory, therefore this waste stream no longer contributes to the ^{99}Tc inventory; and
- The waste stream 2B03 (Empty uranium hexafluoride containers at Capenhurst), which had no post-2007 volume in the 2004 UK National Inventory, has a volume of over 57,000 m^3 in the 2007 UK National Inventory and a significant ^{99}Tc specific activity. This waste stream contributes 78.7% of future forecast ^{99}Tc activity for LLWR disposal in the 2007 UK National Inventory.

^{226}Ra

- The total inventory of ^{226}Ra in LLW in the 2004 UK National Inventory was 4.9 TBq, compared with 3.9 TBq in the 2007 UK National Inventory (of which 3.8 TBq is designated for consignment to the LLWR);
- The waste stream 7A33 (Aldermaston contaminated land) is listed in the 2007 UK National Inventory as not expected to be disposed of to the LLWR; and
- The waste stream 7S01 (Defence Estates contaminated soil, ash and rubble) had no volume post-2007 in the 2004 UK National Inventory. An updated volume of 476 m^3 in the 2007 UK National Inventory makes this waste stream the highest contributor of ^{226}Ra, with 98.8% of future forecast activity.

^{129}I

- The total inventory of ^{129}I in LLW in the 2004 UK National Inventory was 3.6E-03 TBq, compared with 3.9E-01 TBq in the 2007 UK National Inventory (of which 3.8E-01 TBq is designated for consignment to the LLWR); and
- The waste streams in the 2D53 and 2F23 (Sellafield Site Services and Thorp LLW respectively) have been replaced by a more-detailed series of '2X' waste streams, of which the most significant, 2X71, contributes approximately 97.5% of future forecast ^{129}I activity.

The implications of these changes on the calculated radionuclide inventories are discussed in more detail in Section 4. As discussed above, it is noted that, in the process of reviewing the 2007 UK National Inventory source data with the Sellafield consignor, a number of errors were discovered, which reveal a significant overestimate in the forecast inventory for particular waste streams. Corrected data were supplied by Sellafield Ltd for some waste streams, but it should be recognised that investigations are ongoing, and the findings of this report may need to be reviewed once the complete set of revised data is available.

3.2. Waste Stream Characterisation Documents

WSCDs are required to be produced for every waste stream routed for LLWR disposal. The documents are valid for a three-year period, after which they must be reviewed and reissued. WSCDs must provide, as a minimum, the following information:

- Unique waste stream identifier;
- Origin of the waste including the processes that created the waste;
- Physical composition of the waste;
- Radioactive composition of the waste;
- Processing of waste;
- Packaging of the waste; and
- Volume to be treated / disposed.

The WSCDs include a description of the methodologies used in deriving the inventory data, and therefore are likely to be of use in providing additional information not given in the 2007 UK Radioactive Waste Inventory. It is noted that the data given in WSCDs are representative of the waste as it arises in the three-year period for which the documentation is valid. Any planned changes to the waste stream beyond the three-year period may be taken into account in the National Inventory forecasts.

3.3. Further information

For waste streams of significance where WSCDs are not available – i.e. those waste streams not forecast to arise within the next three years - calculations or assumptions underpinning the published National Inventory may be obtained to assist in understanding the uncertainties surrounding the LLWR ^{234}U, ^{238}U, ^{36}Cl, ^{99}Tc, ^{226}Ra and ^{129}I inventories. This additional information may be obtained directly from the waste producers. This approach may also be taken where an assessment of WSCDs for existing waste streams has not yielded information of sufficient clarity.

Waste Receipt Monitoring (WRM) records are available from the Waste Monitoring and Compaction Plant (WAMAC) at Sellafield. These show actual activities measured using a High Resolution Gamma Scanner (HRGS) for selected waste streams received for processing at WAMAC. These data are worth examining to identify potential differences between measured and declared activities for disposals.

4. Assessment of LLWR inventory uncertainty for key radionuclides

It was determined that the assessment of uncertainty in the LLWR inventory of disposals should be focused primarily on the future forecast waste streams, as it was considered that further assessment of the historical records would be unlikely to yield any additional benefit. The assessment would take particular account of the physical makeup of the principal waste streams containing the radionuclides of interest in order to provide an understanding of the distribution of activity through different material types and hence inform a study of release rates through groundwater and gas pathways.

The assessment began with a review of the 2007 UK National Inventory dataset to identify the major-contributing waste streams for the radionuclides of interest. These were compared with the 2004 UK National Inventory to determine the changes from the dataset used to derive the inventory detailed in Wareing *et al*. (2008). An appraisal of the material contents of the principal wastes in the 2007 UK National Inventory was undertaken to ascertain how activity is distributed across material types. From this, key waste streams were identified; in particular those waste streams with materials and/or waste-form of significance to the safety case with regard to activity release.

Further information was sought from the WSCDs, waste producers and the WRM records in order to cross-check National Inventory data and improve understanding of specific issues relating to waste characterisation for the key waste streams.

The following sub-sections discuss these steps in more detail.

4.1. Review of 2007 UK National Inventory data

The 2007 UK National Inventory data were acquired from the NDA as Microsoft Access database tables to enable manipulation. Radionuclide fingerprints were assessed to identify those waste streams containing ^{234}U, ^{238}U, ^{36}Cl, ^{99}Tc, ^{226}Ra and ^{129}I. Annual arising activities in TBq were calculated for each waste stream and summed for each year to give, for each radionuclide, a total annual arising activity for all LLW in the 2007 UK National Inventory.

Figures 1 to 6 show the total annual arising activity of ^{234}U, ^{238}U, ^{36}Cl, ^{99}Tc, ^{226}Ra and ^{129}I respectively, for all LLW split by the stated waste stream disposition routes as given in the 2007 UK National Inventory.

A total of 4.6 TBq of ^{234}U is forecast to arise in UK LLW up to 2129; however, it can be seen in Figure 1 that the large majority of this will have arisen by around 2030. These arisings are dominated by the waste stream 2B03 – hex cylinders, which are designated for LLWR disposal. These wastes are forecast to arise between 2020 and 2030 (shown in red in Figure 1). The majority of the remaining ^{234}U arisings are from the Sellafield stream 2X31 – Oxide Ponds LLW, miscellaneous operational arisings routinely disposed of to the LLWR. The notable contribution of 0.2 TBq of ^{234}U in stock is from the waste stream 2N05/C – Vault 8 disposals, which can be discounted from further consideration in this study. An assessment of the inventory for 2N05/C suggests it may be derived solely from specific radionuclide activities as given in the waste tracking database. The disposal records include additional activity from unspecified or unknown radionuclides (as accounted for in Wareing *et al*., 2008), but this does not appear to have been taken into account in 2N05/C.

Forecast arisings of ^{238}U, of which there is a total of 3.2 TBq up to 2129 (Figure 2), mirror those for ^{234}U, with 77.5% of future arisings contributed by 2B03 and the majority of remaining arisings from 2X31.

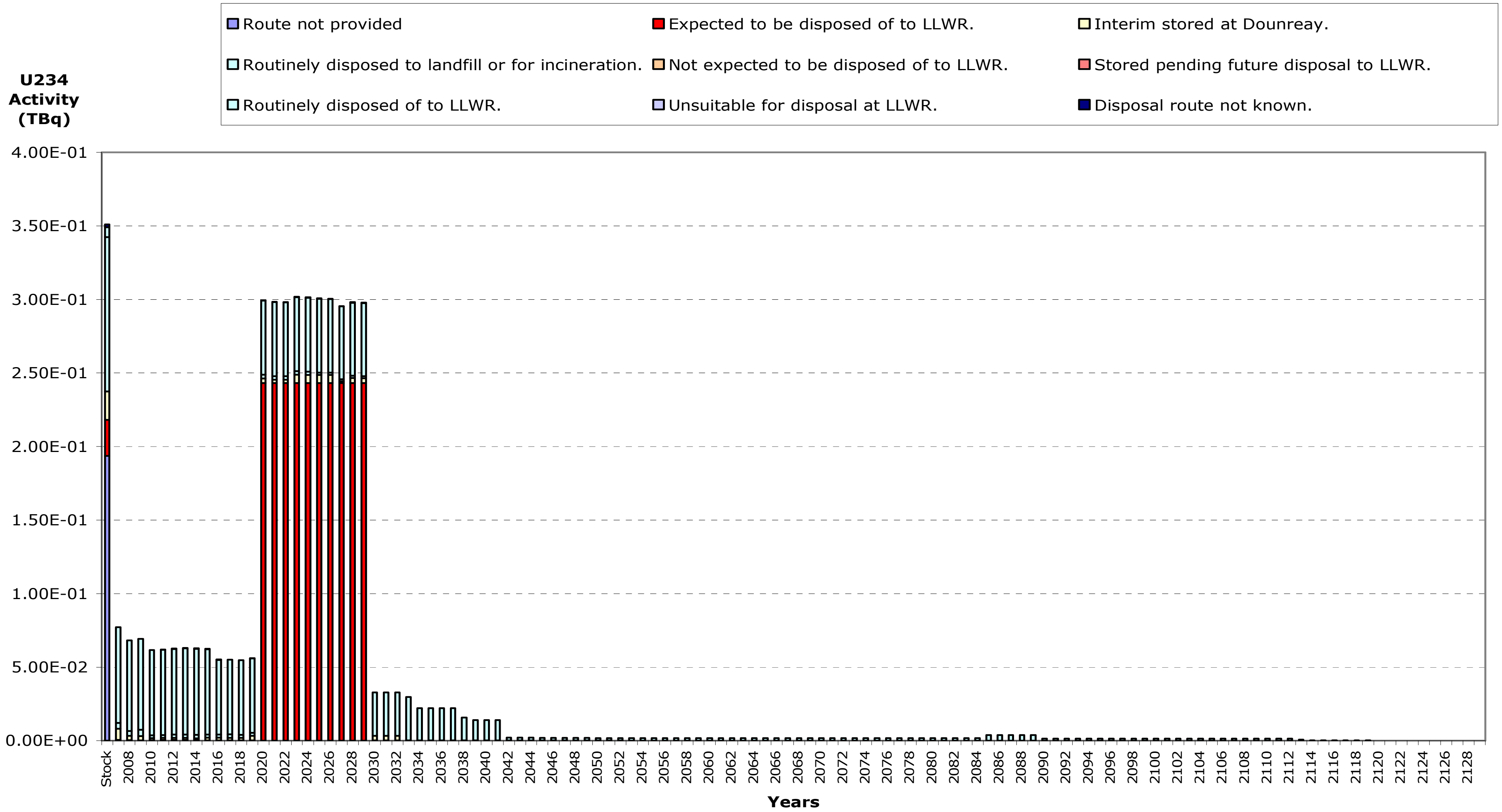

Figure 1 ^{234}U by each LLW disposition route in the 2007 UK National Inventory

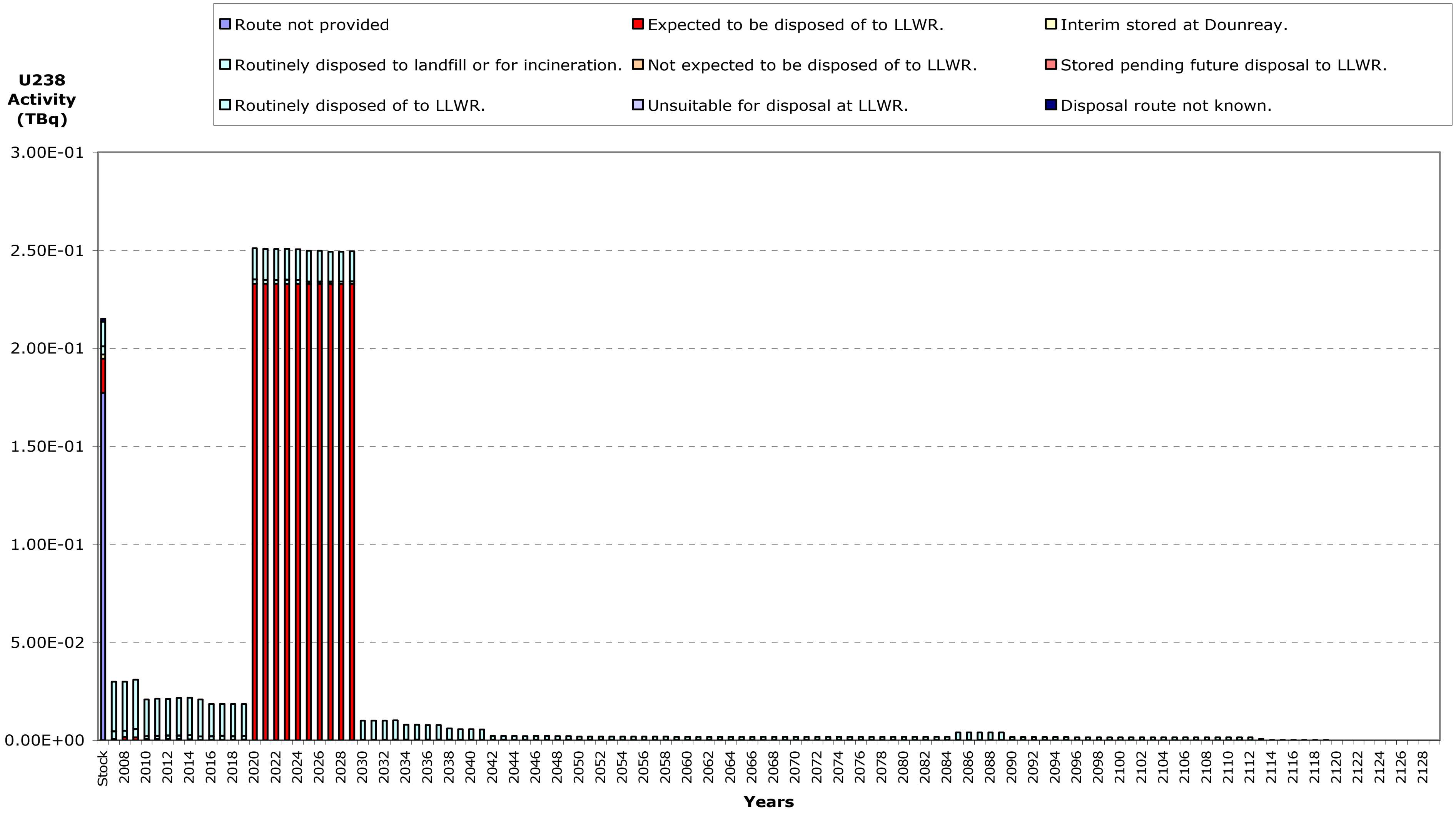

Figure 2 ^{238}U by each LLW disposition route in the 2007 UK National Inventory

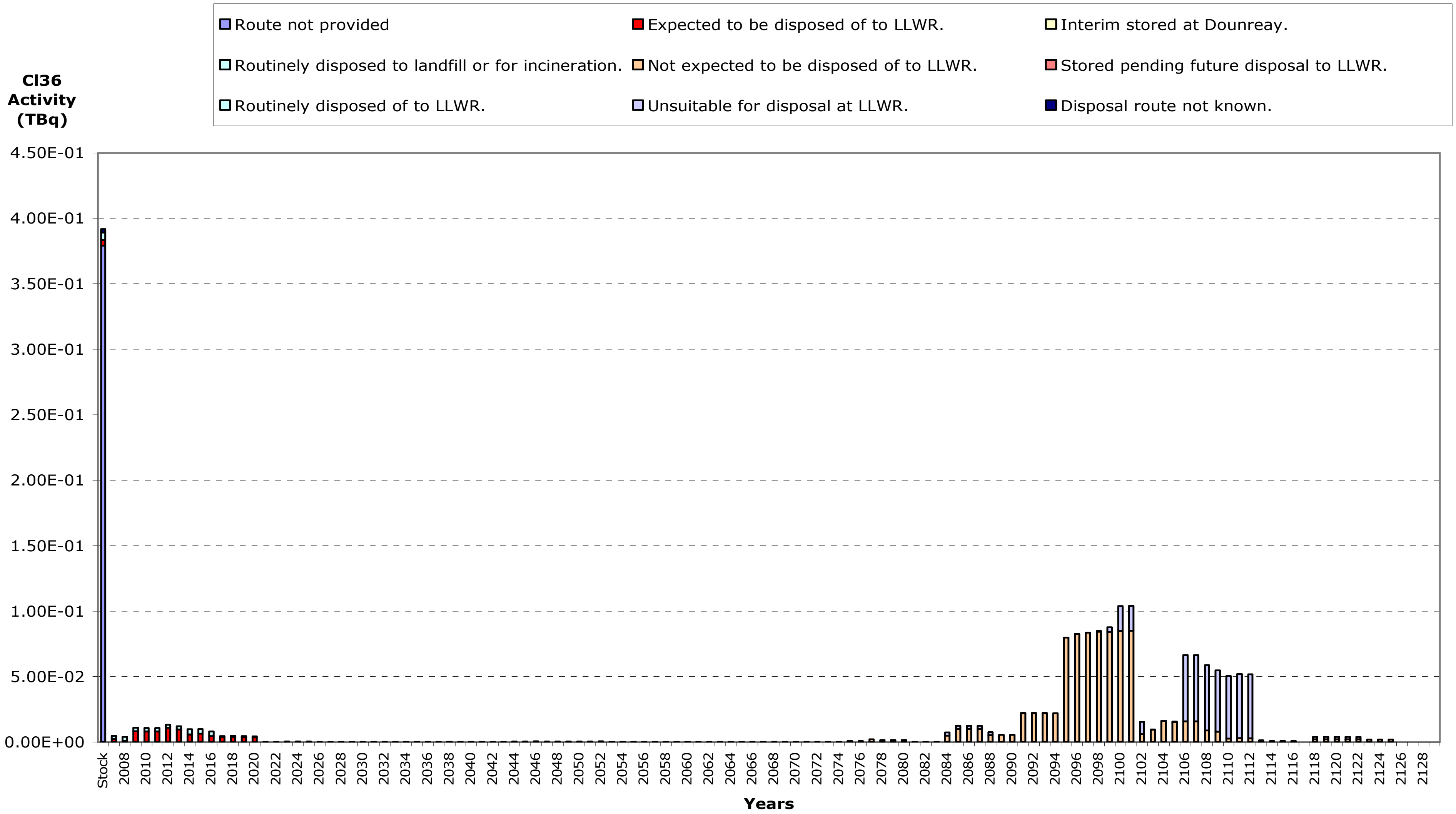

Figure 3 ^{36}Cl by each LLW disposition route in the 2007 UK National Inventory

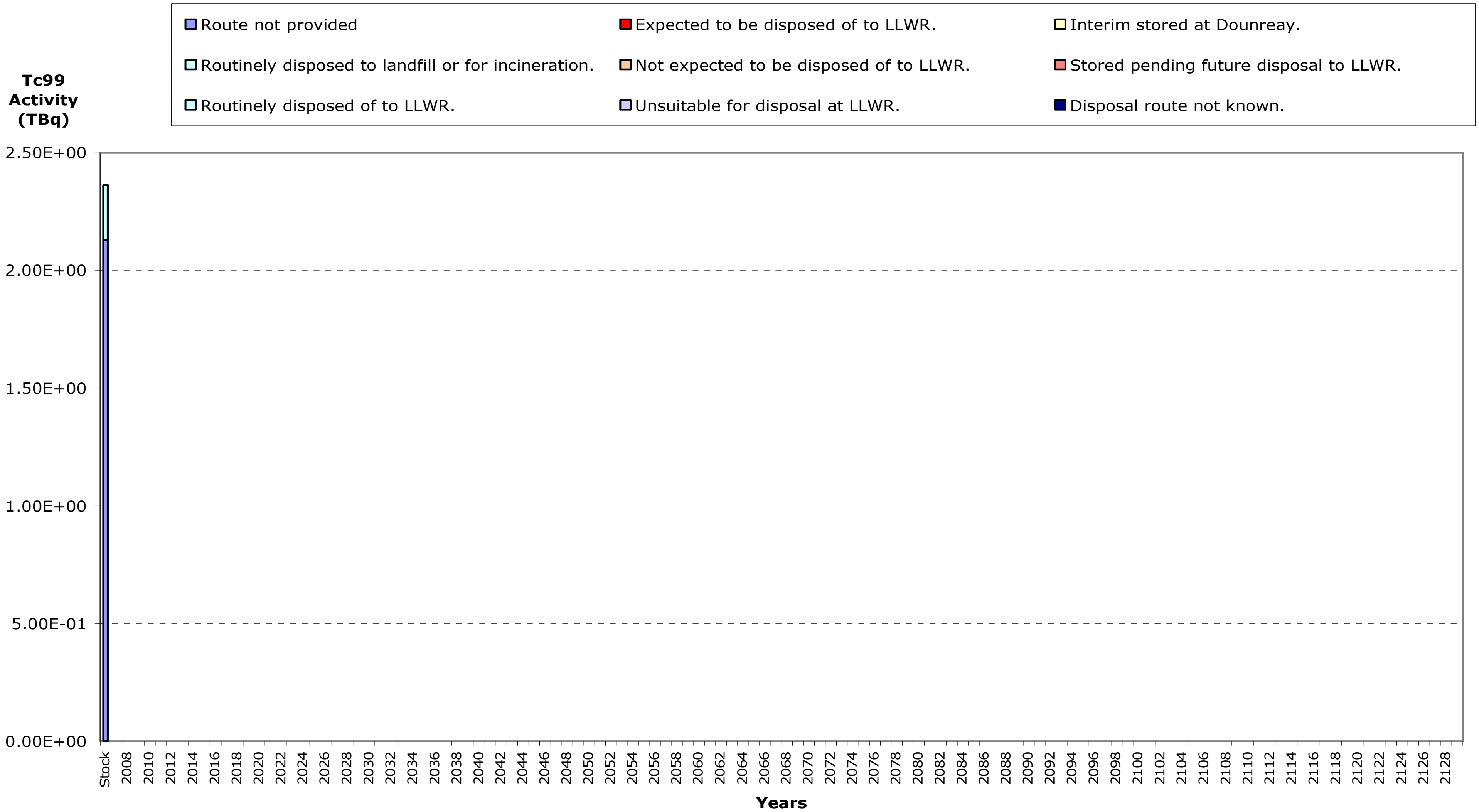

Figure 4 ^{99}Tc by each LLW disposition route in the 2007 UK National Inventory

Figure 5 ^{226}Ra by each LLW disposition route in the 2007 UK National Inventory

Figure 6 ^{129}I by each LLW disposition route in the 2007 UK National Inventory

1.8 TBq of ^{36}Cl is forecast to arise in the 2007 UK National Inventory. Approximately one quarter of this is attributed to 2N05/C – Vault 8 disposals, which can be discounted from further consideration in this study. 0.16 TBq of future ^{36}Cl arisings is designated for consignment to the LLWR. It is shown in Figure 3 that this component (in red) is forecast to arise in the period from present day up to around 2020. Further investigation shows that these arisings are evenly distributed across a number of waste streams, with the majority contributor, 9C911 – Dungeness Care & Maintenance LLW, providing only 15% of the total. Arisings beyond 2020 are predominantly designated as not expected to be disposed of, or not suitable for disposal at, the LLWR.

It should be noted, however, that the waste streams designated 'Not expected to be disposed of to the LLWR' are not necessarily unacceptable for LLWR disposal in terms of their meeting the current Conditions for Acceptance (CFA). Guidance given to waste producers in completing questionnaire returns for input to the 2007 UK National Inventory (Nirex, 2007) states "*The LLWR has a finite volumetric and radiological capacity; it should be assumed that disposals would stop in 2050. For LLW streams that arise after 2050 you should respond: 'Not expected to be consigned to the LLWR'* ". These waste streams could, therefore, be of potential significance to the LLWR should operations be extended beyond 2050.

Figure 4 shows that the large majority (approximately 79%) of the 14.7 TBq of ^{99}Tc forecast to arise in the 2007 UK National Inventory will arise between 2020 and 2030. This is attributable to just one waste stream, 2B03 - Empty uranium hexafluoride containers at Capenhurst, which, as discussed above, is also the major contributor of uranium in the future forecast inventory. This waste stream is designated for disposal at the LLWR. There are no significant arisings of ^{99}Tc beyond 2030.

The approximately 2 TBq of ^{99}Tc shown in Figure 4 under "stocks" is largely from the waste stream 2N05/C – Vault 8 disposals, which can be discounted from further consideration in this study.

It can be seen in Figure 5 that almost all (approximately 97%) of the 3.9 TBq total arisings of ^{226}Ra in the 2007 UK National Inventory is forecast to arise before 2008. This activity is equally split between stocks and arisings in 2007, and is attributable to one waste stream, 7S01 - Defence Estates contaminated soil, ash and rubble. This waste stream is designated in the 2007 UK National Inventory as stored pending disposal to the LLWR.

Figure 6 shows the future forecast arisings of ^{129}I. Approximately 0.39 TBq are forecast to arise up to 2129; and it can be seen that the majority of these arisings will be between present day and 2030. This activity is dominated by one waste stream, 2X71 – Solvent treatment plant LLW, a Sellafield operational LLW stream routinely disposed to the LLWR. Arisings of ^{129}I continue beyond 2030, but are not expected to be of significance.

Gaining an understanding of the uncertainties in future forecast inventories of waste streams contributing the majority of activity of key radionuclides, as shown in Figures 1 to 6, is clearly of importance, since most have been shown to arise in the early period up to around 2030 and are designated for disposal at the LLWR.

Table 4 shows the top ranking ^{234}U, ^{238}U, ^{36}Cl, ^{99}Tc, ^{226}Ra and ^{129}I-bearing waste streams in the 2007 UK National Inventory that are forecast for disposal at the LLWR and will contribute 0.1% or above of activity, ranked in descending order of total activity.

Table 4 Waste streams forecast to contain the majority of ^{234}U, ^{238}U, ^{36}Cl, ^{99}Tc, ^{226}Ra and ^{129}I in the LLWR future vaults (as stated in the 2007 UK National Inventory)

Order	Activity (GBq)	Waste stream	% of Total activity in LLW	Raw volume (m^3)	Packaged volume (m^3)	First year of arisings	Final year of arisings	Upper banding (stock / arising)	% increase in total inventory when upper banding applied	Activity received by the LLWR pre 2007 (GBq)
^{234}U										
1	2,433	2B03	59.2	57,927	32,154	Stock	2029	A/A	30	
2	1,264	2X31	30.8	1,394	924	2007	2041		Unknown	0.18
3	136.9	2X927	3.3	4,199	5,049	2007	2113	C	30	0.00
4	80.6	7A26	2.0	713	797	2007	2038	C	18	
5	66	2X49	1.6	13,603	5,493	2007	2119	C	14	0.03
6	26.9	2X140	0.7	670	771	2012	2089	C	6	0.00
7	16.5	2X53	0.4	936	333	2007	2015	C	4	14.20
8	13.3	7L05	0.3	35	40	Stock	2009		Unknown	
9	7	2B107	0.2	157	394	Stock		C	2	
10	6.8	2P02	0.2	405	179	2007	2033	C	1	
11	6.6	2B102	0.2	384	489	Stock		C	1	10.24
12	5.6	7A07	0.1	775	2,519	Stock		B	0	
Total	**4,107**		**100**		**723,699**	**Stock**	**2119**			
^{238}U										
1	2,329	2B03	77.5	57,927	32,154	Stock	2029	A/A	39	
2	351	2X31	11.7	1,394	924	2007	2041	C	105	0.04
3	137	2X927	4.6	4,199	5,049	2007	2113	C	41	0.00
4	37.7	2X49	1.3	13,603	5,493	2007	2119	C	11	0.02
5	27.6	2X140	0.9	670	771	2012	2089	C	8	0.00
6	23.5	7L05	0.8	35	40	Stock	2009		Unknown	
7	10.2	5C41	0.3	52	239	Stock	2009	B/B	1	0.40
8	8.6	6H02	0.3	8,600	11,781	2007	2049	C	3	
9	7.3	5F02	0.2	2,171	987	2007	2019	C	2	0.01
10	6.7	2P02	0.2	405	179	2007	2033	C	2	
11	6.6	5C309	0.2	768	959	Stock	2015	B/B	0	6.52
12	6.6	2D109	0.2	67,302	55,515	2012	2095	C	2	
13	6.6	2X68	0.2	28,500	10,541	2007	2119	C	2	0.16
14	5.8	7A24	0.2	756	896	2007	2039	C	2	
15	5.7	2X10	0.2	1,260	581	2007	2015	C	2	31.35
16	5.4	2X53	0.2	936	333	2007	2015	C	2	2.67
17	4.5	2X55	0.1	171	61	2007	2015	C	1	0.33
Total	**3,004**		**100**		**723,699**	**Stock**	**2119**			
^{36}Cl										
1	24	9C911	15.2	2,438	2,417	2009	2020	C	137	
2	23	5G301	14.6	6,666	8,657	2007	2013	B	29	
3	17	9E104	10.7	172	112	2023	2108	C	96	
4	12	3L11	7.6	173	174	Stock	2016	C/C	68	4.57
5	11	9J949	7.0	3,760	4,587	Stock	2016	C/C	63	0.83
6	8.1	9E914	5.1	1,160	1,380	2010	2017	C	46	
7	6.6	9H922	4.1	825	1,341	2012	2020	C	37	
8	6.0	3J12	3.7	474	476	Stock	2020	C/C	34	1.27
9	3.5	9H914	2.2	116	110	2012	2020	C	20	
10	3.3	3L14	2.1	33	21	Stock	2016	C/C	19	0.41
11	3.0	3L13	1.9	266	267	Stock	2016	C/C	17	6.13

Table 4 (continued)

Order	Activity (GBq)	Waste stream	% of Total activity in LLW	Raw volume (m^3)	Packaged volume (m^3)	First year of arisings	Final year of arisings	Upper banding (stock / arising)	% increase in total inventory when upper banding applied	Activity received by the LLWR pre 2007 (GBq)
12	3.0	3L110	1.9	298	325	2014	2021	C	17	
13	2.9	9B910	1.8	7,229	7,301	2007	2016	C	16	0.00
14	2.8	9H923	1.8	354	575	2012	2020	C	16	
15	2.7	9D48	1.7	34	60	Stock		C	15	
16	2.6	9R102	1.6	512	908	Stock	2011	C/C	14	0.03
17	2.5	9F19	1.6	50	62	Stock		C	14	
18	1.9	9F910	1.2	4,870	4,934	2009	2018	C	11	
19	1.5	9F31	1.0	5	7	Stock	2009	C/C	9	
20	1.5	9E958	0.9	5,076	6,041	2008	2019	C	9	
21	1.1	9A105	0.7	124	81	2012	2073	C	6	
22	0.9	9E960	0.5	88	75	2010	2014	B	1	
23	0.8	9E959	0.5	2	1	2010	2017	B	1	
24	0.8	9H14	0.5	28	27	Stock	2012	C/C	5	0.07
25	0.8	9C912	0.5	830	1,090	2009	2020	C	5	
26	0.8	3S301	0.5	8,131	4,719	2044	2053	D	50	
27	0.8	9D913	0.5	2,669	5,205	Stock	2023	C/C	4	
28	0.8	9G109	0.5	400	780	Stock	2011	B/B	1	0.06
29	0.8	9H104	0.5	190	124	2021	2115	C	4	
30	0.7	9C13	0.5	72	68	Stock	2009	C/C	4	0.08
31	0.7	3M15	0.4	80	52	Stock	2025	C/C	4	0.23
32	0.7	3N110	0.4	235	256	2012	2015	C	4	
33	0.6	9H11	0.4	158	150	Stock	2012	C/C	4	1.35
34	0.6	4B110	0.4	195	213	2012	2015	C	3	
35	0.6	9D916	0.4	283	552	Stock	2023	C/C	3	
36	0.4	3S303	0.3	735	919	2045	2053	C	2	
37	0.4	9H911	0.3	108	103	2012	2020	C	2	
38	0.4	9E59	0.2	2	1	Stock	2014	B	0	0.01
39	0.4	3K14	0.2	64	65	Stock	2015	C/C	2	3.11
40	0.4	9H13	0.2	9	8	Stock	2012	C/C	2	0.07
41	0.4	9G105	0.2	354	575	Stock	2011	B/B	0	0.70
42	0.3	5G303	0.2	2,143	2,996	2007	2014		Unknown	
43	0.3	9E913	0.2	1,578	1,941	2010	2017	C	2	
44	0.3	9F33	0.2	1	1	Stock	2009	C/C	2	
45	0.3	9D11	0.2	5	3	Stock		C	2	
46	0.3	3N12	0.2	73	73	Stock	2013	C/C	2	1.86
47	0.2	2X36	0.1	730	322	2007	2016	C	1	0.02
48	0.2	9G106	0.1	692	1,170	Stock	2011	B/B	0	0.56
Total	**161**		**100**		**723,699**	**Stock**	**2119**			
^{99}Tc										
1	11,585	2B03	94.2	57,927	32,154	Stock	2029	C/C	848	
2	219	2X17	1.8	225	102	2007	2021	C	16	11.14
3	180	2X68	1.5	28,500	10,541	2007	2119	C	13	1.37
4	74.4	2X49	0.6	13,603	5,493	2007	2119	C	5	0.03
5	61.0	2X71	0.5	750	300	2007	2021	C	4	0.13
6	55.4	2X75	0.5	96	25	2007	2021	C	4	0.01
7	22.0	2B102	0.2	384	489	Stock		C	2	2,196
8	18.8	2X50	0.2	2,442	752	2007	2041	C	1	7.47

Table 4 (continued)

Order	Activity (GBq)	Waste stream	% of Total activity in LLW	Raw volume (m^3)	Packaged volume (m^3)	First year of arisings	Final year of arisings	Upper banding (stock / arising)	% increase in total inventory when upper banding applied	Activity received by the LLWR pre 2007 (GBq)
9	16.0	2X125	0.1	7,418	5,725	2007	2029	B	0	0.16
10	11.4	2X114	0.1	160	178	2007	2010	C	1	0.03
11	10.9	2X11	0.1	1,950	1,797	2007	2039	C	1	1.05
12	9.35	2D109	0.1	67,302	55,515	2012	2095	C	1	
13	7.91	2X140	0.1	670	771	2012	2089	C	1	0.00
14	7.65	2X25	0.1	9,000	2,426	2007	2028	C	1	0.01
Total	**12,298**		**100**		**723,699**	**Stock**	**2119**			
^{226}Ra										
1	3,808	7S01	98.8	476	684	Stock	2007	A/A	49	
2	10.25	2X927	0.3	4,199	5,049	2007	2113	C	2	0.00
3	9.67	5C309	0.3	768	959	Stock	2015	B/B	1	3.94
4	7.64	2X140	0.2	670	771	2012	2089	C	2	0.00
5	4.3	6H02	0.1	8,600	11,781	2007	2049	C	1	
6	3.99	6C37	0.1	81	53	Stock	2010	B	0	0.17
7	2.51	1A04	0.1	330	413	2007	2039	A	0	2.13
8	1.93	2X26	0.1	2,870	939	2007	2045	C	0	0.00
Total	**3,856**		**100**		**723,699**	**Stock**	**2119**			
^{129}I										
1	375	2X71	97.5	750	300	2007	2021	C	878	0.00
2	2.99	2X19	0.8	567	419	2007	2021	C	7	0.03
3	2.87	2X140	0.7	670	771	2012	2089	C	7	0.11
4	1.20	2X68	0.3	28,500	10,541	2007	2119	C	3	0.01
5	0.88	2X131	0.2	110	138	Stock		C	2	0.02
6	0.35	2X16	0.1	3,356	3,356	2007	2095	C	1	0.02
7	0.26	2X927	0.1	4,199	5,049	2007	2113	C	1	0.00
Total	**384**		**100**		**723,699**	**Stock**	**2119**			

Key to upper uncertainty banding:

A	A factor of 1.5 times higher
B	A factor of 10 times higher
C	A factor of 100 times higher
D	A factor of 1000 times higher

It is noted that the activities shown in Table 4 are as given in the 2007 UK National Inventory. Subsequent discussion with Sellafield Ltd has revealed a number of significant overestimates in the data for Sellafield '2X' waste streams, which are currently under investigation. The assessment described in this section uses partially corrected data.

It can be seen in Table 4 that, with the exception of ^{36}Cl, the top-contributing waste stream for each radionuclide of interest provides over 50% and in most cases over 90% of the total future forecast activity for that radionuclide. ^{36}Cl is more evenly distributed across the waste streams, and it is notable that the first waste stream contributing 0.1% or less of ^{36}Cl activity is 47th in the rankings.

A number of waste streams are highlighted in green where future forecast activities are significantly lower than have been disposed of to Vault 8 in the past. The most notable of these is 2B102 – Capenhurst ^{99}Tc-contaminated decommissioning LLW, which has consigned around 2,196 GBq of ^{99}Tc to Vault 8, but has a future forecast ^{99}Tc inventory of just 22 GBq, in approximately 384 m^3. Examination of the radionuclide fingerprint for

2B102 shows the ^{99}Tc concentration to have been re-estimated for the 2007 UK National Inventory, being reduced by around an order of magnitude from the 2004 UK National Inventory.

The waste stream volumes and activity uncertainty bandings shown in Table 4 are of interest. Where waste streams have a high forecast arising volume and a high uncertainty band then application of the upper uncertainty band could have a significant effect on the total activity contribution. For example, 3S301 - Sizewell B Decommissioning mild steel LLW, has an arising volume of 8,131 m^3 and an upper uncertainty band of D (a factor of 100). If the upper uncertainty band were to be applied then the total ^{36}Cl activity contribution from this waste stream would rise from 0.8 GBq, representing around 0.5% of total future arisings, to 80 GBq, which would represent around 33% of a significantly larger total.

It should be noted that the waste stream 2B03 – empty uranium hexafluoride containers at Capenhurst, which is the top-contributing waste stream for ^{234}U, ^{238}U and ^{99}Tc; representing 59.2%, 77.5% and 94.2% respectively of the future forecast inventory for these radionuclides, has an upper uncertainty band of C (a factor of 10) for ^{99}Tc. If this upper uncertainty band were to be applied then the ^{99}Tc forecast inventory would increase by around 850%. The upper uncertainty bands for ^{234}U and ^{238}U are A (a factor of 1.5) for this waste stream, indicating that the uranium concentrations are understood to a greater degree of certainty than the ^{99}Tc concentration.

4.2. Identification of key waste streams

In order to focus effort on waste streams of highest potential impact, a subset of waste streams was identified where further information should be gathered beyond that given in the 2007 UK National Inventory. Waste streams were identified on the basis of either total future lifetime activity content, or having insignificant or zero future activity content that are present in past consignments to Vault 8 for which significant activity was declared.

Table 5 lists the top 40 waste streams identified for further investigation. The waste streams have been ranked in descending order of overall significance based on the sum of their individual rankings in contribution of activity for each radionuclide. Of these, 19 are in the top 5 waste streams contributing activity of key radionuclides to LLWR future disposals (Table 4), accounting for approximately 90% of future forecast activity for these radionuclides; 13 are waste streams that are present in Vault 8 consignments having significant amounts of activity for the radionuclides of interest (>1 GBq) but are forecast to consign insignificant or no activity in the future; and 8 are waste streams contributing significant key radionuclide activity outside of the top 5 rankings.

Table 5 Waste streams identified for further investigation

Site / Origin	Waste Stream	Order	^{234}U	^{238}U	^{36}Cl	^{99}Tc	^{226}Ra	^{129}I
Capenhurst	2B03	1	**1**	**1**		**1**		
Sellafield	2X71	2				**5**		**1**
Dungeness A	9C911	3			**1**			
MOD Other	7S01	4					**1**	
Sellafield	2X31	5	**2**	**2**				
Sellafield	2X927	6	**3**	**3**			**2**	
Sellafield	2X19	7				18		**2**
Winfrith	5G301	8			**2**	19		
Sellafield	2X17	9				**2**		
Sellafield	2X140	10	6	**5**		13	**4**	**3**
Sellafield	2X68	11		13		**3**		**4**

Table 5 (continued)

Site / Origin	Waste Stream	Order	^{234}U	^{238}U	^{36}Cl	^{99}Tc	^{226}Ra	^{129}I
Harwell	5C309	12	18	11			**3**	
Oldbury	9E104	13			**3**			
Sellafield	2X49	14	**5**	**4**		**4**		
Heysham 1	3L11	15			**4**			
Aldermaston	7A26	16	**4**					
Sellafield	2X36	17	**Y**			16		**5**
Misc	6H02	18	16	8			**5**	
Hunterston A	9J949	19			**5**			
Amersham	1A03	20			**Y**	**Y**	**Y**	
Amersham	1A04	21			**Y**	**Y**	7	
Springfields	2E101	22	**Y**	**Y**		**Y**		
Sellafield	2X07	23		**Y**		**Y**		
Sellafield	2X54	24	**Y**	**Y**				
Amersham	1A02	25				**Y**		
Sellafield	2X124	26	28			**Y**		
Sellafield	2X11	27				11	**Y**	
Amersham	1B03	28					**Y**	
Amersham	1A01	29				**Y**		
Sellafield	2X51	30	**Y**					
Hunterston B	4B13	31			**Y**			
Sellafield	2X09	32					**Y**	
MOD Other	7L05	33	8	6				
Oldbury	9E914	34			6			
Sellafield	2X75	35				6		
Harwell	5C41	36		7			10	
Capenhurst	2B102	37	11	20		7		
Sellafield	2X53	38	7	16				
Wylfa	9H922	39			7			
Sellafield	2X26	40	8					

Key:		
	3	Stream in top 5 contributors of activity for radionuclide (number denotes ranking)
	Y	Stream in Vault 8 consignment with significant activity (>1GBq), but having no future forecast for the relevant radionuclide
	8	Stream contributing to radionuclide activity outside of top 5 (number denotes ranking)

4.3. Assessment of material/activity association in wastes containing key radionuclides

The physical form of the disposed waste can have a significant influence on the timing and nature of contaminant release to the biosphere and geosphere. For example, degradation of organics may lead to release of CO_2 and CH_4, which may assist in the transport of radon gas derived from ^{226}Ra decay. It is therefore important to understand how the activity is distributed in relation to the material content of the waste.

In addition, activity may potentially be associated with one specific material type within a waste stream. This is an important point to consider, as activity concentrations stated in the 2007 UK National Inventory apply as an average across the whole waste stream. If it could be determined that activity is associated with only a fraction of a waste stream, then the actual concentration within that fraction would be higher than stated for the total waste stream in the 2007 UK National Inventory. For example, if it were determined that the activity of a specific radionuclide was associated entirely within a material representing only 50% of the waste volume, then the actual concentration of the activity within that material would be twice that for the whole waste stream.

To investigate these issues, an assessment of the 2007 UK National Inventory data for all waste streams stated as planned for disposal to the LLWR was undertaken to identify the material content of the waste streams bearing the radionuclides of interest. Activities were then apportioned for each waste stream in two distinct ways:

- By distribution across the waste stream materials in proportion to the material concentrations in the waste stream; and
- By allocation in total separately to each material in each waste stream, to determine the concentration if activity were associated with one material type, providing an upper estimate.

The calculated concentrations by material were then grouped according to 14 concentration bands in descending order of magnitude from greater than 10 TBq/m^3 to zero (i.e. not present), as shown in Table 6.

Table 6 Concentration bandings used in material activity assessment

Band	1	2	3	4	5	6	7	8	9	10	11	12	13	14
From (TBq/m^3)	>1.00E+01	1.0E+01	1.0E+00	1.0E-01	1.0E-02	1.0E-03	1.0E-04	1.0E-05	1.0E-06	1.0E-07	1.0E-08	1.0E-09	1.0E-10	0.0E+00
To (TBq/m^3)	1.0E+01	1.0E+00	1.0E-01	1.0E-02	1.0E-03	1.0E-04	1.0E-05	1.0E-06	1.0E-07	1.0E-08	1.0E-09	1.0E-10	1.0E-17	0.0E+00

Table 7 shows the activity in GBq associated with the different material types, apportioned by both waste stream and material, and for both best-estimate and upper bound concentrations from the 2007 UK National Inventory.

Table 8 shows the volumes of materials containing both significant and all activity associated with the key radionuclides of interest. A particular banding was taken to have significant activity if it represented 1% or more of the total activity for that material group. Bands with non-zero levels of activity less than 1% of the total were taken to be insignificant.

Table 7 and Table 8 may be examined together to identify particular points of interest, as follows:

- Over half of ^{226}Ra activity is associated with soil and rubble. This is attributed to waste stream 7S01 – Defence estates soil and rubble. However, it can be seen in Table 8 that the majority of this activity is in only 265 m^3 of soil and rubble.
- Over a third of the approximately 85,000 m^3 of forecast cellulosic arisings contain ^{226}Ra activity, 99% of which is contained within 11,000 m^3 of cellulose.
- The large majority of ^{99}Tc activity (over 97%) is associated with metals. This is attributed to the waste stream 2B03 –hex cylinders, which is almost all metal (containing residual, trace activity as contamination), and accounts for around one third of metallic waste arisings.
- ^{129}I is distributed widely across the material types.
- Although ^{36}Cl activity is well distributed across a number of waste streams (Table 4), it can be seen in Table 7 that around a third of this activity is associated with metallic wastes. This is anticipated to be from activation of chlorides.
- Activities for both ^{234}U and ^{238}U are predominantly associated with metals. As for ^{99}Tc, this is due to the waste stream 2B03 accounting for the large majority of uranic activity.
- Application of upper uncertainty bands generally raises activities by no more than a factor of 10.
- Materials showing the largest difference between activities distributed proportionally and activities assigned in total to individual materials are those with the smallest volumes. These materials, such as complexants, generally make up only a small

fraction of a waste stream, and therefore would account for an insignificant portion of the waste stream activity where this is distributed proportionally across all materials. The implication of this is that, should such a material contain all the activity for a key radionuclide in a waste stream, the concentration of the radionuclide in that material could potentially be high.

Table 7 Activity (GBq) of key radionuclides associated with materials, distributed by material and by waste stream

Activity (GBq)	**^{226}Ra**				**^{99}Tc**				**^{129}I**				**^{36}Cl**				**^{234}U**				**^{238}U**			
Material Type	WS	U WS	Mat	U Mat	WS	U WS	Mat	U Mat	WS	U WS	Mat	U Mat	WS	U WS	Mat	U Mat	WS	U WS	Mat	U Mat	WS	U WS	Mat	U Mat
Cellulosic	3	30	36	215	114	1122	373	3601	1	11	6	66	20	197	133	1147	76	739	258	2359	35	316	165	1346
Complexants	0	0	17	57	2	17	202	1904	0	0	2	18	0	0	42	414	0	1	21	112	0	2	36	252
Graphite	0	1	5	44	0	0	17	56	0	0	0	2	0	0	9	69	1	13	89	882	1	9	16	148
Inorganic	372	584	3830	5846	8	78	337	3242	1	12	5	58	12	110	94	750	25	172	231	2167	20	142	134	1176
Liquid	733	1102	3810	5717	0	0	0	1	0	0	0	0	0	0	3	32	0	0	2	6	9	27	12	35
Metals	594	912	3836	5850	11685	116767	11952	119385	1	18	3	37	61	632	154	1421	2503	4256	2678	5817	2372	3770	2471	4570
Organic	0	1	25	125	4	35	306	2938	0	1	3	25	0	1	82	794	3	20	95	883	2	14	97	800
Plastic/Rubber	4	27	36	215	115	1147	373	3602	1	8	6	66	33	325	135	1162	61	607	248	2400	35	341	144	1323
Soil/Rubble	2137	3270	3843	5926	31	285	351	3377	2	16	6	62	31	203	95	758	38	272	246	2240	39	266	157	1273
Unknown	1	4	4	13	1	13	22	221	0	0	0	0	2	16	5	52	4	40	26	245	1	14	11	93

Key:
- WS — Activity split across the waste stream materials in proportion to the material concentrations
- U WS — Upper bound activity (from 2007 UK National Inventory) split across the waste stream materials in proportion to the material concentrations
- Mat — Activity for each waste stream allocated separately and in total to each material
- U Mat — Upper bound activity (from 2007 UK National Inventory) allocated separately and in total to each material for each waste stream

Table 8 Volume of material associated with key radionuclide activity

Radionuclide	Cellulosic (m^3)			Complexants (m^3)		
	Significant	Insignificant	None	Significant	Insignificant	None
^{226}Ra	11,021	19,811	54,112	2	9	331
^{99}Tc	35,147	21,458	28,339	277	4	60
^{129}I	26,251	4,497	54,196	286	5	50
^{36}Cl	4,437	1,658	78,849	2	1	339
^{234}U	18,949	33,590	32,405	12	15	316
^{238}U	36,007	27,032	21,905	287	15	40
	Graphite (m^3)			Inorganic (m^3)		
	Significant	Insignificant	None	Significant	Insignificant	None
^{226}Ra	180	3	125	326	1,207	15,975
^{99}Tc	4	0	305	2,438	445	14,624
^{129}I	2	3	305	965	1,459	15,084
^{36}Cl	15	0	294	4,056	731	12,720
^{234}U	278	15	16	1,212	3,038	13,258
^{238}U	278	15	16	1,995	2,842	12,670
	Liquid (m^3)			Metals (m^3)		
	Significant	Insignificant	None	Significant	Insignificant	None
^{226}Ra	91	45	178	553	27,854	344,266
^{99}Tc	4	-	310	57,927	142,500	172,244
^{129}I	0	1	313	22,128	99,577	250,967
^{36}Cl	0	0	314	33,663	2,800	336,208
^{234}U	15	1	299	59,315	147,919	165,438
^{238}U	45	19	251	60,975	151,097	160,599
	Organic (m^3)			Plastic / Rubber (m^3)		
	Significant	Insignificant	None	Significant	Insignificant	None
^{226}Ra	387	932	2,401	11,019	5,599	71,811
^{99}Tc	1,621	730	1,369	33,416	20,064	34,950
^{129}I	1,557	74	2,089	29,448	10,844	48,137
^{36}Cl	149	42	3,529	7,733	1,804	78,892
^{234}U	1,696	790	1,234	23,996	26,857	37,576
^{238}U	2,015	757	948	36,101	26,306	26,022
	Soil/Rubble (m^3)			Unknown (m^3)		
	Significant	Insignificant	None	Significant	Insignificant	None
^{226}Ra	265	42,884	139,645	597	441	11,604
^{99}Tc	28,144	69,516	85,134	134	16	12,492
^{129}I	16,463	74,691	91,640	459	-	12,182
^{36}Cl	12,718	6,961	163,115	408	29	12,205
^{234}U	56,364	55,867	70,563	632	374	11,636
^{238}U	38,966	75,965	67,863	632	374	11,636

Note: A particular banding was taken to have significant activity if it represented 1% or more of the total activity for that material group. Bands with non-zero levels of activity less than 1% of the total were taken to be insignificant. For example, the total ^{226}Ra activity associated with 19,811 m^3 of cellulosics is less than 1% of the activity associated with 11,021 m^3 of cellulosics. The 54,112 m3 of cellulosics contains no declared ^{226}Ra activity.

It is of interest to examine the volumetric distribution of ^{36}Cl in metals and concrete, as these materials generally contain ^{36}Cl as an activation product rather than as surface contamination. This is important, since the rate of release of ^{36}Cl from the waste in the disposal vaults is dependent on its accessibility to water flowing through the waste. ^{36}Cl within metal or concrete as activated material is likely to be less accessible to water, and therefore less mobile, than loose, surface contamination.

Figure 7 shows the forecast volume and activity of ^{36}Cl-bearing metals for LLWR disposal.

It is shown that wastes containing significant ^{36}Cl activity arise in the short-term period up to around 2020, with a significant 'spike' of arisings of up to around 3,500 m^3 per year between 2010 and 2015. As has been discussed earlier, ^{36}Cl activities, unlike for other key radionuclides discussed in this report, are not dominated by one or two significant waste streams, but are spread reasonably widely across a number of waste streams. However, this early period of high volume and activity metallic arisings is contributed to by a few waste streams with large volumes, including, most notably, 5G301 – Winfrith Stream-Generating Heavy Water Reactor (SGHWR) decommissioning waste, 9B910 – Bradwell reactor care & maintenance waste, and 9C911 – Dungeness A reactor & boiler systems care & maintenance waste.

Following a period of low ^{36}Cl arising activity between 2021 and 2043, a spike of arisings is forecast around 2046. Approximately 90% of this volume and around half of the ^{36}Cl activity in this period are contributed by the waste stream 3S301 – Sizewell B decommissioning mild steel LLW.

No information is available in the 2007 UK National Inventory as to whether the ^{36}Cl activity in these waste streams is present as contamination or activation. However, a study of the ^{36}Cl content of reactor wastes (Harrison, 1997) concludes that ^{36}Cl production occurs in fuel and core materials from the activation of ^{35}Cl. The majority of activated ^{36}Cl will therefore occur in the internal reactor structures and will arise as ILW. Reactor structures external to the core, which form the majority of LLW reactor decommissioning wastes, will generally have ^{36}Cl present in relatively small proportions through activation; the majority being from surface contamination transferred through operations such as the handling of spent fuel.

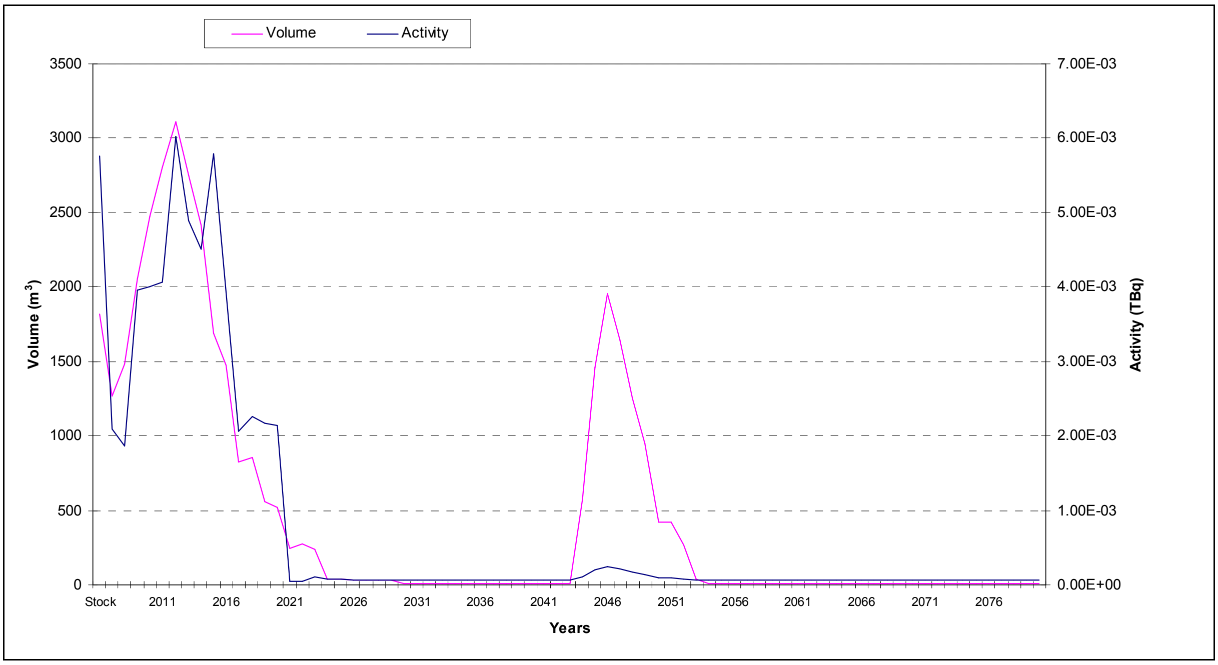

Figure 7 Forecast volumes and activities of ^{36}Cl-bearing metals for LLWR disposal

Figure 8 shows the forecast volume and activity of ^{36}Cl-bearing concrete for LLWR disposal.

The pattern of arisings is clearly similar to that exhibited for the ^{36}Cl-bearing metallic wastes shown in Figure 7, with a significant 'spike' of arisings of up to around 1,200 m^3 per year between present day and 2021, followed by a period of low arisings, then a further spike' of arisings around 2052. This similarity in pattern is due to similarities in contributing waste streams; in particular 5G301 – Winfrith SGHWR decommissioning waste, which has both a metallic and concrete component and accounts for over half the ^{36}Cl activity in this period.

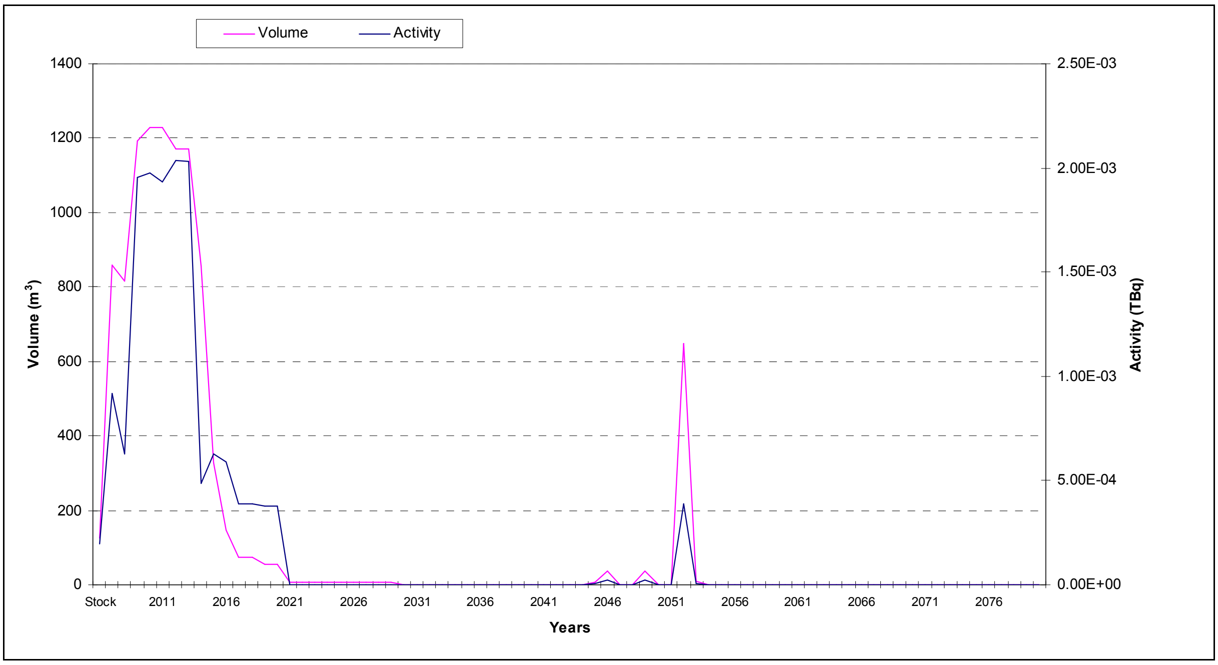

Figure 8 Forecast volumes and activities of ^{36}Cl-bearing concrete

Metallic and concrete wastes account for around half of the forecast ^{36}Cl inventory for LLWR disposal. The nature of the key waste streams contributing to this inventory, i.e. reactor decommissioning LLW, is such that much of the activity is expected to be from secondary, surface contamination from activation products arising in the reactor fuel and moderator, rather than direct activation of waste materials (Harrison, 1997). Whether the activity is present as contamination or as activated material is of relevance in the safety assessment. Activity present as surface contamination may be more easily leached than activation products, which will be present within solid phases in the waste material. Given the increased mobility of surface contaminants over activation products present within the structure of the waste, the early development and deployment of treatment technologies to segregate and decontaminate metallic and concrete wastes prior to LLWR disposal would have a positive effect in reducing the impact from ^{36}Cl.

It is understood that Magnox will be undertaking a programme of work in 2009 to scope the quantity of VLLW present in decommissioning wastes. It is recommended that this is monitored closely by the LLWR, so that such information can be expediently used in good time for the ESC in 2011.

4.4. Additional information gathering

The gathering of additional data to reduce uncertainty in the future ^{36}Cl inventory fell into three categories:

- WSCDs for waste streams currently consigning to the LLWR;
- Direct discussion with waste producers for waste streams not yet arising; and
- Assessment of Waste Receipt Monitoring data from Vault 8 disposals.

At the time of writing, further information was only available for a limited number of the waste streams identified in Table 5. Table 9 shows the applicable data sources for the waste streams where further information was available, and summarises the key findings.

Table 9 Sources identified for further information on waste streams contributing significantly to the ^{234}U, ^{238}U, ^{36}Cl, ^{99}Tc, ^{226}Ra and ^{129}I inventory in the future vaults

Waste Stream	Radionuclide(s)	Further information gathered from	Key findings
2B03	^{234}U, ^{238}U, ^{99}Tc	Sellafield Consignor	The consignor advised that the radionuclide fingerprint given in the 2007 UK National Inventory for 2B03 was likely to have been derived prior to analysis of the containers and was not expected to be accurate, despite the uranium activities having uncertainty bands of A. Analysis has now been carried out, but the compiler had not assessed the results at the time of writing. Containers are likely to be washed prior to disposal, which is expected to remove much of the contamination. It is possible that activity levels following washing may be low enough for Clifton Marsh disposal, hence removing this waste from future LLWR inventory estimates.
2X927	^{99}Tc, ^{129}I	Current WSCD	The consignor advised that a review of Sellafield LLW radionuclide fingerprints was being undertaken, following the discovery of a number of significant overestimates of around three orders of magnitude. For 2X927, the fingerprints given in the 2007 UK National Inventory were based on the WSCD for this waste stream; however the data had been transposed with incorrect units. Further information is provided in Khan *et al*., 2009.
2X31	^{234}U, ^{238}U	Current WSCD	As for 2X927, the fingerprints given in the 2007 UK National Inventory were based on the WSCD for this waste stream; however the data had been transposed with incorrect units to give an overestimate of around three orders of magnitude. Further information is provided in Khan *et al*., 2009.
1B03	^{226}Ra	WSCD (expired Dec 08)	There is no current WSCD for this waste stream, the most recent one (2005) having expired in December 2008. A check was made of two WSCDs, dated 2000 and 2005. It was found that both these WSCDs showed no activity for ^{226}Ra and zero total alpha activity. Whilst the historical disposal records show ^{226}Ra present in consignments containing 1B03, they do not show ^{226}Ra present in consignments where 1B03 represents 100% of the waste. It is therefore likely that 1B03 has not historically contained ^{226}Ra.
1A02	^{99}Tc	WSCD (expired Dec 08)	There is no current WSCD for this waste stream, the most recent one (2005) having expired in December 2008. A check was made of the two previous WSCDs, dated 1997 and 2005. No ^{99}Tc activity was declared in either of these WSCDs. Whilst the historical disposal records show ^{226}Ra present in consignments containing 1A02, they do not show ^{226}Ra present in consignments where 1A02 represents 100% of the waste. It is therefore likely that 1A02 has not historically contained ^{226}Ra.
1A03	^{36}Cl, ^{99}Tc, ^{226}Ra	WSCD (expired Dec 08)	There is no current WSCD for this waste stream, the most recent one (2005) having expired in December 2008. A check was made of the two previous WSCDs, dated 2000 and 2005. Activity is declared for ^{226}Ra + ^{232}Th at 1.3 MBq/te in the 2000 WSCD and for ^{226}Ra + ^{232}Th at 7.5E-03 MBq/te in the 2005 WSCD. It was found that ^{226}Ra + ^{232}Th activity represented proportionally more of the total activity in the 2005 WSCD than in the 2000 WSCD. No activity was declared for ^{36}Cl and ^{99}Tc in either of the two WSCDs. Assessment of the historical disposal records shows activity for ^{36}Cl, ^{99}Tc and ^{226}Ra declared in consignments where 1A03 represents 100% of the consignment. Further investigation is required to understand the reasons for these differences.

The waste stream 7S01 – Defence Estates contaminated soil, ash & rubble, which contributes around 99% of future forecast ^{226}Ra, was examined. The volume for this waste stream as given in the 2007 UK National Inventory is split into 241 m^3 stock and arisings in 2007/08 of 235 m^3. The ^{226}Ra concentration of 8.0E-03 TBq/m^3 results in total activities of 1.93 TBq in stock and 1.88 TBq in arisings in 2007/08. Upper and lower uncertainty bands of A (a factor of 1.5) are stated, indicating strong confidence in the estimates. However, a separate comment on radioactivity states that '*accuracy is generally low'*. The ^{226}Ra contamination is stated as consisting of "*insoluble Ra-226 sulphate paint loose in a matrix of soil (unsealed sources)*".

The current annual LLWR activity disposal limit for $^{226}Ra/^{232}Th$ is 0.03 TBq. Clearly, if 7S01 were to arise in a single year as forecast, disposal to the LLWR would not be possible under current licence arrangements. However, the National Inventory states that "*The rate of waste arisings will be dependent on the site specific ground conditions and the remediation strategy employed. These may differ from site to site as will the degree of contamination and as a result the quantities of waste generated will differ*". It is noted that disposals would need to be spread over 127 years (i.e. significantly longer than the anticipated lifetime of the LLWR) in order not to exceed annual limits. Moreover, the total ^{226}Ra activity forecast for this waste stream is over four times the remaining site radiological capacity of ~0.9 TBq for $^{226}Ra/^{232}Th$.

Notably, it is stated in the 2007 UK National Inventory datasheet for 7S01 that "*The waste meets the LLWR's Conditions for Acceptance (CFA). The waste has a current WSCD. Inventory information is consistent with the WSCD*".

WRM data were obtained for disposals to Vault 8 between 2002 and 2008 and assessed for the waste streams identified in Table 5. The WRM programme actively measures the activity content of consignments for comparison with the declared activity on the disposal records. Consignments containing single waste streams are of particular interest, as obtained results are applicable only to that waste stream. Where consignments contain a mixture of waste streams, it is often not possible to determine the relative contributions from the different components. Assessment results were found for consignments containing only 2X927, 2X19, 2X68, 2X49, 2X36, 2X53 and 2X26. Few specific comments relating to the radionuclides of interest to this study were found against these waste streams, but it was considered that the observed results for other radionuclides could be used to determine the overall accuracy of the inventory data, and hence infer the accuracy of the radionuclides of interest. Table 10 presents the comments extracted from the WRM records for these waste streams.

Table 10 Comments in Waste Receipt Monitoring Records for key contributing waste streams

Waste Stream	Date of assessment	Comment
2X927	15/02/2006	No comment available for this assessment
	17/01/2007	Pass. Low activity. Over-declared on major gammas
	20/12/2007	Low activity. Waste Receipt Assessment Procedure (WRAP) pass
2X19	23/11/2004	Over on ^{60}Co, ^{134}Cs, ^{137}Cs, ^{125}Sb, ^{144}Ce and ^{144}Ru
2X68	07/05/2003	Overestimate of ^{137}Cs, ^{134}Cs, ^{125}Sb, ^{10}6Ru
2X49	26/01/2004	Reasonable agreement, very low activity
	25/11/2004	Overestimated ^{137}Cs
	13/07/2006	WRAP Pass. OK results. Over on ^{60}Co, ^{137}Cs and ^{106}Ru
	25/06/2008	Low activity consignment. Most radionuclides at Limit Of Detection
2X36	14/06/2004	Reasonable results
2X53	16/04/2004	Failed WRAP by overestimating uranium
2X26	13/04/2004	Overestimate of ^{137}Cs, ^{134}Cs, ^{60}Co, ^{125}Sb and ^{106}Ru

It can be seen that the general trend in WRM is one of over-declaration of radionuclide activities in the disposal forms. It is observed that Sellafield waste stream activities in particular tend to be over-declared, whilst greater accuracy is demonstrated for non-Sellafield wastes. This has implications for the future forecast inventories, since assessments have shown that National Inventory fingerprints tend to be conservative compared with activities declared in the disposal records. If the disposal records are, in turn, conservative compared with the actual activity of the waste in the consignments, there could potentially be a significant overestimate of forecast activity in the National Inventory data.

4.5. Implications

The findings of the assessment of underpinning inventory data for the key waste streams have shown a general trend of overestimation in the 2007 UK National Inventory. Assessment of WSCDs and discussion with the consignors has revealed that inventories for a number of key waste streams, representing a significant proportion of future forecast activity, may be revised. The future inventory of ^{129}I, of which over 97% is contributed by the Sellafield waste stream 2X71, could potentially be decreased by around three orders of magnitude. Activities for the top contributing waste stream for both uranium and ^{99}Tc, 2B03 – hex cylinders at Capenhurst, are likely to be overestimated. Moreover, this waste stream may undergo washing to remove contamination, potentially leading to its being suitable for Clifton Marsh disposal. Up to around 59%, 77% and 94% respectively of future forecast ^{234}U, ^{238}U and ^{99}Tc for LLWR disposal may be removed if successful.

The majority contributor of future forecast ^{226}Ra, 7S01 – Defence Estates contaminated soil, ash & rubble, is unlikely to be accepted for LLWR disposal given the current LLWR annual and total activity disposal limits. Removal or revision of this waste stream in future forecast inventories could reduce the future vaults ^{226}Ra inventory by up to 98%.

The potential impacts of the findings on the calculated trench disposal inventories vary according to radionuclide. Trench uranium and ^{226}Ra activities are predominantly derived from actual disposal records and are considered to have a high degree of accuracy. These are not expected to be influenced by the findings of this assessment.

Trench inventories of ^{36}Cl, ^{99}Tc, and ^{129}I were calculated from the backfitting of Vault 8 disposal records and present-day or future forecast waste streams from the 2004 UK National Inventory considered representative of historical disposals. ^{36}Cl activity is relatively low in the trenches, as it is expected that the majority of activity for this radionuclide will arise in the future from reactor decommissioning. Trench ^{99}Tc activity was derived from the backfitting of Sellafield and Capenhurst waste streams (uranium hexafluoride cylinders) from the 2004 UK National Inventory. If the radionuclide fingerprint for 2B03 as given in the 2007 UK National Inventory is revised as discussed above, there may be some cause for a subsequent reduction in the trench ^{99}Tc inventory, although this will be limited by the influence of 2B03 on the whole of the trench ^{99}Tc inventory.

The inventory of waste stream 2E101 – Springfields decommissioning LLW, has been revised between the 2004 and 2007 UK National Inventory submissions following investigation by LLWR into the activity levels of uranium and neptunium isotopes. Whilst the activities and codes against the specific radionuclides have been removed from the fingerprint, it is noted that the total forecast alpha activity for this waste stream, at 2.2 TBq, remains significant, and that "*The main source of activity is contamination by uranium and its daughters*". If this activity were to be assigned to ^{234}U and/or ^{238}U then the total future forecast contribution for these radionuclides could increase by up to 55%.

^{129}I activities, which are evenly spread across the trenches and vaults, have been calculated for the trenches predominantly from Sellafield waste streams. However, much of the activity has been derived from Vault 8 disposal records, and would not be expected to change significantly following revision of the Sellafield waste streams.

It is known from the waste tracking system database that GE Healthcare Ltd's sites at Amersham and Cardiff have consigned significant amounts (greater than 1 GBq each) of ^{226}Ra, ^{36}Cl and ^{99}Tc to Vault 8, whilst future forecasts for these waste streams show no activity expected for these radionuclides. Amersham clearly used to consign more active wastes, and the future vaults wastes may not represent this appropriately.

Key findings and the potential qualitative impacts of these on the Wareing *et al*. (2008) inventory are summarised for each radionuclide in Table 11.

Table 11 Impacts of key findings on the calculated inventories of ^{238}U, ^{36}Cl, ^{99}Tc, ^{226}Ra and ^{129}I in Wareing *et al*., 2008

Rad	Key findings	Potential impact on Wareing *et al*. (2008) inventory		
		Trench	Vault 8	Future Vaults
^{234}U	1. Increase in the forecast for LLWR disposal from 2004 to 2007 UK National Inventory of 1.7 TBq. 2. Change in the top-contributing waste stream from 2E101 to 2B03, due to removal of uranium isotope activity from 2E101 fingerprint. 3. Top-contributing waste stream 2B03 likely to be overestimated. Washing of containers to remove contamination may lead to these being suitable for Clifton Marsh disposal.	Inventory based on actual disposal records is considered accurate and is not expected to change.	The inventory is predominantly based on actual disposal records. 2B03 is not present in Vault 8 disposals; therefore removal of 2B03 from LLWR future forecasts would result in no net change.	If washing of 2B03 leads to this waste being routed to Clifton Marsh, a 10% reduction in the future forecast inventory for ^{234}U (by around 0.7 TBq) may result. Assigning alpha activity from 2E101 to ^{234}U would increase future forecast activity by 55%.

Table 11 (continued)

Rad	Key findings	Potential impact on Wareing *et al*. (2008) inventory		
		Trench	**Vault 8**	**Future Vaults**
^{238}U	4. Significant decrease in the forecast for LLWR disposal from 2004 to 2007 UK National Inventory of 3.0 TBq. 5. Change in the top-contributing waste stream from 2E101 to 2B03, due to removal of uranium isotope activity from 2E101 fingerprint. 6. Top-contributing waste stream 2B03 likely to be overestimated. Washing of containers to remove contamination may lead to these being suitable for Clifton Marsh disposal.	Inventory based on actual disposal records is considered accurate and is not expected to change.	The inventory is predominantly based on actual disposal records. 2B03 is not present in Vault 8 disposals; therefore removal of 2B03 from LLWR future forecasts would result in no net change.	If washing of 2B03 leads to this waste being routed to Clifton Marsh, a significant reduction in the future forecast inventory for ^{238}U (by around 5 TBq) may result. Assigning alpha activity from 2E101 to ^{234}U would increase future forecast activity by 55%.
^{36}Cl	7. Decrease in the forecast for LLWR disposal from 2004 to 2007 UK National Inventory of 0.8 TBq. 8. Activity is contributed by several significant waste streams, and is found predominantly in reactor decommissioning metallic and concrete wastes.	The trench inventory of ^{36}Cl is not considered significant. The inventory is calculated from a combination of Vault 8 disposals and 2004 UK National Inventory waste streams. Some influence from the revised 2007 UK National Inventory forecasts could reduce the trench inventory further.	The inventory is predominantly based on actual disposal records. A very small decrease based on the limited influence of the National Inventory data could result when using revised 2007 UK National Inventory estimates.	A decrease in the ^{36}Cl future forecast activity by around 0.8 TBq is anticipated.
^{99}Tc	9. Significant increase in the forecast for LLWR disposal from 2004 to 2007 UK National Inventory of 11.8 TBq. 10. Top-contributing waste stream 2B03 likely to be overestimated. Washing of containers to remove contamination may lead to these being suitable for Clifton Marsh disposal.	Limited influence of National Inventory on the Trench ^{99}Tc inventory from future forecast waste streams. However, the calculated trench ^{99}Tc inventory has some influence from 2B102 disposals in Vault 8, which may not be representative of trench wastes. Possible revision downwards.	The inventory is predominantly based on actual disposal records. 2B03 is not present in Vault 8 disposals; therefore removal of 2B03 from LLWR future forecasts would result in no net change.	Revision of the 2B03 fingerprint could negate the increase exhibited in the 2007 UK National Inventory, resulting in no significant net change.
^{226}Ra	11. Significant increase in the forecast for LLWR disposal from 2004 to 2007 UK National Inventory of 3.3 TBq. 12. The top-contributing waste stream, 7S01 (~99% of future forecast), is unlikely to be acceptable for LLWR disposal on current licence arrangements. Accuracy of fingerprint is stated as low.	The trench ^{226}Ra inventory is derived from actual disposal records of mineral ores. No significant influence is anticipated from National Inventory future forecasts.	The waste stream 7S01 is not representative of Vault 8 disposals, therefore is not expected to influence change in the Vault 8 inventory for ^{226}Ra.	Further investigation of 7S01 is required. If this is found to be accurate and the waste stream is acceptable, the future forecast inventory could increase by around 7 times.

Table 11 (continued)

Rad	Key findings	Potential impact on Wareing *et al*. (2008) inventory		
		Trench	**Vault 8**	**Future Vaults**
^{129}I	13. Increase in the forecast for LLWR disposal from 2004 to 2007 UK National Inventory of 0.4 TBq. 14. The top-contributing waste stream, 2X71, is overestimated by around three orders of magnitude.	The ^{129}I trench inventory is derived from Vault 8 disposals supplemented by additional data from the 2004 UK National Inventory. The two-order of magnitude increase in the future forecast inventory (based on 2X71) may be revised downwards in light of more-recent information, resulting in no significant net change to the trench inventory.	Consignments of 2X71 with ^{129}I activity data are present in the Vault 8 disposals records. The National Inventory radionuclide tables would therefore not be used to 'backfit' this information. No significant change is anticipated.	The two-order of magnitude increase in the future forecast inventory (based on 2X71) may be revised downwards by around three orders of magnitude. A small decrease may result.

5. Conclusions

An assessment of the uncertainty in the ^{234}U, ^{238}U, ^{36}Cl, ^{99}Tc, ^{226}Ra and ^{129}I content of future forecast UK LLW in the 2007 UK National Inventory designated for disposal at the LLWR has been undertaken. It was found that, with the exception of ^{36}Cl, the top-contributing waste stream for each radionuclide of interest provides over 50% and in most cases over 90% of the total future forecast activity for that radionuclide. ^{36}Cl was found to be more evenly distributed across the waste streams.

Future forecast activities have increased from the 2004 to the 2007 UK National Inventory for ^{234}U, ^{99}Tc, ^{226}Ra and ^{129}I. Increases of 11.8 TBq and 3.3 TBq respectively in the ^{99}Tc and ^{226}Ra inventories are substantial.

The future forecast activity for ^{238}U has decreased by around 50% from the 2004 to the 2007 UK National Inventory, whilst the future forecast inventory for ^{36}Cl has decreased by almost an order of magnitude.

Enquiries made of the 2007 UK National Inventory data revealed a number of errors for Sellafield LLW '2X' stream fingerprints, reducing the activity for these streams by up to three orders of magnitude. New data were obtained for some of these waste streams and uploaded to the assessment database for subsequent analysis.

Investigation of the material content of waste streams destined for LLWR has shown that the majority of future forecast activity for all the radionuclides of interest is associated with metals or soil and rubble. Upper estimate activity levels in specific material types were calculated by assuming, for each material type within a waste stream, that all the waste stream activity for a radionuclide is associated with that material. Examination of these upper estimate specific activities showed that, typically, large deviations from the best estimate across the whole of the waste were only observed for materials with very small volumes, such as complexants; whilst deviations in specific activity for materials with large volumes, such as metals, were not significant.

Following identification of a limited number of waste streams in the 2007 UK National Inventory contributing the large majority of future forecast activity for ^{234}U, ^{238}U, ^{36}Cl, ^{99}Tc, ^{226}Ra and ^{129}I for LLWR disposal, additional data were sought to check the accuracy of the 2007 UK National Inventory entries. For waste streams currently consigned to the LLWR, WSCDs were obtained, whilst future waste streams were checked through direct contact with the waste producers. It is noted that, at the time of writing, only a limited number of these data sources were available. The checks consistently found that 2007 UK National Inventory activities are higher than those stated in the WSCDs; sometimes by several orders of magnitude.

Discussion of 2007 UK National Inventory data with consignors led to a number of potential reductions in the activities due to conservatisms in the 2007 UK National Inventory data being highlighted. Of particular note is the top contributor of uranium and ^{99}Tc, 2B03 – empty uranium hexafluoride containers at Capenhurst, for which a process of washing to remove the majority of contamination is being assessed. If the process is successful the waste will contain minimal amounts of ^{99}Tc and uranium, and may be suitable for disposal at Clifton Marsh. Furthermore, regardless of future treatment, it is understood that the radionuclide fingerprint for this waste stream is likely to be an overestimate and may be revised following physical analysis.

Magnox decommissioning streams, a significant source of ^{36}Cl contamination, are to be reviewed, with potentially large proportions of the volumes being reclassified as VLLW.

It is concluded that, pending confirmation of initial findings, the future forecast activities of ^{234}U, ^{238}U, ^{36}Cl, ^{99}Tc, ^{226}Ra and ^{129}I calculated in Wareing *et al*. (2008) are unlikely to change substantially. Increases in the ^{234}U, ^{99}Tc, ^{226}Ra and ^{129}I inventories for the 2007 UK National Inventory are attributed either to waste streams for which radionuclide fingerprints are likely to undergo significant revision downwards or, in the case of ^{226}Ra, to a waste stream for which LLWR disposal is unlikely to be viable. Future forecasts for both ^{234}U and ^{238}U may be reduced following potential revision of the 2B03 fingerprint, since activity from the top-contributing waste stream in the 2004 UK National Inventory, 2E101, has been removed in the 2007 UK National Inventory. However, if total alpha activity in 2E101 were to be assigned to ^{234}U and/or ^{238}U then future forecasts for these radionuclides could increase by up to 55%.

It is recognised that uncertainties in the waste streams contributing less than 1% of future forecast activity may contribute additional activity, if the upper band limits given in the 2007 UK National Inventory were to apply.

Impacts of the findings on the calculated trench and Vault 8 inventories are not expected to be significant.

6. Recommendations

It is recommended that further investigations into the radionuclide fingerprint errors highlighted for Sellafield wastes be undertaken. A review of these data is currently ongoing by Sellafield Ltd, and the findings should be taken into account when available.

The output of the work undertaken to categorise activity levels according to material type should be taken into account by the near-field assessment to provide improved modelling of potential radionuclide release.

A further programme of discussions with consignors for key waste streams should be developed to further understand the methods used in deriving activity data and how activity is distributed between different waste forms.

A waste material assessment should be carried out for trench and Vault 8 disposals to provide better understanding of the association of radionuclides and materials for these wastes, hence developing an improved dataset for input to the near-field models.

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