COMMERCIAL

Environmental Safety Case: Disposal of Low Activity Low-level Radioactive Waste at the Port Clarence Landfill Sites – Report (with Appendices A to D)

Reference: ENE-0154/F2/001

Issue: 1

To :

From: Eden Nuclear and Environment Ltd

Eden Nuclear and Environment

August 2019

Eden Nuclear and Environment Ltd
Unit 3 Mereside, Greenbank Road, Eden Business Park, Penrith, Cumbria. CA11

Tel: **+44 (0) 1768 868985**
Email: **info@eden-ne.co.uk**
Web: **www.eden-ne.co.uk**

Eden Nuclear and Environment

DOCUMENT ISSUE RECORD	
Document Title:	**Environmental Safety Case: Disposal of Low Activity Low-level Radioactive Waste at the Port Clarence Landfill Sites – Report (with Appendices A to D)**
Project	**Assessment of LLW disposal at Port Clarence Landfill**
Reference:	**ENE-0154/F2/001**
Project Manager:	**Eden Nuclear and Environment Ltd**

Document Status

Issue	Description	Author(s)	Review	Approver	Date
01	Technical Report				13/08/19

Document Restrictions and Accessibility

You can apply restrictions on access and security for the document using permissions and security in MS or Acrobat. Further, you can set the document so that it is shared with other users. Details of any restrictions if the document is to be provided digitally should be highlighted here.

Any previous versions must be destroyed or marked superseded.

Distribution

Issue	Copies	Name	Organisation
1			

Environmental Safety Case for the Disposal of Low Activity Low-level Radioactive Waste at the Port Clarence Landfill Sites: Proposal Summary

This is a summary of the application for a Permit for the receipt and disposal of low-level radioactive waste (LLW) at the Port Clarence hazardous and non-hazardous waste landfills. The disposal of radioactive waste in England and Wales is regulated by the Environment Agency under the Environmental Permitting (England and Wales) Regulations 2016 (as amended 2018) (EPR2016). An Environmental Safety Case (ESC) has been submitted to the Environment Agency to support the application.

The application is for the disposal of radioactive wastes that would be classified as inert, non-hazardous or hazardous wastes in terms of their content of non-radioactive materials. The radioactive waste disposals do not need to be segregated from other, non-radioactive wastes disposed in the landfill.

The Port Clarence Landfills

Augean is the operator of the Port Clarence site, which comprises a non-hazardous and hazardous waste treatment facility at which materials are recycled, recovered and hazardous properties reduced, and two landfills at which a range of hazardous wastes and non-hazardous wastes are disposed in adjacent but separately engineered landfill sites. The site comprises land that was reclaimed from salt marshes and mudflats using waste from iron, steel and coke works and a tar distillation plant (from the 1800s to the 1960s). The site is close to the River Tees with a small area of the non-hazardous waste landfill located within the flood plain.

The Port Clarence landfill sites were granted planning permission in September 1996 (planning application reference TDC/94/065) for use as a waste disposal site (see planning reference 94/1049) and the most recent planning variation (planning reference 14/3135/VARY) for the site was granted by Stockton-on-Tees Borough Council in June 2015. This extended the operational life of the non-hazardous and hazardous waste landfill sites beyond 2016 with no fixed completion date. The two landfill sites are the subject of separate Environmental Permits which are regulated by the Environment Agency and which control the engineering of the containment systems as well as the waste acceptance and management procedures. A further Environmental Permit is in place for the waste treatment facility located to the south of the landfill sites.

Low-level Waste

Low-level radioactive wastes form the bulk of all the radioactive wastes in the United Kingdom. About 95 percent of the total physical volume of radioactive wastes is LLW; however, LLW only contains a small fraction of the total radioactivity in all the wastes, much less than one percent of the total. LLW contains a wide range of materials, including: paper, tissue, wood, resins, plastic, steels and other metals, graphite, building rubble, and soil. It includes radioactive wastes from the nuclear industry and from other sources including the oil industry, research facilities, remediation of contaminated sites and hospitals. LLW can contain different mixtures of radionuclides and it is not possible to know now the exact mixture of radionuclides that will be contained in future radioactive wastes received at Port Clarence.

Naturally Occurring Radioactive Material

Waste naturally occurring radioactive material (NORM) has been disposed at the Port Clarence site since 2016 under an exemption from the need for a Permit. Augean completed a radiological assessment of the exposure to the public and workers before disposals of waste NORM started and used this to calculate the tonnage that could be buried in accordance with the specified dose limit for these wastes. Augean will continue to accept waste NORM at the Port Clarence site in compliance with this exemption.

Protecting People and the Environment

The overall safety strategy for the disposal of LLW at Port Clarence involves both active (operational) management and the construction of passive barriers (low permeability cap and liner) ensuring that wastes disposed of will give rise to negligible impacts, within the dose constraints and risk guidance levels specified by the Environment Agency for the protection of people and the environment. The ESC contains detailed calculations and analysis of the impact of the disposal of LLW at the landfill sites on people and the environment, both during operations at the site and after the site has been closed and restored. The approach follows guidance for assessing disposal sites prepared by the Environment Agency who regulate radioactive waste disposal in England.

The amount of LLW that can be safely accepted at the Port Clarence Landfills has been determined from the results of the radiological assessment for LLW: this is described in the ESC. These results demonstrate that for all reasonably foreseeable circumstances, doses or risks remain below the relevant dose and risk guidance levels that have been defined by the Environment Agency based on international criteria, both for the protection of people and the environment. For people, in the long term and for events that are expected to occur the Environment Agency guidance requires that a radiation dose of no more than 0.02 mSv y^{-1} arises that could affect members of the most exposed group. This dose is less than 1% of that received from natural background radiation.

Radiological capacity of the site

The total quantity of radionuclides in LLW that can be disposed of at the landfills will be controlled through a “sum of fractions” approach specified in a clear condition of the permit. This approach maintains the flexibility to respond to future mixtures of radionuclides in LLW whilst maintaining the overall dose within accepted levels and is an approach that is used at other sites receiving low activity radioactive waste. The permit will specify the total capacity of the site (both landfills together). There is no predetermined division between the quantity disposed of at the hazardous waste landfill and at the non-hazardous waste landfill. A further condition in the permit will require calculation of the combined dose to people from the waste NORM and the LLW disposed of at the site, before acceptance of LLW, to ensure that the combined dose meets the regulatory requirements. Details of the approach and the radiological capacity values are provided in the ESC.

Activity concentrations

LLW contains radionuclides at different radionuclide activity concentrations, up to the limits specified for the classification of waste as LLW. The activity limits that can be accepted at the site will be determined on a risk based approach to ensure that dose limits are not exceeded. The full details of the management of the approach are provided in the ESC.

Operating procedures

Work management culture and safety procedures ensure that wastes are transported and handled safely reducing the potential for impacts on the dose received by the workforce and the risk of accidents. Wastes accepted for disposal will be compliant with Augean's Conditions For Acceptance (CFA) for radioactive waste specified in the site procedures for handling LLW. The CFA will include a limit on the dose rate close to the consignment on receipt at the site. Each waste consignment will be evaluated before it is directed to the site to check that it meets the criteria on the total activity and on the activity concentration set through the 'sum of fractions' approach. Waste will be placed in the landfill as soon as practicable after inspection on arrival, and within a maximum of 24 hours following acceptance for disposal at the Port Clarence site. Any waste not accepted for disposal will be placed in quarantine and returned to the consignor as soon as practicable. The dose rate from the buried waste is also limited in order to protect the workforce. The measures to protect the workforce will also provide protection to people visiting the site and the surrounding area.

Environmental Monitoring

Augean will undertake radiological and environmental monitoring during the period over which the site is operated and managed including after the site has ceased accepting waste. Environmental samples will be taken on a regular basis and results will be reported to the Environment Agency who will review the data. It is anticipated that the Environment Agency also will undertake an independent sampling programme. Monitoring data will be summarised on the Augean website for review by the public.

Communication

Augean will engage with the local community through publication of an information leaflet regarding the proposals, public exhibitions, site open days, the ongoing publication of a twice-yearly newsletter and the establishment and maintenance of a register of stakeholders that will provide the community with updates and further information. The planning authority has been kept up to date with the programme for this application for an Environmental Permit for LLW as parallel applications are being made for planning permission to accept LLW at the site.

Contents

Tables and Figures

1 Introduction

1. This document is an Environmental Safety Case (ESC) that supports an application for an Environment Agency Permit, for receipt and disposal of low-level radioactive waste (LLW) at the Port Clarence Landfill sites (the Port Clarence site contains two landfill sites: the centre of the hazardous waste landfill site lies approximately at OS Grid Reference NZ 51841 22242, 54.5927º N 1.1992º W and the centre of the non-hazardous landfill site lies at approximately at OS Grid Reference NZ 51785 22505).

2. Augean North Limited (Augean) is the operator of the Port Clarence site. The site comprises a Waste Recovery Park (WRP) at which materials are recycled, recovered and hazardous properties reduced and two landfill sites at which a range of hazardous wastes, non-hazardous wastes and naturally occurring radioactive material (NORM) waste are disposed. The Port Clarence site covers an area of 59 hectares (ha) (MJCA, 2019a) and the landfill sites have a combined residual void space in excess of 5 Mm^3.

3. The current planning permission does not specify an end date for disposals. Capacity at Port Clarence will be available beyond the 2026 planned end-date of the landfill at the East Northants Resource Management Facility (ENRMF) that has a permit for the disposal of LLW. The Port Clarence site comprises land that was reclaimed from salt marshes and mudflats, using wastes from iron, steel and coke works and a tar distillation plant (from the 1800s to the 1960s). The location of the site is near to the River Tees with a small area located within the Tees Estuary flood plain.

4. The guidance on requirements for authorisation of near-surface disposal facilities for solid radioactive wastes (the NS-GRA) (UK Environment Agencies, 2009) has been used as the basis for the analysis undertaken in this ESC. The NS-GRA contains fourteen requirements, of which Requirement 3 of the NS-GRA is for an ESC:

> "An application under RSA 93 relating to a proposed disposal of solid radioactive waste should be supported by an environmental safety case." NS–GRA (UK Environment Agencies, 2009) para 6.2.1

5. The guidance notes on how to apply for an environmental permit for the burial of radioactive waste have also been considered (Environment Agency, 2016).

Document structure

6. An ESC provides a safety assessment and related safety arguments that bear on the acceptability of proposed disposals of radioactive waste at a facility. The ESC is required to demonstrate that members of the public and the environment are adequately protected and it is required to be proportionate to the hazard presented by the waste. The section titles of this ESC indicate where each NS-GRA requirement is addressed, for example sub-section 4.1 has the title "Process by Agreement {R1}" indicating where Requirement 1 is addressed. The relevant sections, as numbered, are listed below:

    4.1 Process by Agreement {R1}

4.2 Dialogue with Local Communities and Others {R2}

5.1 Environmental Safety Case {R3}

5.2 Environmental Safety Culture and Management System {R4}

6.1 Dose constraints during the period of authorisation {R5}

6.2 Risk guidance level after the period of authorisation {R6}

6.3 Human intrusion after the period of authorisation {R7}

6.5 Optimisation {R8}

6.6 Environmental radioactivity {R9}

7.1 Protection against non-radiological hazards {R10}

7.2 Site investigation {R11}

7.3 Use of site and facility design, construction, operation and closure {R12}

7.4 Waste acceptance criteria {R13}

7.5 Monitoring {R14}

7. Site characteristics, the local environment and its natural evolution are described in Section 2 with waste characteristics detailed in Section 3. The contents of Sections 4 to 7 cover the NS-GRA requirements as listed above and Section 8 draws together the safety assessment and related safety arguments. Supporting information is provided in appendices.

8. The rest of this section provides background information on LLW management within the United Kingdom (UK), provides a summary of existing site permits, describes Port Clarence development plans and the proposal for disposal of LLW and lastly highlights features of the environmental safety strategy (ESS) set out in the ESC.

1.1 Background

9. Within the UK, LLW is defined by Government policy as:

> "radioactive waste having a radioactive content not exceeding four gigabecquerels per tonne (GBq/te) of alpha or 12 GBq/te of beta/gamma activity". (Defra, DTI and the Devolved Administrations, 2007)

10. There is a sub-classification of LLW referred to as high volume very low-level radioactive waste (HV-VLLW) that is defined as:

> "Radioactive waste with maximum concentrations of four megabecquerels per tonne (MBq/te) of total activity which can be disposed of to specified landfill sites. For waste containing hydrogen-3 (tritium), the concentration limit for tritium is 40 MBq/te. Controls on disposal of this material, after removal from the premises

where the wastes arose, will be necessary in a manner specified by the environmental regulators". (Defra, DTI and the Devolved Administrations, 2007)

11. The permit application will be for receipt and disposal of LLW including HV-LLW and reference to LLW throughout this document is assumed to include this lower activity waste classification.

12. The use of landfill is an established approach to the disposal of waste with low specific activity and is supported by Government policy (Defra, DTI and the Devolved Administrations, 2007). The UK strategy for the management of solid LLW from non-nuclear sources is presented in two parts; the first considers anthropogenic radionuclides (DECC, 2012) and the second part (DECC, 2014) deals with naturally occurring radioactive materials (NORM). Disposal of LLW to landfill is authorised as a radioactive substances activity under the Environmental Permitting (England and Wales) Regulations 2016 (as amended) (UK Government SI, 2016; UK Government SI, 2018), referred to as EPR2016, using permits issued by the Environment Agency in England.

13. Disposal routes for LLW are limited in the UK. The majority of LLW continues to be sent to the Low Level Waste Repository (LLWR), located near the village of Drigg in Cumbria. The UK is predicted to generate significantly more LLW than the planned disposal capacity at the LLWR, resulting in a need for alternative ways to manage LLW, including the use of alternative disposal routes. The Nuclear Decommissioning Authority (NDA) strategy focusses on preserving capacity at the LLWR, by diverting materials to alternative management routes in order to maximise the lifetime of the LLWR facility (NDA, 2016). This is consistent with the UK nuclear industry recognition that to meet all the LLW disposal requirements, alternative treatment and disposal options may be required for appropriate waste streams through implementation of the waste hierarchy (DECC, 2016).

14. The LLWR does not have capacity for the expected volumes covering the full range of LLW (up to 4000 Bq g^{-1} alpha activity and 12,000 Bq g^{-1} beta/gamma activity) that will be generated by the nuclear industry (NDA, 2016). The disposal of LLW at the lower end of the range of specific activity is not a sustainable use of the repository, which has been designed and engineered to a standard suitable for materials with a radioactive content at the higher end of the range for LLW. The strategic approach for alternative fit for purpose disposal routes established in 2010 (NDA, 2010) has continued within the latest UK nuclear industry LLW strategy (DECC, 2016) and for the non-nuclear industry in UK Government policy (Defra, DTI and the Devolved Administrations, 2007). This is reinforced by recent management strategies developed for waste generated by non-nuclear industries in the United Kingdom concerning anthropogenic radionuclides (DECC, 2012) and NORM (DECC, 2014).

15. Port Clarence is ideally placed to serve the producers of LLW from the nuclear and non-nuclear industries in the north east (Figure 1). Able UK's facility at Seaton Port is around 3 miles from the Port Clarence site. Able have been producing NORM as part of their operations to decommission redundant oil and gas platforms for the last 12 years. Historically some of this waste, as it has activity greater than 10 Bq/g, has had to be transported to the ENRMF or to Lancashire for final disposal. Depending on the

amount of decommissioning Able complete each year around 100 to 200 tonnes of NORM is produced and requires disposal.

16. Alongside the filter cake that Venator already dispose of to the Port Clarence site around 50 tonne (t) of highly NORM contaminated filter cloths are currently disposed of to the LLWR and the ENRMF. These filter cloths are produced as part of the titanium dioxide production process and have activities ranging from 100 to 1000 Bq g^{-1}.

17. Port Clarence is geographically closer to EDF Power Stations (Hartlepool and Torness) than other currently permitted landfill disposal sites. Port Clarence is also closer to Sellafield and LLWR than Augean's current permitted landfill disposal facility, the ENRMF. For many of the LLW producers who dispose of their LLW currently at the LLWR near Drigg, Port Clarence provides a convenient alternative for LLW at the lower end of the range of specific activity.

18. The LLW that will be considered for disposal at Port Clarence can be handled safely by workers in a manner similar to other low hazard wastes. Although the material is radioactive waste by legal definition, these wastes do not need special security measures.

1.2 Existing site status

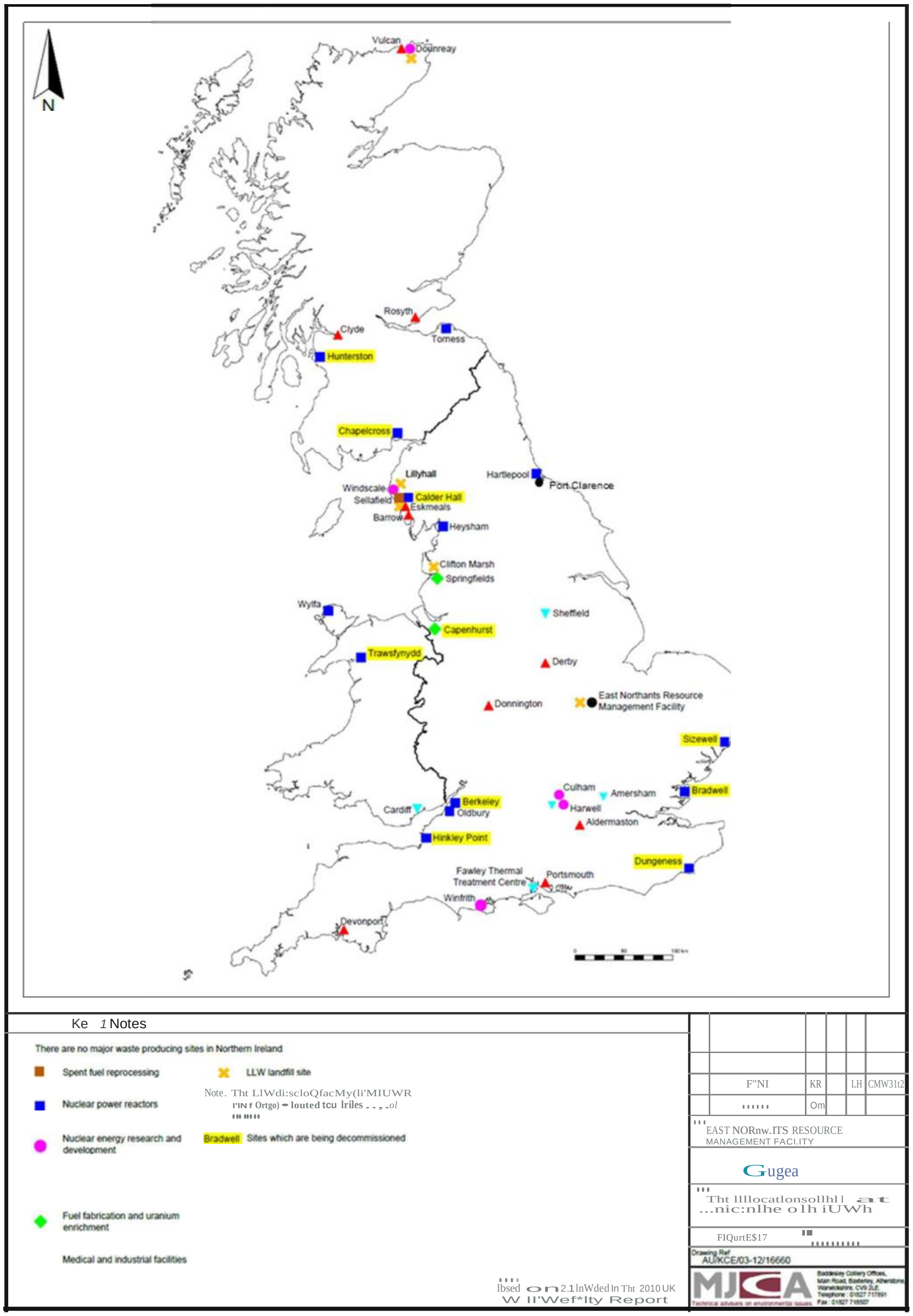
Planning permission

19. The most recent planning variation (planning reference 14/3135/VARY) for the site was granted by Stockton-on-Tees Borough Council in June 2015. This was supported by an Environmental Statement (ES), published in November 2014 (Augean, 2014) that considered extending the operational life of the non-hazardous and hazardous waste landfill sites beyond 2016 with no fixed completion date. The consented design is for 18 waste disposal cells within the two landfills (Augean, 2014) as shown in Figure 2.

Environmental Permits - Waste to Landfill

20. Environmental controls are regulated by the Environment Agency through Environmental Permits (UK Government SI, 2016). All operations at the landfill site are performed in accordance with the conditions of permits EPR/BV/1399IT for the disposal of hazardous waste and EPR/BV/1402IC for the disposal of non-hazardous waste. The permits include a list of waste types that can be accepted at the landfill site together with details for monitoring of leachate, landfill gas, particulate matter and groundwater and frequency of reporting to the Environment Agency. Separate permits considered operations at the Waste Recovery Park (WRP; YP/3234XR) and Chemical Treatment Centre (YP/3024XH) until May 2015 when a consolidated permit was issued (reference EPR/YP/3234XR/V002) for these operations.

Figure 1 Approximate locations of the facilities at which the majority of the LLW is produced



21. Annual disposal limits are specified in the environmental permits (see Table 1).

Table 1 Annual waste disposal limits specified in the permits

Category	Non-hazardous permit (BV/1402IC) Table S1.4	Hazardous permit (BV/1399IT) Table S1.4
Hazardous waste (tpa)	-	500,000
Non-hazardous waste (tpa)	995,000	-
Inert waste (tpa)	50,000	100,000[(1)]
Asbestos waste[(2)] (tpa)	150,000	-

Note: 1) For cover. 2) Including construction material containing asbestos.

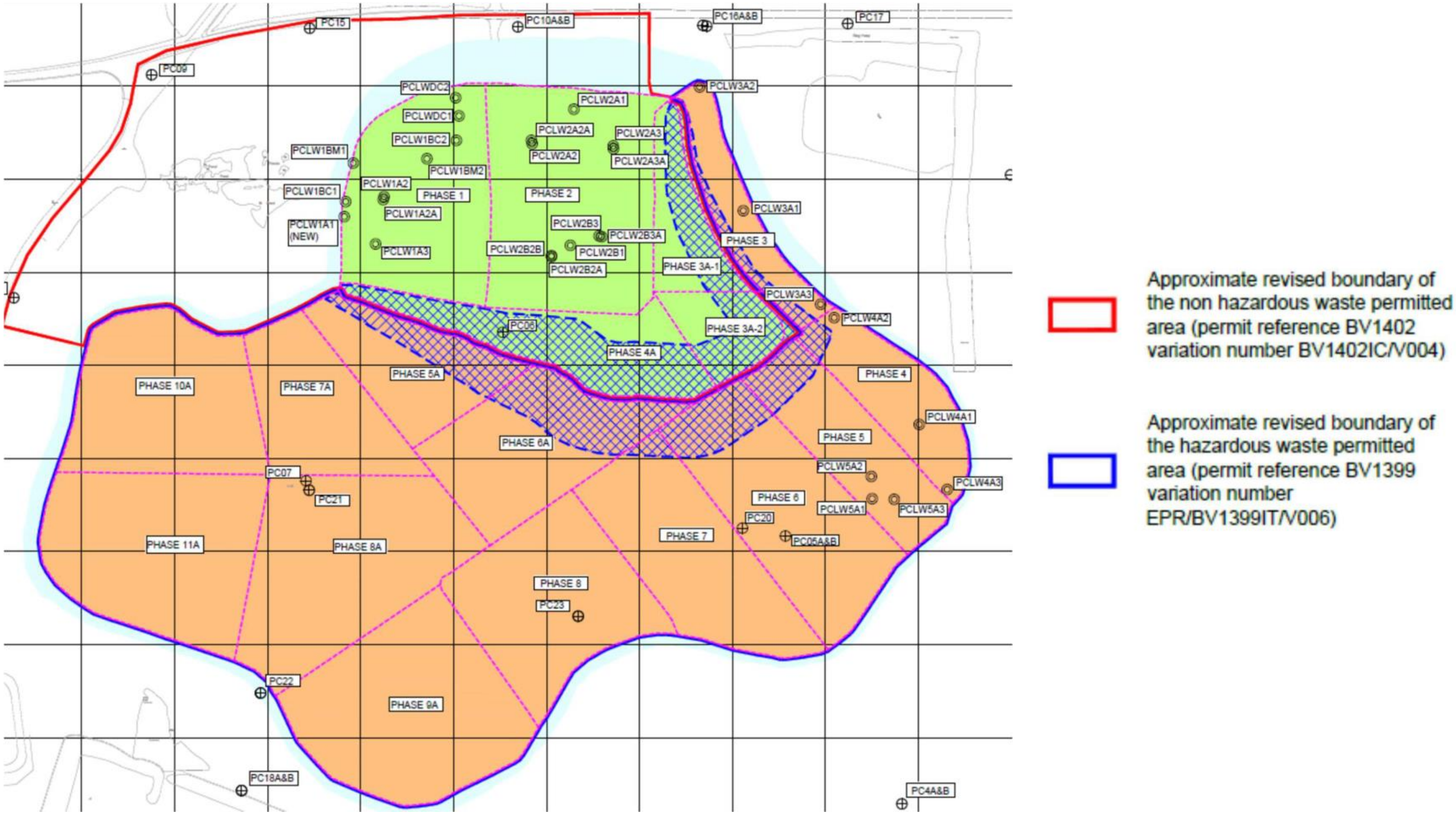
22. The non-radioactive wastes accepted at the Port Clarence landfills cover a broad spectrum of waste but exclude explosive, flammable, corrosive and infectious materials. Those defined as hazardous under the European Waste Catalogue are subject to the hazardous waste acceptance criteria under the Landfill Directive (European Commission, 1999).

Disposal of NORM waste under Environmental Permitting Regulations

23. Very low-level naturally occurring radioactive waste (NORM) has been disposed at the Port Clarence site since 2016 under an exemption from the need for a Permit for Type 2 NORM. Hence, Type 2 NORM waste with concentrations between 1 and 2 Bq g^{-1} is disposed at Port Clarence through compliance with Paragraphs 18 and 19 in Section 6 of Part 6 to Schedule 23 of the EPR2016. Type 2 exemption was required because the total annual activity for disposal exceeded the limit for Type 1 NORM exemption. Augean completed a radiological assessment of the exposure to the public and workers before disposals started and used this to calculate the tonnage that could be buried in accordance with the specified dose limit for these wastes (Jones, et al., 2014).

24. The quantity of NORM waste that could be disposed at the maximum concentration (10 Bq g^{-1}), without exceeding Environment Agency guidance, was derived. The calculated total capacity for the non-hazardous and hazardous landfill sites was 2.8 10^5 t and 1.5 10^6 t of NORM waste, respectively.

Figure 2 Consented site layout



Environmental Permitting – Hazardous Waste Treatment

25. The WRP is located next to the hazardous waste landfill immediately to the south. The consolidated permit (reference EPR/YP/3234XR/V002) for the facilities operated by Augean Treatment Limited lists the permitted waste management activities (and directly associated activities) that includes:

Waste Wood Energy Recovery;

Plasma Treatment;

Thermal Desorption;

Tank Farm;

Effluent Treatment;

Anaerobic Digestion;

Waste Recovery Facility;

Waste Transfer Station;

Soil Washing;

Waste Stabilisation;

Bio-remediation;

Storage prior to treatment;

Cement storage and blending;

Storage of non-hazardous wood materials;

Gas storage and gas flare (from landfill);

Surface water management including storage;

Storage of non-hazardous materials (for processes); and,

Storage of waste, oil, raw materials (for processes).

1.3 Site development plans

26. There is a plan to change the design of the landfills at the site (MJCA, 2018). The revised design will allocate 44% of the void to disposal of hazardous waste, 54% to non-hazardous waste and the remainder (2%) to an engineered separation bund constructed from specified hazardous waste (see Figure 3 and Figure 4). The proposed change to the boundary between the two landfill sites will result in a hazardous waste landfill area of approximately 19.5 ha and a non-hazardous waste landfill area of approximately 20.3 ha (MJCA, 2019a). The proposed revised void allocation is shown in Table 2 and this split is used for the radiological assessments.

Figure 3 Proposed revised site layout

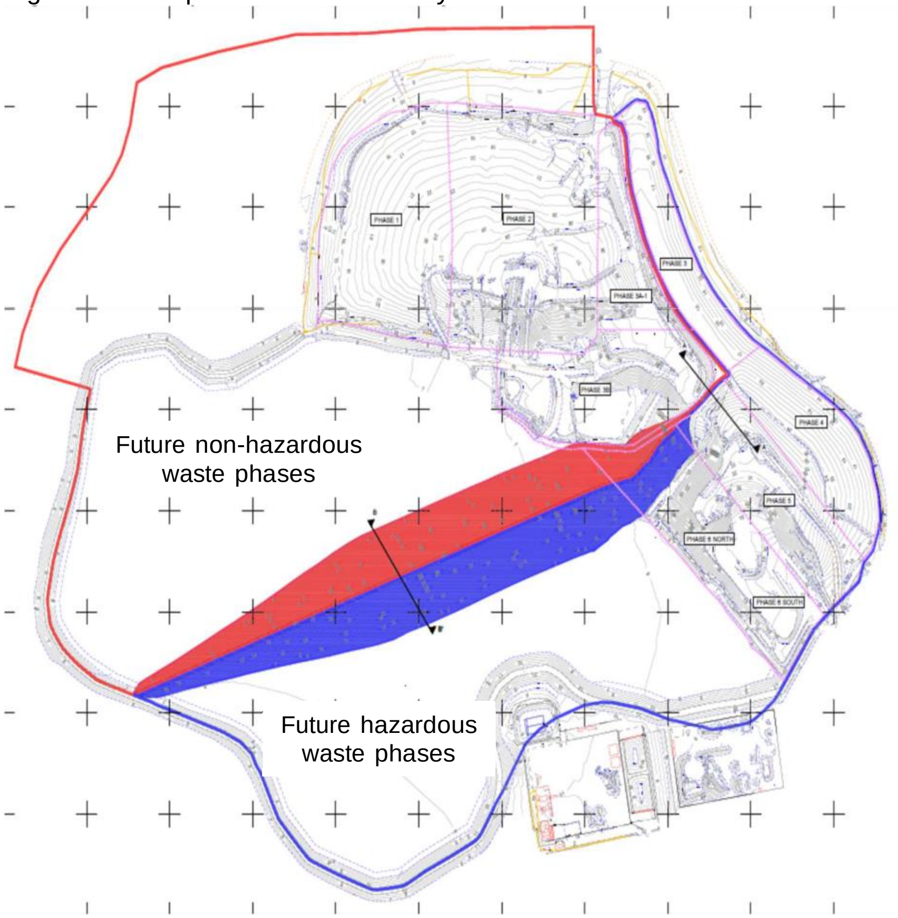


Figure 4 Illustrative cross section of the current design of the separation bund

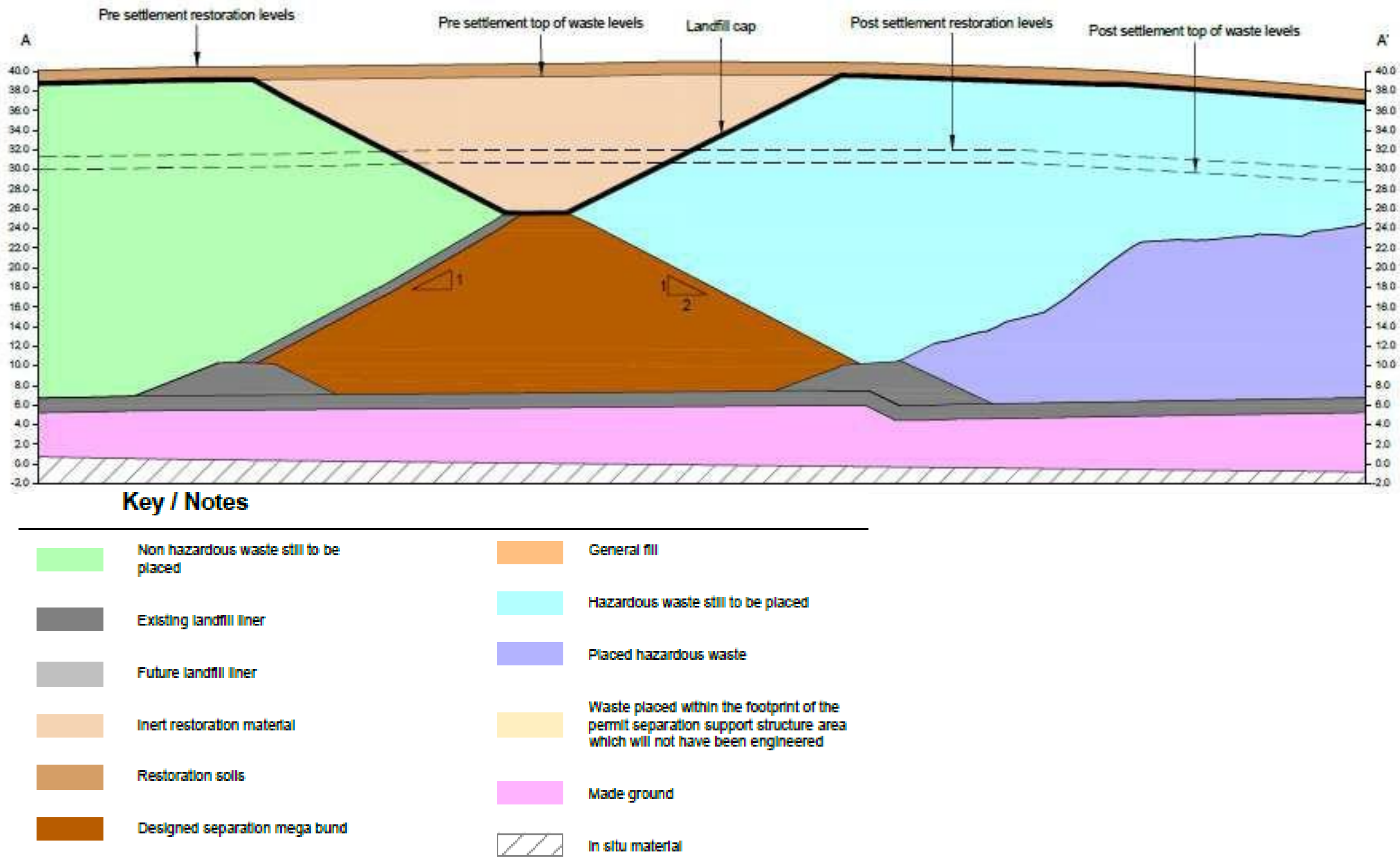


Figure 5 Proposed future design of separation bund

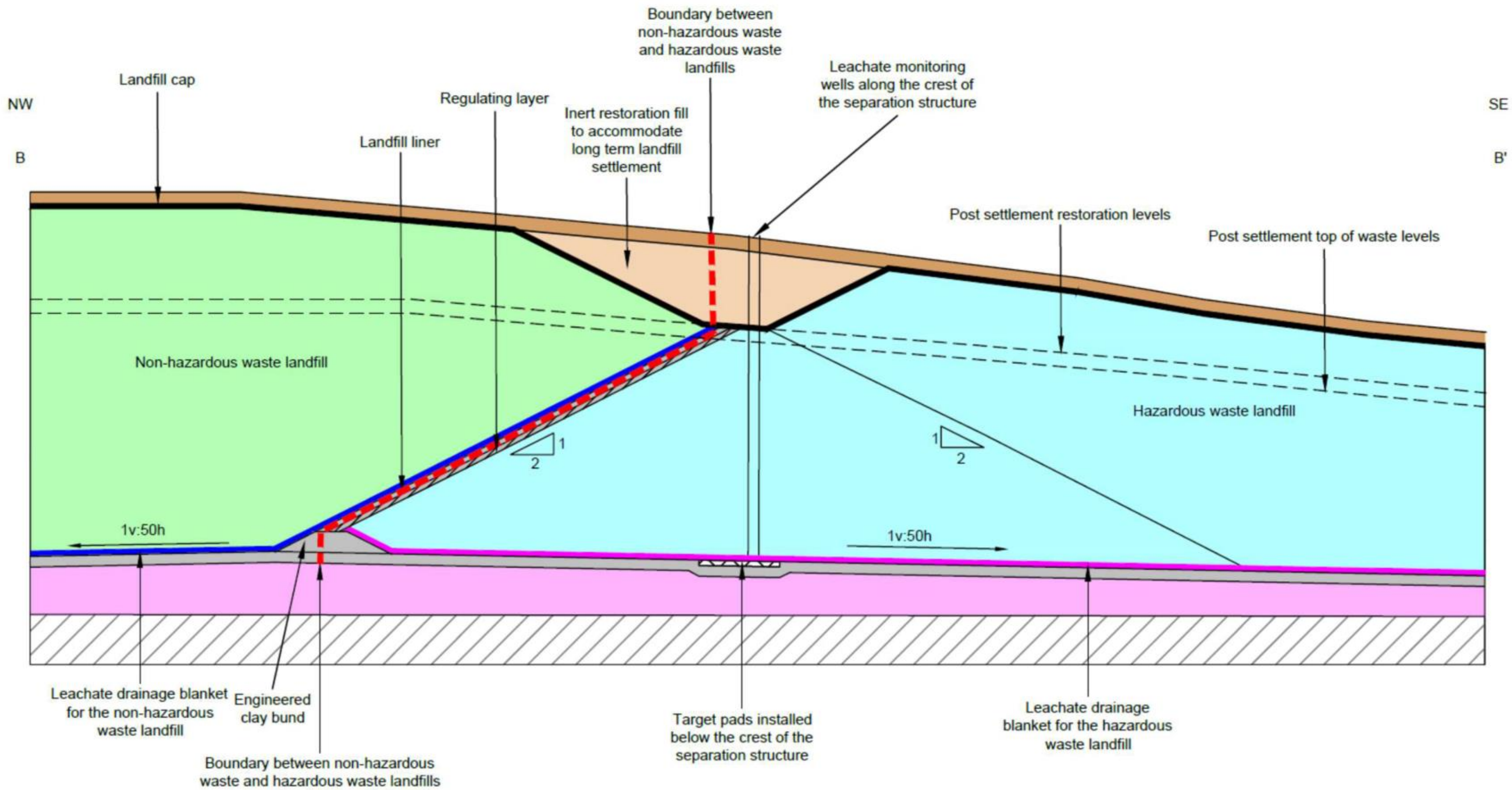


Table 2 Proposed void space at Port Clarence landfill

Waste type	Phase	Void when built (m^3)
Non-hazardous	Future phase	2,594,910
Hazardous	Future phases including separation structure	2,841,500

27. The current Hydrological Risk Assessment (Augean, 2006) was considered adequate after a review in 2010 and an update is in preparation (MJCA, 2018).

28. The landfill is designed and operated based on the principle of containment in accordance with modern standards and the use of Best Available Techniques in accordance with the Landfill Directive. The base and sides of the disposal cells are lined with engineered low permeability material and a high-density polyethylene (HDPE) flexible membrane lining system. Once waste has been placed to final levels a low permeability engineered cap is constructed on the top and restoration materials are placed over the cap. The main difference in design between the hazardous and non-hazardous cells is the thickness of the gravel leachate drainage layer and the thickness of the artificial geological barrier comprising clay with a hydraulic conductivity no greater than 1 10^{-9} m/s. The construction designs for the cells that would be used for LLW are presented in Table 3.

Table 3 Construction design of the hazardous and non-hazardous waste cells

Design feature	Non-hazardous waste cells	Hazardous waste cells
Leachate drainage system (depth of gravel) (m)	0.5	0.5
Artificial geological barrier (depth of clay)(1) (m)	1	1.5
HDPE liner and protective geotextile (mm)	2	2

Note: 1) Clay with a hydraulic conductivity no greater than 1 10^{-9} m/s.

29. Each phase of operation is restored progressively under a defined scheme of capping and restoration. In accordance with the planning permission the landfills will be restored to areas suitable for nature conservation and amenity use.

30. Operating details for the site are not presented here and are available in the supporting documentation for the existing permitted operations. There are about 110 separate operating procedures and risk assessments relating to the waste operations. The operating arrangements and culture at the site are consistent with the arrangements proposed for LLW disposal in the application.

1.4 The Proposal

31. In order to dispose of low activity LLW at the Port Clarence landfill site an Environment Agency permit for the disposal of LLW and a variation to the existing planning permission for the site are required. The boundary for disposal of LLW matches that for the hazardous and non-hazardous waste disposal permits shown in Figure 3.

32. The permit application is for the receipt, temporary storage (a maximum of 24 hours unless quarantined pending return to origin) and disposal of radioactive waste to the hazardous and non-hazardous landfills. Augean procedures will ensure prompt burial of radioactive waste, either on the day of receipt or the next working day if waste has been delivered to the site too late to allow burial on that day. Disposed wastes will otherwise be compliant with Augean's Conditions For Acceptance (CFA), specified in site procedures for handling LLW, relating to the properties of the waste:

    disposal of radioactive wastes to the hazardous waste landfill that would be classified as inert, non-hazardous or hazardous in terms of their content of non-radioactive materials; and,

    disposal of radioactive wastes to the non-hazardous waste landfill that would be classified as inert or non-hazardous in terms of their content of non-radioactive materials.

33. The radioactive waste disposals will not be segregated from other, non-radioactive wastes disposed in the landfill. Radioactive waste containing hazardous waste will not be disposed to the non-hazardous waste landfill. The location of disposals will be recorded using GPS.

34. The proposed permit uses a sum of fractions approach to regulate disposal. The permit will require the operator to calculate, for each radionuclide, the ratio of the activity of the radioactive waste disposed of at Port Clarence to the relevant values specified in the disposal table. It will be a permit condition that the sum of these ratios shall be less than 1. A sum of fractions approach allows the operator greater flexibility in determining the final radioactive waste inventory without compromising environmental safety. The sum of fractions approach has been used in other recent permits (e.g. for the ENRMF and LLWR disposal sites). The overall radioactive waste disposals at the site will also be controlled using the sum of fractions approach.

35. To ensure the greatest flexibility for future disposals the table of disposal limits in the permit will incorporate relevant values for individual assessment scenarios as appropriate (for example groundwater, erosion and gaseous releases). NORM waste will be accounted for as a separate waste stream and compared with the NORM radiological capacity. A further check will ensure that the combined dose from the NORM and LLW disposals does not exceed the appropriate dose criterion.

36. The specific activity limit applied to a consignment is calculated from the radiological assessments and is therefore different for each radionuclide. A sum of fractions approach will also be applied to the specific activity of a consignment. Based on records to the July 2019, the waste streams consigned for disposal at the ENRMF

have an average specific activity across all LLW consignments of less than 15 Bq g^{-1}. The specific activity limits apply to a consignment or over every successive 10 tonnes whichever has the lowest mass.

37. Compliance with the Paris Convention (NEA, 2017) means that the disposal activity concentrations for certain radionuclides will be limited as shown in Table 4.

Table 4 Radioactivity concentration limits for the application of the Paris Convention on Third Party Liability

Radionuclide	Bq g^{-1}
H-3	10,000
C-14	10,000
Co-60	200
Sr-90	200
Tc-99	200
Cs-137	200
U-238	200
Pu-239	100
Am-241	100

38. Methodologies have been developed to evaluate disposal of consignments containing particles and for loose tipping of a specific waste stream. It is proposed that disposal of particles is permitted to defined particle activities and loose tipping is permitted to defined specific activities in a consignment, above which Environment Agency permission will be sought.

39. The minimum depth of non-radioactive waste or material covering LLW and the constraining time periods for cover to be in place following disposal are 0.3 m (metre) and 8 h (hours), respectively. Operating procedures will include specifications on the depth of non-radioactive waste that will be placed at the base (2 m), sides (2 m) and top (1 m) of a landfill waste cell. Waste will be buried within 24 hours of arriving on site. Radioactive waste will not be deposited in the engineered separation bund.

40. An additional limitation is proposed for wastes containing a significant quantity of Ra-226 (Radium contaminated wastes) with a requirement to bury these wastes at least 5 m below the restored surface of the site. The proposed criterion for wastes containing a significant activity concentration of Ra-226 is waste containing >5 Bq g^{-1} Ra-226.

41. Port Clarence accepts Type 2 NORM waste under the conditions of the exemption from the need for a Permit under EPR2016 for Type 2 NORM. The interaction between these NORM wastes and the radiological capacity for radioactive wastes is considered in the ESC and the preferred approach is to apply the Type 2 NORM waste capacity and the radiological capacity for artificial radionuclides independently at the initial stage, and then to do a final check which involves comparing the dose from the combined disposals to the dose criterion. This would allow the inputs of NORM to be monitored based on tonnage delivered to the site and compared with the site capacity expressed in tonnes to ensure that the disposal capacity was not exceeded. The input

of artificial radionuclides would be monitored using a sum of fractions approach, comparing the total activity of each artificial radionuclide with their radiological capacity. The LLW permit would specify the radiological capacities of the artificial radionuclides and the use of the sum of fractions approach. The LLW permit would specify the activity concentrations of the artificial radionuclides and apply the sum of fractions approach to limiting total activity concentration. It would also specify that the Type 2 NORM disposal capacity is considered separately of this radiological capacity, and that the doses from the combined disposals must be below the dose constraint.

42. Specific limitations on disposals of radioactive waste in the non-hazardous landfill are proposed based on the results of the ESC.

43. Each phase of operation is progressively restored under a defined scheme of capping and restoration. The minimum depth of restoration material above the engineered cap will be 1 m or greater and the depth of the engineered cap will be 0.3 m. In accordance with the planning permission, the landfill site will be restored to areas of grassland, scrub and woodland and the surrounding areas will be restored to areas of open water, aquatic marginal vegetation, scrub, wet meadow and ruderal grassland with small hollows, banks and ridges suitable for nature conservation use.

1.5 Environmental Safety Strategy

44. The objective is to dispose of LLW to the Port Clarence landfills in such a way as to ensure that impacts to people and to the environment are protected to a high level, both in the short and long-term, based on current limits, targets and guidance, without any reliance on waste retrieval or other intervention measures.

> "The Fundamental Protection Objective is to ensure that all disposals of solid radioactive waste to facilities on land are made in a way that protects the health and interests of people and the integrity of the environment, at the time of disposal and in the future, inspires public confidence and takes account of costs." (UK Environment Agencies, 2009) para 4.2.1

45. This will be achieved through use of both engineered and natural barriers to contain the disposed radionuclides for as long as reasonably practicable and thereafter limit the rate at which any radionuclides are released to the accessible environment.

46. The NS-GRA requires an environmental safety strategy that is supported by an ESC. Such a strategy should:

> "… present a top-level description of the fundamental approach taken to demonstrate the environmental safety of the disposal system. It should include a clear outline of the key environmental safety arguments and say how the major lines of reasoning and underpinning evidence support these arguments." (UK Environment Agencies, 2009) para 7.2.2

47. As discussed further in Section 2.9 the Port Clarence site is not at risk of erosion from the relatively slow moving River Tees but could be impacted by sea level rise due to climate warming. There is a risk of flooding to the north of the site but this will not

overlap with the cell liner under current projections (to 2115). Consideration is also given to the long-term evolution of the site and the likelihood and potential impact of tidal erosion.

48. The strategy to achieve the objective of low impacts at all times following waste disposal consists of disposing of wastes that represent a low inherent risk due to their relatively low specific activity and a restriction on the total quantity that can be disposed at Port Clarence. Our approach is the same as that used at the ENRMF and as such wastes will be disposed to a facility that:

- has an established track record - Port Clarence has been in operation since 2000 with a hazardous waste landfill site and a non-hazardous waste landfill site;
- is based on well tried and tested technologies that are BAT;
- is robust and incorporates multiple engineered barriers and safety functions;
- is regularly reviewed for compliance with current standards as subsequent phases for developing disposal cells are planned;
- is subject to active management control; and,
- maximises use of passive safety features.

49. The overall safety strategy for the disposal of LLW at Port Clarence involves both active (operational) management and the construction of passive barriers ensuring that wastes disposed of will give rise to low impacts, within the dose and risk guidance levels laid down in the NS-GRA. The following steps will be taken (italics indicate changes of approach since the ENRMF ESC (Eden NE, 2015a; Eden NE, 2015b)):

- limits will be set on the specific activity in each consignment and the total activity to be disposed (the total volume of waste that can be accepted is already limited by the planning consent);
- Waste Acceptance Criteria (WAC) will be specified, covering radiological and non-radiological properties of the wastes, and a written specification of acceptable waste types will be provided to any person seeking to dispose of waste at Port Clarence (the CFA);
- a waste inventory regulated using a sum of fractions approach for LLW and a separate capacity for NORM wastes;
- a specific activity regulated using a sum of fractions approach;
- the landfill design with fit-for-purpose disposal cells with basal and side-wall liners, as well as a low permeability capping layer, provides an engineered barrier, reducing leachate generation and migration over periods of many decades or centuries;
- work management culture and safety procedures ensure that wastes are transported and handled safely reducing the potential for dose impact to the workforce and the risk of accidents leading to unplanned impacts on the environment;

waste will be placed in the landfill as soon as practicable after inspection on arrival at the landfill and within a maximum of 24 h following acceptance for disposal at the landfill site, any waste not accepted for disposal will be placed in quarantine and returned to the consignor as soon as practicable;

the wastes will be covered immediately to reduce the risk of dust suspension and hence the risk of impacts via the inhalation pathway during the operational period;

active collection of leachate during and following the operational period and use on site at the treatment facilities or transported for discharge via a reed bed or aqueous waste treatment plant reduce the risk of contamination of groundwater in the vicinity of the disposal site;

cell caps will be constructed once disposal cells are full, reducing water ingress, and hence reducing potential leachate generation;

environmental monitoring during the period of authorisation will check the integrity of barriers and safety plans;

scenarios involving exposure to waste during normal operations and expected site evolution have been considered ensuring doses or risks remain below the relevant dose and risk guidance levels;

a full range of scenarios involving unplanned exposure to waste have been considered, in order to ensure that for all reasonably foreseeable circumstances doses or risks remain below the relevant dose and risk guidance levels; and,

the impact of uncertainty in estimated doses and risks has been considered to demonstrate that the ESC is robust in meeting all relevant dose and risk guidance levels.

50. Waste retrieval is not planned and the assessments in this ESC relate to waste disposal (see NS-GRA, para 3.6.2). Nonetheless, retrieval would be feasible both in the short and longer term if required because the location of disposals will be recorded using GPS. This provides an assurance of last resort that, should an unforeseen (and unacceptable) impact occur, intervention to reduce or eliminate the impact could be undertaken. It is emphasised however, that it is considered that under all foreseeable circumstances it will not be necessary nor should it form any part of contingency planning.

2 Site Characteristics

2.1 Introduction

51. The NS-GRA (UK Environment Agencies, 2009) requires that the site characteristics including the geological environment and the biosphere are characterised, understood and capable of analysis to the extent necessary to support the ESC. Such characterisation has been undertaken (Augean, 2014) and is the basis for the description set out in this section.

52. This section presents a summary of the current understanding of the characteristics of the site, including information on the physical setting, land use and hydrology, and of the regional and local geosphere including lithology, stratigraphy, resource potential, hydrogeology and geochemistry relevant to the assessment of the proposed disposal facility. Consideration of the potential for disruption of the landfills under reasonably foreseeable future conditions is also presented.

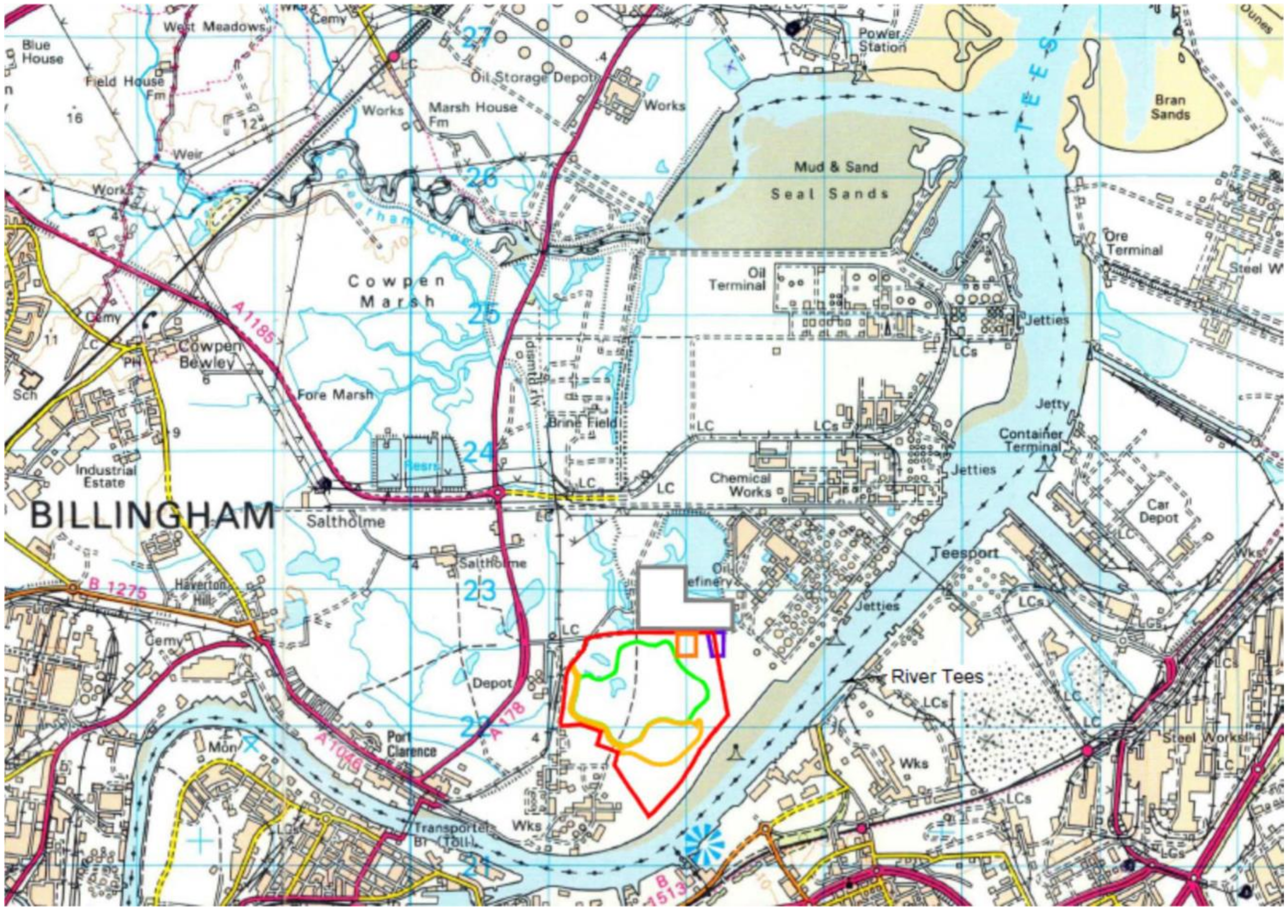
2.2 Location

53. The Port Clarence landfills are located about 7 kilometres (km) from the open sea and about 3 km from the tidal flats at Seal Sands (Figure 6). The site covers 107 ha within which the landfills occupy approximately 40 ha to the north and the WRP occupies approximately 13 ha immediately adjacent and to the south of the landfill sites. The remaining land in the area subject to the planning consent is occupied by partially re-vegetated slag and pools of standing water some of which has developed ecological interest and is preserved for that purpose. An aerial photograph of the site is presented as Figure 7.

54. The operational landfill area is situated about 280 metres (m) from the northern bank of the River Tees and approximately 2.6 km north-east of Middlesbrough Station. Between the WRP and the river bank there is an embankment (about 14 to 15 m AOD [above ordnance datum] along its length).

55. The boundary of the Tees and Hartlepool Foreshore and Wetlands Site of Special Scientific Interest (SSSI) surrounds the site and is found at varying distances from the landfills depending on direction of travel. The SSSI comprises 7 units (areas) and includes Dormans Pool about 230 m north of the landfill at its closest point. The SSSI also includes the River Tees approximately 280 m from the south east boundary of the landfill. Overlapping designations include Saltholme Nature Reserve (RSPB), the Teesmouth and Cleveland Coast Ramsar (covering the north bank of the River Tees, and parts of the nature reserve including Dormans Pool) and the Teesmouth and Cleveland Coast Special Protection Area. The nature reserve is located approximately 20 m to the north of the site at its closest point (Dormans Pool area), separated from the site by Huntsman Drive. The nature reserve also encompasses land to the west of the landfill and is designated for supporting an internationally important population of wildfowl and waders.

Figure 6 The site location



Key / Notes

- Red: Boundary of the area the subject of planning consent TDC/94/065 and the area under the control of the applicant
- Green: Boundary of the operational landfill
- Yellow: Boundary of the waste recovery park the subject of planning consent 07/2984/EIS
- Grey: Approximate extent of reclaimed land developed for waste and renewable energy facilities
- Purple: Approximate extent of a gas production facility
- Orange: Approximate extent of the vitrified aggregate storage area

Figure 7 Aerial view of the site showing planning consent boundary

2.3 Development of the Tees Estuary

56. In the 18th century the estuary was wide and bell-shaped. The tidal limit on the River Tees was 49 km from the mouth of the estuary at Low Moor (NZ 36508 10520) with saline intrusion to 33 km (Environment Agency, 1999). The Tees Estuary developed under the influence of fluvial sediments deposited by the slow-moving river combined with coarser sediments of marine origin deposited by tidal action to form a broad expanse of tidal mudflats and salt marshes with shallow shifting channels towards the sea. Of the original 2,470 ha of inter-tidal mudflats and sandbanks present in 1850, only 200 ha now remain (Environment Agency, 1999).

57. The Tees Estuary has been modified by extensive engineering works over the last 200 years. The first embankments were constructed in 1723 to reduce tidal flooding of Coatham Marsh, an attempt to improve grazing (Fouracre, 2005). In 1810, the Mandale Cut removed a 5 km loop of the estuary to improve access to Stockton-on-Tees for shipping, in 1831 the Portrack Cut removed a shorter more hazardous bend and in 1855 the current channel from Middlesbrough Dock to the sea was formed (Fouracre, 2005) by first shutting off the northern and middle channels, constructing retaining walls and dredging to deepen the channel (Baker, et al., 2007). Routine dredging of the River Tees began in 1853 (Le Guillou, 1978).

58. The first edition of Ordnance Survey (OS) maps (dated 1853) shows the southern limit of the high water mark (of an ordinary spring tide) as close to the route of the Middlesbrough to Redcar railway line (MJCA, 2007). Land above the Port Clarence settlement to the north is shown as liable to flooding and records indicate reclamation work started in 1853 (Le Guillou, 1978). Extensive embankments are in place by 1856 protecting Saltholme and Port Clarence Iron Works from tidal flooding. Towards the end of the 19th century iron works are shown at many other sites on the south bank and slag wastes from this industry was used to train the navigation channel and reclaim the foreshore (Fouracre, 2005). The South Gare Breakwater at the mouth of the estuary was completed in 1888 (Baker, et al., 2007) and construction of the North Gare Breakwater was stopped in 1891.

59. Successive maps in the 20th century show embankments and land reclamation extending seaward. The land to the south of the Port Clarence landfill facility was reclaimed by 1913 but most of the facility remained below the high water mark (of ordinary tides). By 1948, embankments protect the area where the landfills are located and at that time the area is shown as marshland surrounding a large bunded lagoon. Maps from 1955 onwards show further reclamation, by 1961 the lagoon is smaller and by 1994 the lagoon no longer exists. The last major reclamation work on Seal Sands was completed in 1974 (Environment Agency, 1999) and reclaimed land is now dominated by large industrial complexes (Baker, et al., 2007). Waterbodies have also formed in depressions caused by brine extraction (from sub-strata) based at Saltholme (Natural England, 2014).

60. The Tees Barrage was completed in 1995 (at OS grid reference NZ 46254 19036) and is now the upper limit of saline intrusion and tidal influence. The barrage has affected

fluvial deposits in the lower estuary and they are now held at the barrage (Nelson, 2003). This has led to a change in the deposition of highly organic fine sediments in the upper and middle estuary with coarser, marine-derived sediments dominating at Teesmouth (Environment Agency, 1999). Accumulating sediments of marine origin are dredged periodically to provide shipping access to Teesport (Villars & Delvigne, 2001).

2.4 Landfill History, Design and Use

2.4.1 Landfill History

61. A brief history of the industrial use of the area is provided below (MJCA, 2019a):

- 1855: Port Clarence ironworks with waste blast furnace slag progressively tipped northwards across the site to reclaim the marshlands;
- early 1900s: industry at the site included gas works, lime works, chlorine works, soda works, blast furnaces and salt evaporating pans;
- by 1930 an iron and steel works had operated and been demolished at the site;
- the western part of the wider site was quarried for slag deposits up until 1976;
- the quarries were licenced to BSC Chemicals by Cleveland County Council for the tipping of potentially combustible industrial waste materials such as tar, bitumen and pitch until 1985 (see areas labelled CLE 45 and CLE 46 in planning application 94/1049/P); and,
- an additional licence was granted for the disposal of pulverised fuel ash, slag, ash, coke, breeze and acid tars with steel slag - material was placed in a depression running north to south to the south of the current landfill area.

62. The Port Clarence landfill sites were granted planning permission in September 1996 (planning application reference TDC/94/065) for use as a waste disposal site (see planning reference 94/1049) for a period of 16 years after waste was first disposed on site. Landfilling commenced at the site in October 2000 and the operation of the two separate landfill sites has been carried out by Augean North Limited since February 2004. A planning variation was agreed in April 2003, increasing the limit on imported materials deposited at the landfill site to 8.5 million cubic metres (Mm^3; see planning reference 02/1987/P) in order to achieve the restoration landform previously agreed. The most recent planning variation (planning reference 14/3135/VARY) for the site was granted by Stockton-on-Tees Borough Council in June 2015.

63. At the end of July 2018, two areas of the hazardous waste landfill have been capped and await restoration (Phases 3 and 4). A small prepared void space remains in Phases labelled 1, 2, 3A-1, 5 and 6 North with larger prepared voids remaining in Phases 3B and 6 South (see Table 5) and a further hazardous waste cell under preparation (May 2019).

Table 5 Allocation of void space at Port Clarence landfill sites

Waste type	Phase	Area label	Void when built (m^3)	Void remaining on 09/01/19 (m^3)	Capping
Non-hazardous	Constructed	1 & 2	830,000	2,540	Not capped
		3A-1	230,000	2,480	Not capped
		3B	444,850	258,180	Not capped
Hazardous	Constructed	3	60,720	0	Capped
		4	126,500	0	Capped
		5	221,500	500	Not capped
		6 North	111,630	6,230	Not capped
		6 South	166,930	47,990	Not capped

2.4.2 Design and Construction

64. Port Clarence landfills have been operational for almost nineteen years. The landfill sites are designed and operated based on the principle of engineered containment with low permeability basal, perimeter and capping seals constructed to an engineering specification which is the subject of approval by the Environment Agency under the Environmental Permit for hazardous waste disposal and non-hazardous waste disposal and the Landfill Directive (European Commission, 1999).

65. The revised design (see Sub-section 1.3) will allocate 44% of the void to disposal of hazardous waste, 54% to non-hazardous waste and the remainder (2%) to an engineered separation bund (see Figure 3 and Figure 4). A series of cells will be filled, capped and restored progressively. The site is operated in a cellular manner to minimise leachate generation. To separate the wastes from the surface environment and to minimise the infiltration of rainfall the landfill will be capped with low permeability layers overlain with restoration materials.

66. The waste cells are formed of a low permeability lining system constructed along the base and sidewalls to an engineering specification which is agreed with the Environment Agency as part of the site Environmental Permit (Augean, 2014). The low permeability liner is constructed using a low permeability mineral liner such as clay and an artificial liner such as a geomembrane. Mineral liners are formed by placing and compacting material in a series of layers until a liner of a specified thickness and low permeability has been formed. The base of each cell is constructed with a suitable gradient to drain rainfall and leachate collecting in the cell to a collection point. Each landfill cell is constructed with a drainage layer comprising free draining material along with pipework connected to a leachate collection sump used to manage leachate levels within the cell. The lining system is constructed by a specialist contractor overseen by a construction quality assurance engineer. The lining system is subject to testing during construction and approval by the Environment Agency.

67. The proposed variation applications to the landfill permits (MJCA, 2019a) are to authorise the construction of a separation support structure within the revised

hazardous waste landfill site. The proposed structure will be constructed from selected treated hazardous waste producing an engineered compacted volume inside the hazardous waste landfill site, i.e. inside the engineered containment.

68. Selected treated hazardous waste soils will be placed above the basal containment lining system in layers and compacted to form a separation support structure along the boundary between the two landfill sites. A side slope landfill liner for the non-hazardous waste landfill site will be constructed over the northern face of the waste separation support structure. The internal cap to the hazardous waste landfill site, which directly overlies the separation support structure, will be formed of a 0.3 m regulation layer with compacted low permeability clay above. The compacted low permeability clay will be overlain by the geomembrane which forms part of the side slope liner system for the non-hazardous waste landfill site. A cross section through the proposed separation support structure is shown in Figure 4.

69. It is anticipated that the waste used for the separation structure will be contaminated soils treated with air pollution control residue (APCR soils). Field compaction trials and laboratory testing have been undertaken on this material and the results demonstrate that the APCR soils can be compacted to achieve high strengths and friction angles and therefore will have the geotechnical properties needed to form the separation structure (MJCA, 2019a). Alternative suitable hazardous waste materials may be proposed for use. The wastes used to form the separation structure will be placed and compacted in accordance with an agreed methodology and/or specification. In order to achieve effective cohesion the material is placed as a wet plastic material which has a low potential to generate dust. Radioactive waste will not be used in the separation bund as this is part of the engineering structure. In accordance with the placement specification radioactive waste will not be placed within 2 m of the engineered separation bund.

70. The proposals to change the location of the boundary between the two landfill sites and to construct the separation support structure of suitable hazardous waste inside the hazardous waste containment landfill do not change the principles of the design and engineered containment for the sites. The detailed design of the low permeability capping layer at the site will be agreed with the Environment Agency and will comprise, a 0.3 m regulating layer, a protection geotextile, a low permeability geosynthetic clay liner and 1 m of restoration soils (MJCA, 2019a). The placement of a cap and restorations soils will reduce significantly the amount of rainfall infiltrating the site and the generation of leachate will become minimal. A temporary cap is placed over filled cells prior to final capping if waste deposit in an area ceases temporarily or, in some circumstances, pending placement of the final cap.

2.4.3 Leachate Management

71. Leachate is formed as a result of the release of liquids entrained in deposited wastes and following the infiltration of rainfall through the waste. The engineered landfill containment system includes a leachate management system for the collection and extraction of leachate. A leachate drainage blanket and collection sumps are constructed at the base of the site immediately above the low permeability basal liner.

The leachate levels are controlled by pumping leachate from the leachate collection sumps or other extraction wells drilled as necessary. The level at which the leachate is maintained will be specified in the Environmental Permit.

72. The leachate generated at the site will not be used for dust suppression. The excess leachate will be pumped into a leachate storage tank and used in the on-site WRP in place of clean water. If the leachate cannot be processed in the on-site waste treatment facility it will be removed from site by tanker for treatment at a suitably authorised waste water treatment plant. Leachate is monitored for chemical characteristics to confirm that the contaminants remain below the levels specified in the hydrogeological risk assessment. This monitoring will be extended to include radiological characteristics.

73. Offsite leachate treatment facilities are the reed bed treatment facility at Norton Bottoms (Scot Bros.) and the industrial effluent treatment works at Bran Sands (Northumbrian Water Limited).

2.4.4 Landfill Gas Management

74. The management of landfill gas at the hazardous and non-hazardous landfill sites is the subject of conditions of the Environmental Permits. Landfill Gas Management Plans are in place and implemented through the Augean management systems. Landfill gas is extracted and pumped to the WRP where it is used to generate electricity and any excess gas is burned in a flare stack.

75. As the amount of landfill gas that is generated in the hazardous waste landfill site is low, a less extensive gas management system is needed compared with that needed for the non-hazardous waste landfill site (MJCA, 2019a).

76. The majority of the landfill gas generated at the site is from the non-hazardous waste landfill site. Information in respect of landfill gas generation was included in the landfill gas risk assessment (LFGRA) prepared as part of the permit application entitled 'Landfill gas generation and risk assessment Port Clarence Landfill Site' reference 03523434.500 and dated June 2003. The LFGRA predicted a landfill gas generation rate at the 95th percentile of 2,730 $m^3\ h^{-1}$ for the year 2018. Based on information provided by Augean and Renewable Power Systems (RPS) the measured average flow rate of gas extracted from the non-hazardous waste landfill site in 2018 was in the range 177 Normal $m^3\ h^{-1}$ ($Nm^3\ h^{-1}$) to 230 $Nm^3\ h^{-1}$ (MJCA, 2019a).

77. The hazardous wastes that are currently and will continue to be deposited at the site have an organic carbon content limited to less than 6%. Putrescible materials are not accepted in the hazardous landfill. The LLW wastes that will be disposed of at the site will have a generally low level of organic matter and are only slowly degradable, if at all. Putrescible materials are not accepted. The levels of radioactivity in LLW are too low to give rise to a risk from radiolytic hydrogen gas evolution. The site operates a gas management system that is able to manage any gas generated from the waste. It is unlikely that significant quantities of landfill gas will be generated from LLW that will be deposited at the site. If gas is generated by the non-hazardous or hazardous waste

and/or LLW, the gas will be collected in the gas management system and be combusted.

78. A dual system of migration control will continue to be operated at the site. The engineered low permeability basal and sidewall liners impede lateral gas and vapour migration and the low permeability cap reduces the emissions to the atmosphere. A pumped landfill gas extraction system will continue to be operated as necessary which prevents the accumulation of gas under elevated pressures in the landfill minimising further the risk of the migration of gas and the emissions of gas to the atmosphere. The collected gas will continue to be directed to the power generation unit to the south east of the landfill and burnt. Combustion of the gas destroys potentially harmful and odorous components in the gas and minimises the release of methane.

79. The landfill gas pumping system and electricity generation unit are surrounded by 1.8 m high fencing. The height of the stack is 8 m. The gas management system and generation plant will remain at the site beyond the completion of landfilling.

2.4.5 Surface Water Management

80. There is no artificial surface water management system at the site as surface water all drains away naturally.

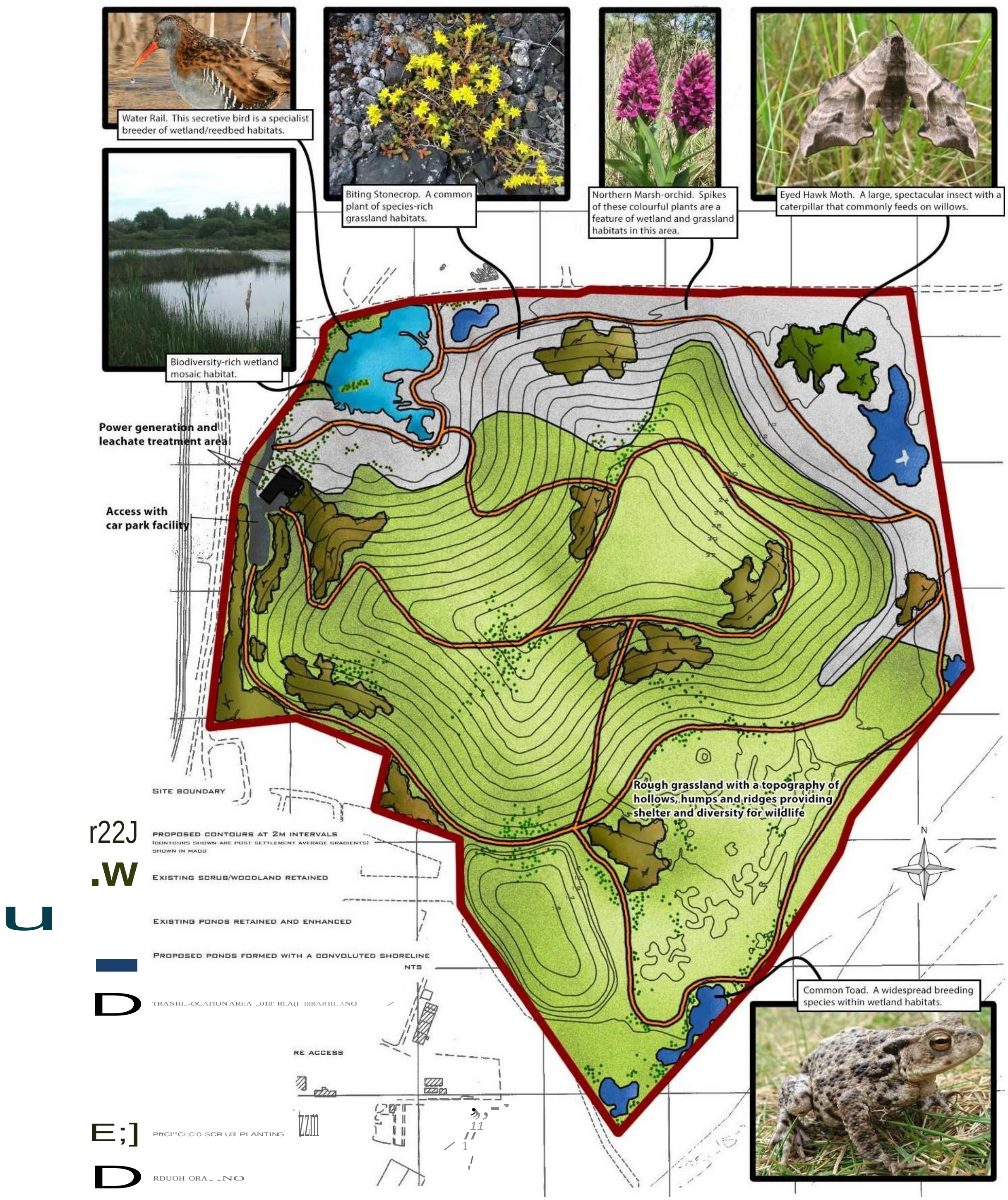
2.5 Restoration and After-use

81. The restoration of the landfill site will be undertaken in a progressive manner following the phased waste disposal operations. The approved restoration scheme is shown on Figure 8.

82. The objectives of the restoration scheme are to:

- reclaim 107 hectares of derelict industrial wasteland;
- to provide a range of ecological habitats consistent with the immediate surrounding area;
- to develop the site in such a way that many of the benefits of the restoration strategy are accomplished as early as possible based on the rate of landfilling at the site;
- to provide public access to the area such that it complements the establishment of the nearby Nature Reserve; and,
- to provide lasting and beneficial after use to the local environment and community.

Figure 8 Landform and landscaping of the restored site



84. Protection of the existing open water body and marginal vegetation in the north west of the site (which is subject to seasonal variations) or the provision of alternative water bodies is established in a Section 106 Agreement associated with the original planning permission reference TDC/94/065. In addition, the Section 106 Agreement provides a commitment to an aftercare fund with oversight of the restoration from the Restoration Consultative Group and the establishment of public access to the restored site. A second S106 Agreement dated February 2008 specifies that soils, lining and restoration materials shall not be stockpiled in the area to the south of the WRP to retain the species rich short turf vegetation.

85. In accordance with the planning permission, the landfill site will be restored to rough grassland, scrub and woodland and the surrounding areas will be restored to areas of open water, aquatic marginal vegetation, scrub, wet meadow and ruderal grassland with small hollows, banks and ridges suitable for nature conservation use.

2.6 Local Environment

2.6.1 Site Access

86. The current highway access to the Port Clarence site will continue to be used. The access to the landfill sites and WRP is from the north west via a private access road to Huntsman Drive which joins the A178 approximately 0.35 km to the north west of the site access. There are no public rights of way, bridleways or footpaths that cross the site or on immediately adjacent land.

2.6.2 Settlements and Activities

87. The site is remote from residential properties. The nearest residential properties are on Port Clarence Road about 1,140 m to the south-west of the site. The properties are separated from the landfill operations by a large area of open ground, the Clarence distribution works and the A178. Land use in the area surrounding the site comprises industrial facilities, areas of protected habitats and wildlife areas (Augean, 2014). The nearest industrial properties are about 130 m immediately to the north of the capped Phase 3 cell and uncapped Phase 1 and 2 cells.

88. Constraints that impact on the site and immediate area are shown in Figure 9. The diagram shows that most of the site lies in Flood Zone 1 where flooding is very unlikely to occur. Partial flooding is most likely to occur from the north and west of the site as a result of tidal flooding in the Tees Estuary. Properties at risk of flooding are located at Port Clarence and the heavily industrialised areas around Tees Mouth. Measures have been taken to improve flood defences (Environment Agency, 2016). Flooding is exacerbated when there are concurrent high fluvial flows, off-shore winds and tidal surge due to low pressure over the North Sea. The wider area context is presented in Figure 10 which also shows the location of flood defences to the north of the site and

the area that these benefit (Environment Agency, 2018). The annual probability of inundation of Flood Zone 2 is given as between 1 in 100 (1 in 200 for tidal flooding) and 1 in 1000 for river flooding.

89. Two fracking licences have been granted in the immediate vicinity of Port Clarence. These are administered by Egdon Resources U.K. Limited and Third Energy UK Gas Limited (Licence references PEDL68 and PEDL259, respectively). We are not aware of any test drilling or site developments being carried out or planned under these licences.

90. The most recent topographical survey shows the ground level at the Port Clarence site is at a height of 2.49 m to 16.5 m AOD, being lowest in the north west area and with most of the site above 5 m AOD (MJCA, 2018). Analysis of planned cell construction profiles indicates that the base of the engineered liner varies from 5.4 to 8.5 m AOD as shown in an illustrative cross section of a waste cell (Figure 11).

91. Tidal levels recorded at Tees Dock, located approximately 2.5 km north east of the site, is on average 0.41 m and varies between -1.39 to 2.03 m AOD (Good Stuff Ltd, 2019). The tidal range can be larger under extreme events and records since February 2015 indicate a range from -2.29 to 2.89 m AOD (95th percentiles).

2.6.3 Flora and Fauna

92. The site lies close to Saltholme Pool and Dorman's Pool and to North Tees mudflat, all constituent parts of the Tees and Hartlepool Foreshore and Wetlands SSSI which itself forms part of the Teesmouth and Cleveland Coast SPA and Ramsar site (ESL, 2014a). The SSSI interests include a range of wintering and passage waterfowl. At Saltholme Pool and Dorman's Pool, breeding waterfowl include shoveler Anas clypeata, pochard, little grebe, great crested grebe Podiceps cristatus and little ringed plover Charadrius dubius. Feeding and roosting birds here include shoveler, teal Anas crecca, wigeon Anas penelope, gadwall, lapwing and golden plover Pluvialis apricaria. Birds feeding and roosting in significant numbers on the North Tees mudflats are shelduck and redshank Tringa totanus.

93. The SPA was designated under Article 4.1 of the Birds Directive (79/402/EEC) by supporting populations of European importance of little tern Sternula albifrons during the breeding season, and of Sandwich tern Sterna sandvicensis on passage. It also qualifies under Article 4.2 of the Directive by supporting populations of European importance of ringed plover on passage and of knot and redshank over the winter. The site further qualifies under Article 4.2 by regularly supporting at least 20,000 waterfowl over winter, including cormorant, shelduck, lapwing, knot Calidris canutus, sanderling Calidris alba and redshank.

94. The SPA also qualifies for listing as a Wetland of International Importance, especially as Waterfowl Habitat, under Criteria 5 and 6 of the Ramsar Convention. It regularly holds a total of more than 20,000 waterfowl over the winter period, and it regularly holds numbers above the qualifying level of redshank on passage, and of knot in

winter. No National Nature Reserves, Local Nature Reserves or Local Wildlife Sites are present within 2km of the site (ESL, 2014a).

Figure 9 Site constraints

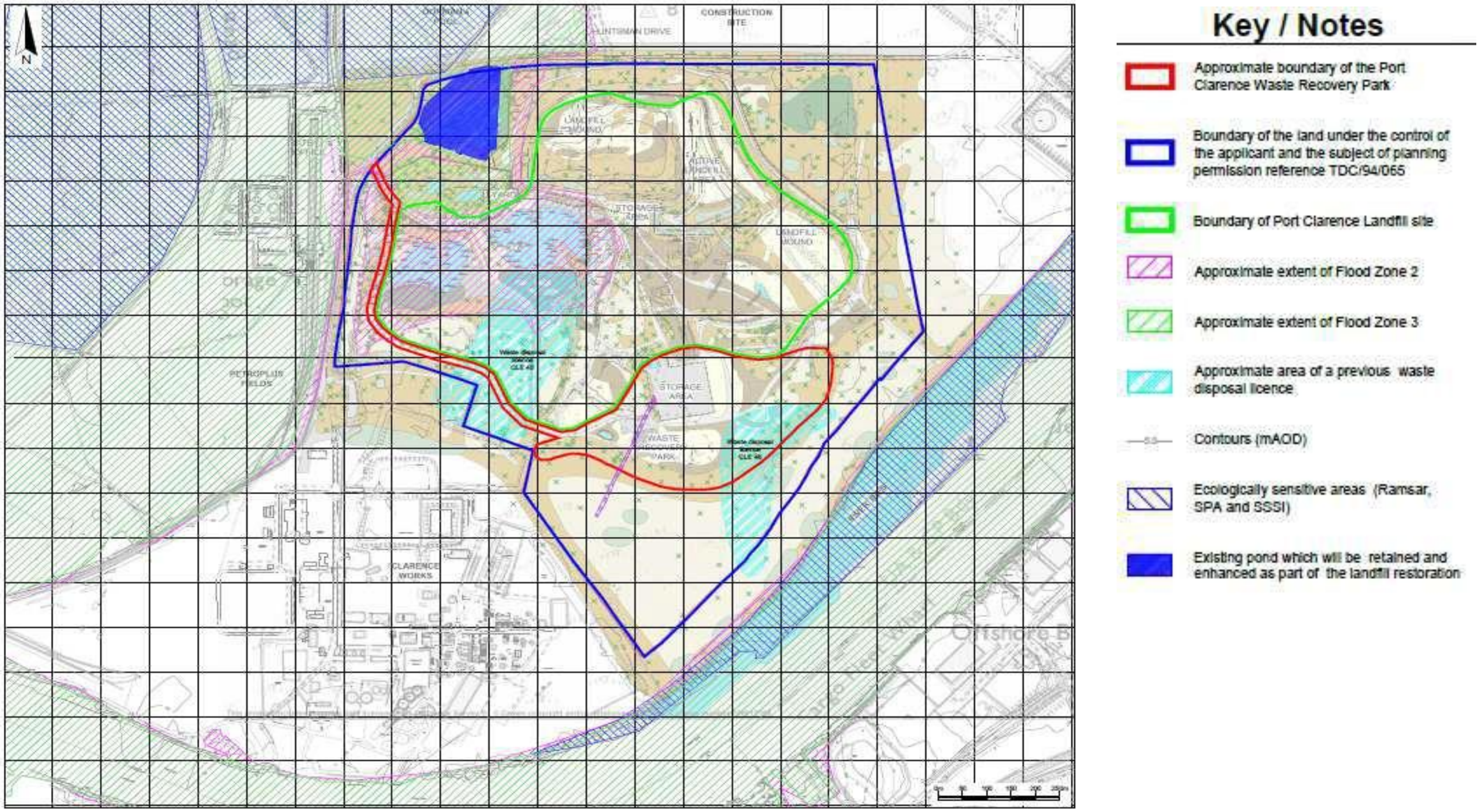


Figure 10 Flood zones

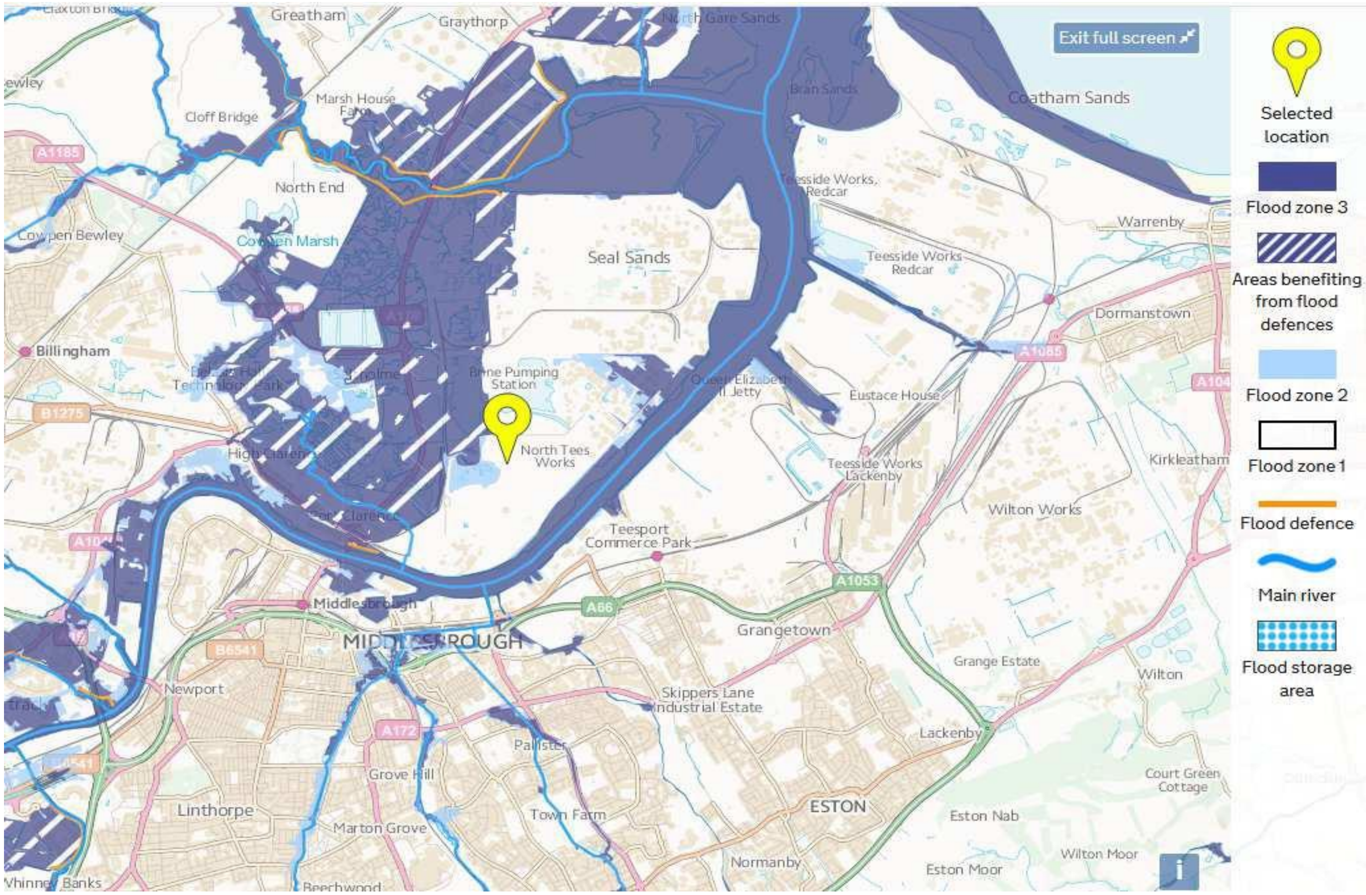
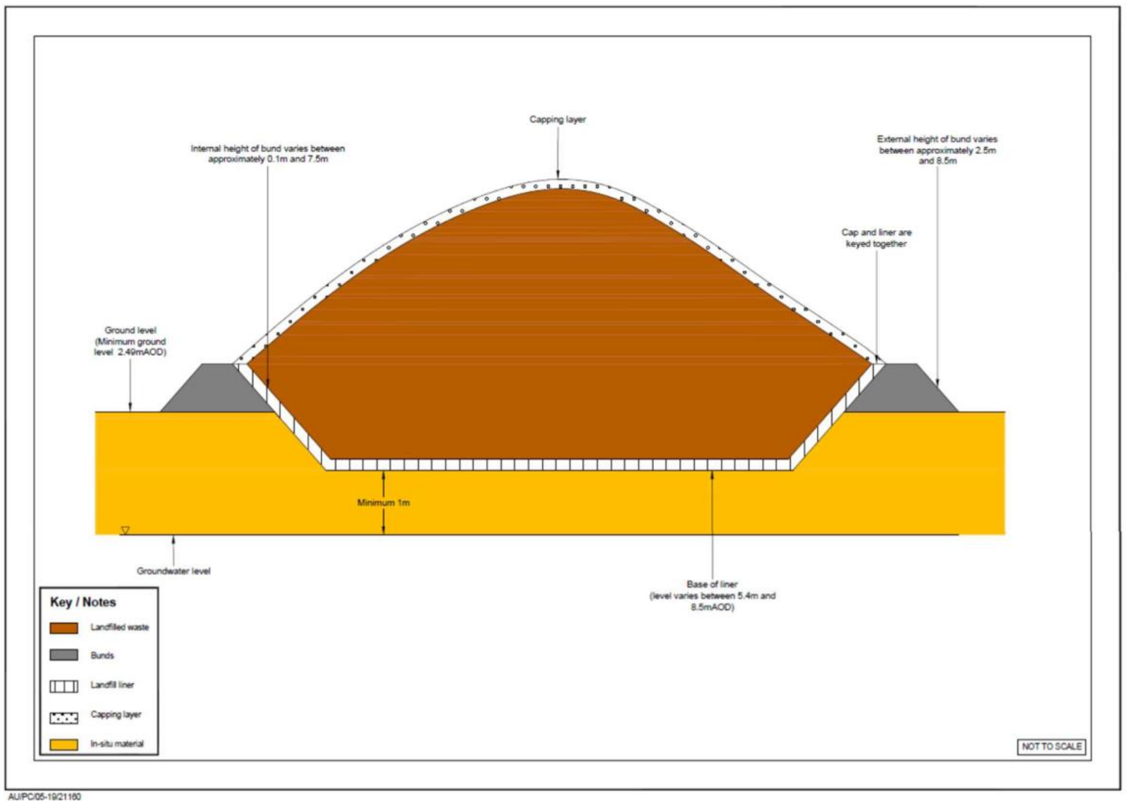


Figure 11 Illustrative cross section of the Port Clarence Landfill Site profile



95. An updated baseline ecological survey was reported in 2014, this followed previous surveys in 2006/07 and 2010 (ESL, 2014a). The study considered the potential effects of the landfill on the habitats and species of international importance and the consultation process concluded:

- there would be no increased disturbance to SPA/Ramsar site birds feeding or roosting on habitats important to them as a result of increased human use of land within the site boundary;
- there would be no loss of land used by SPA/Ramsar site birds for feeding or roosting to the proposed development;
- there would be no indirect loss of land used by SPA/Ramsar site birds due to disturbance from noise, light or movement connected with or resulting from the proposed development; and,
- there would be no reduction in estuarine water quality due to discharges from the site, resulting in reduced abundance of intertidal invertebrates forming prey species for the SPA/Ramsar site birds.

96. Natural England agreed that there will be no adverse effect on the integrity of the site from any of these causes.

97. The most recent survey found no reptiles, bats, badgers, water voles or otters (ESL, 2014a). Species recorded on the site include:

- mammals noted using the site comprised common shrew, rabbit, brown hare, field vole, wood mouse, fox and roe deer;
- common frogs;
- sixteen butterfly species were observed most common and widespread, four of importance were dingy skipper, wall, grayling and small heath.
- principal nesting bird species were lapwing, curlew, herring gull, skylark, yellow wagtail, dunnock, song thrush, starling, linnet, bullfinch and reed bunting;
- other species that are probable/possible nesters were gadwall, pochard, water rail, oystercatcher, ringed plover, snipe, meadow pipit, wheatear, lesser whitethroat, carrion crow and magpie; and,
- a further seven species were noted using the site or immediately adjacent land during other site visits, including marsh harrier (a Schedule 1 species), shelduck, lesser black-backed gull and cuckoo.

98. A further study considered ornithological impacts in greater detail (ESL, 2014b). There was a particular focus on the potential for increased disturbance to SPA/Ramsar site birds breeding, feeding or roosting on habitats important to them by increased gull populations attracted to the area as a result of the continuing use of the landfill. An earlier study (reported as Percival (2004)) indicated no adverse effect at that time, but since then conservation management has increased in the surrounding area and other

landfill sites are now operating in the area. The report concluded that the gull populations would have no significant adverse effect on the integrity of the European site, alone or in combination with other developments in the area.

99. The study also concluded that the number of wetlands birds now using the study area was impressive (breeding, wintering and on passage) and had increased with the creation and conservation management of wetlands in the area. The proposed habitat restoration scheme for the site including further wetland areas was considered beneficial in maintaining and perhaps increasing the attractiveness of the area to wetland birds.

2.7 Geology and Hydrogeology

100. The Tees Estuary surface geology of Quaternary alluvium and glacial till (formerly known as boulder clay) are underlain in turn by Triassic Mercia Mudstone Group and then Sherwood Sandstone Group. The inclined geology results in Sherwood Sandstone Group surfacing towards the north and the Jurassic Lias Group bedrocks surfacing towards the south (Inst. of Geological Sciences, 1981). The Triassic Mercia Mudstone and Permo-Triassic Sherwood Sandstone underlie the Quaternary deposits at a depth ranging from approximately 10 m to approximately 27.5 m across the site (Augean, 2014).

101. The Tidal Flat Deposits (alluvium) is designated by the Environment Agency as a secondary (undifferentiated) aquifer and the Till (boulder clay) is designated as unproductive strata. The Mercia Mudstone and Sherwood Sandstone are designated by the Environment Agency as a Secondary B Aquifer and a Principal Aquifer respectively. Both the made ground and the Tidal Flat Deposits (alluvium) are water bearing and in hydraulic continuity with each other. Groundwater in both strata flow generally to the south east towards the River Tees.

102. The River Tees is tidal where it passes the site. Although the undeveloped areas of the site are relatively flat, with no known drainage features, there are a number of surface water ponds located in the north west of the site. The water quality in the groundwater in the made ground and the Tidal Flat Deposits (alluvium) is influenced by the water quality in the Tees Estuary.

103. The pathway for the migration of leachate from the site will be through the basal liner of the landfill and vertically through the unsaturated zone of the underlying made ground. For the purpose of the assessment it is assumed that groundwater flow in the saturated zone of the made ground is predominantly vertical and flows to the alluvium. Lateral flow will occur in the alluvium towards the River Tees. It is likely that groundwater flow in the alluvium is affected by tidal influences of the River Tees (Augean, 2006).

2.8 Site Security

104. Site security is subject to control through the Environmental Permit. The security fencing at the site comprises post and wire fencing topped with barbed wire and is

approximately 2.4m high along the northern and north eastern boundaries and in the area of the site reception facilities. Lockable gates are provided at the site entrance and at the access to Phases 1 and 2. Additional lockable gates are located approximately mid-way along the northern boundary. Site staff are present at the site entrance, offices and on the landfill site during normal operating hours. Security staff patrol the site outside of permitted operating hours. The landfill operations at Port Clarence are screened from the surrounding area by a perimeter bund.

105. The fencing at the site will be maintained, extended and repositioned as necessary during the continued operation of the site. The fencing at the site will be extended and maintained around operational cells as engineering progresses. A movement activated 24 hour closed circuit television system is in operation which is monitored by a surveillance company. If intruders are detected the surveillance company will inform the intruder via the speakers located at the site that their presence will be reported to the police.

2.9 Factors influencing the natural evolution of the site

106. A fundamental component of an ESC is to demonstrate an understanding of the future evolution of the site, its environmental setting, and related uncertainties. This section considers the processes that are important to the evolution of the Port Clarence site.

107. The NS-GRA (UK Environment Agencies, 2009) requires that disposals should occur in such a way that unreasonable reliance on human action to protect the public and the environment against radiological and any non-radiological hazards is avoided both at the time of disposal and in the future. At this site, human actions have affected site development for the last 200 years and are very likely to continue to do so into the future.

108. In the recent past, the area has been subject to land reclamation and impacted by large industrial developments. These changes have been rapid relative to radiological assessment timescales used in the ESC. In the medium term, although commercial land requirements and use of the estuary by shipping is likely to be balanced against maintenance of local wildlife habitats, there is no guarantee this will continue indefinitely.

109. The key interacting factors that will impact evolution of the site include:

- maintaining the Tees Barrage after the planned 100 y design life;
- halting or changing dredging activities in the Tees Estuary;
- maintenance, managed realignment, enhancement or abandoning coastal and flood defence schemes;
- the rate and magnitude of sea-level rise resulting from climate change; and,
- the local sediment balance - impact of off-shore sandbanks, the potential for locations along the coast to supply sediment to the estuary and deposition of fluvial sediments.

110. The position of the site means that it is unlikely to be affected by erosion from the slow moving River Tees, which even when in spate would tend to impact the southern bank away from the landfills.

111. In a reclaimed environment such as the Tees Estuary there will be a succession of management plans for the shoreline and the emphasis in these plans may change over time.

112. The current shoreline management plan for area MA13 (Guthrie & Lane, 2007) is to hold the line at North Gare and South Gare and allow natural development of the North Gare Sands, Bran Sands and sands north and south of the breakwaters. The policies remain the same for each unit until 2105 except for North Gare Sands where retreat or realignment is planned from 2055. A flood prevention scheme has recently been completed in the estuary with additional defenses for Port Clarence (completed in 2015) and a managed realignment of embankments at Greatham Creek (completed 2018) to create new habitats (Environment Agency, 2011).

2.9.1 Sea level rise

113. Coastal mudflats and saltmarshes are sedimentary intertidal habitats created by deposition in low energy coastal environments (particularly estuaries) and the natural features of an estuary are expected to move inland with sea level rise (TVCCRG, 2012). This realignment of the estuary could lead to reversion of reclaimed land to mud flats and saltmarsh in the long term. The tendency of the area to accumulate sediments suggests that erosion of the site under normal conditions is not credible. In these circumstances the landfills would become surrounded by deposited sands and muds and over time become subject to tidal inundation.

114. The present-day global sea level was reached about 6,000 years ago and until about 150 years ago had varied only by about 15-20 cm (Lambeck, et al., 2014). Climate change model projections show that sea level will rise due to the increase in global air temperature causing thermal expansion of the oceans and melting of glaciers and ice sheets (Stocker, et al., 2013). The glacial isostatic adjustment at Port Clarence (Lowe & et al., 2009) is slightly negative (-0.05 mm y^{-1}).

115. The Modaria II programme (Lindborg, 2018) has considered the long-term impact of climate change on sea-level rise and has summarised the studies available since the last major report of the IPCC (Stocker, et al., 2013). In northern Europe climate change induced sea level rise will produce an increase of about 0.7 m by 2100 (Grinsted, et al., 2015) under a cautious high greenhouse gas emissions scenario (RCP8.5). Under the same scenario projected global mean sea level (GMSL) rise is between 1.51 to 6.63 m by 2500 with some projections showing a 10 m rise in GMSL by 4500 (Lindborg, 2018) and a maximum of 15 m at equilibrium (Stocker, et al., 2013).

116. Revised climate change marine projections were published for the UK in November 2018 (UKCP18) and indicate a sea level rise in 2100 of between 0.3 and 0.94 for the Edinburgh area under the RCP8.5 climate change scenario (Palmer, et al., 2018). An

illustrative range of 0.7 to 3.6 m was given for the year 2300 to be used to assess vulnerabilities. These ranges encompass the 5th to 95th percentile projections.

117. Based on these projections it will take about 440 years for mean sea level to get to the same level as the base of waste cells (see Figure 11) located at 5.4 m AOD (a sea level rise of 5 m). Assuming that radioactive waste is located at least 3.3 m above this level, the current maximum recorded tide heights will be at the same level as the base of the deposited radioactive waste after about 460 years.

2.9.2 Tidal flooding

118. The area of the site that is below the potential 2100 sea level (0.3 to 0.94 m) is in the north western corner in the vicinity of the site offices and weighbridge. The areas of land that are below the potential 2100 sea level roughly correspond with Flood Zone 2 indicated in pink cross-hatching in Figure 9. The diagram shows that inundation is most likely to occur from the north of the site. Flooding is expected to occur from Greatham Creek to the north and Flood Zone 2 includes land to the north and west of the site (Figure 10). The bathtubbing scenario is considered to be more cautious than a flooding event that will be of shorter duration and is unlikely to overtop a waste cell liner.

119. Guidance on flood risk assessments and climate change allowances is published by the Environment Agency (Environment Agency, 2015). The highest recorded flood level in recent years was in 2013 affecting Port Clarence properties when low pressure and strong off-shore winds produced a storm surge with a tidal height of 4.09 m causing a breach of tidal flood defences (Stockton on Tees Borough Council, 2013). Flood defences have since been improved in two phases and were only completed in 2018 providing protection to 4.4 m AOD.

120. If the main channel is not dredged then a shallower channel may increase the likelihood of flooding but erosion of the site by the River Tees is not expected to occur. Projected sea level rise will see exceptional high tides at the same elevation as radioactive waste within the landfill in about 460 years. The bathtubbing scenario, assumed to occur after 450 years, is considered more conservative (and bounding) because water will saturate at least part of a cell and will not be restricted to the base layer of cells.

121. Local flooding or sea level rise may see saturation of soil/made ground rise to a level that is above the base of the landfill at some locations. There is an engineered clay barrier beneath each cell and a liner that will minimise water entering waste cells. There are also coarse materials on the base of the liner to assist with leachate collection, above which is a further 2 m of waste from which LLW will be excluded. When the HDPE liner degrades (and although still protected by the clay layer) there is the potential for saturation of the base of the landfill from floodwater for short periods and subsequent drainage to surrounding land.

122. A further component to consider is the impact of climate change on storm surge. However, at the present time, there is low confidence and no consensus on the future

storm surge and wave climate, stemming from diverse projections of future storm track behaviour (ONR, 2018) and this is reinforced in UKCP18 which presents a range from a best estimate of zero additional contribution with both positive and negative impacts on sea level rise (Palmer, et al., 2018).

123. On this basis we do not therefore anticipate excluding LLW from those areas most likely to be affected by flooding between now and 2115.

2.9.3 Tidal erosion

124. A key factor affecting coastal erosion is the strength of the waves breaking along the coastline. A wave's strength is controlled by its fetch and wind speed with longer fetches and stronger winds producing more powerful waves with greater erosive power. As waves travel into an estuary they lose energy due to friction with the seabed and estuaries are generally considered to be low energy environments. The rate of coastal erosion varies with location and is affected by many factors (BGS, 2012) including topography, local currents and tidal range, wave climate and sediment supply. The estuary is expected to accumulate sediment and there is no information to support erosion of the estuary coastline. However, tidal erosion has been considered in the ESC and a cautious erosion rate of 10 cm y^{-1} has been adopted for modelling purposes, based on the observation that 72% of the British coastline exhibits a lower rate of erosion (Blott, et al., 2013). The erosion rate used for the LLWR assessment of a relatively exposed coastline was 0.45 m y^{-1} (Towler, et al., 2010).

125. Sea-level rise could expose the north eastern side of the landfills to tidal action but this is unlikely to occur before the year 2480 based on the IPCC high greenhouse gas emissions scenario (RCP8.5). There will also be a delay before exposure of the proposed LLW disposals due to existing completed cells (minimum of 200 m width) on the seaward side that do not contain LLW. This would add a further 2,080 years before LLW is encountered if an erosion rate of 10 cm y^{-1} is assumed. We have therefore concluded that an erosion scenario impacting LLW will not occur before the year 4560 at the earliest.

126. If dredging stops, the development of sand bars in the estuary may guide the flood tide to the north bank of the current channel (Leuven, et al., 2016) where erosion could then occur during flood tides. Assuming an erosion rate of 10 cm y^{-1} it will take over four thousand years to erode land and embankment to the south of the LLW disposal cells. Consideration of erosion of the seaward side of the landfill is therefore considered to be more cautious.

127. The onset of erosion and the impact of sea level rise on the restored landfill is uncertain. The start of erosion depends on cell location, the increase in global temperature, rate of sea level rise and the future management of the estuary, barrage and coastal defenses. For these reasons it is uncertain as to whether, and when, sea-level rise will result in erosion exposing LLW at the site. The approach adopted here is to use very cautious assumptions to suggest the earliest time at which it could occur.

3 Waste Characteristics

3.1 Introduction

128. Hazardous waste and non-hazardous waste that will be disposed at the site will be consistent with legislation and the Environmental Permits for the site. The hazardous waste types principally comprise treatment residues, contaminated materials including soils, and materials containing asbestos. Wastes that will not be accepted for disposal include liquid wastes, corrosive wastes, flammable wastes and wastes that are classified as oxidising. The non-radioactive hazardous wastes that are permitted for disposal are subject to a limit on their total organic carbon content and on the solubility of specified contaminants (subject to leaching tests). A list of non-hazardous waste permitted for disposal is provided in Schedule 2 of the site permit. Analysis of the waste codes from waste received in the last quarter of 2017 indicates a broad range of non-hazardous waste.

129. Low level radioactive waste (LLW) is a category of waste that contains small amounts of radioactivity (up to 4000 Bq g^{-1} alpha activity and 12,000 Bq g^{-1} beta/gamma activity). LLW typically comprises construction and demolition waste such as rubble, soils, crushed concrete, bricks and metals from the decommissioning of nuclear power plant buildings and infrastructure, lightly contaminated miscellaneous wastes from maintenance and monitoring at these facilities such as plastic, paper and metal, residues from plant at which LLW is incinerated and wastes from manufacturing activities, science and research facilities and hospitals where radioactive materials are used.

130. Naturally occurring radioactive material (NORM) waste is also disposed of at the site under an EPR exemption allowing disposal of waste containing less than 10 Bq g^{-1}. NORM waste contains radioactive substances that arise naturally in the environment and includes radionuclides of natural terrestrial and cosmic origin. NORM wastes generally fall into the LLW or very low level radioactive waste (VLLW) categories and are most commonly generated through processes that concentrate solid, liquid and gaseous NORM as a by-product (e.g. activities such as mining, the processing of minerals and earth materials, oil and gas operations, etc.). The physical, chemical and radiological characteristics of NORM wastes can vary markedly depending on the industrial process.

131. Activity concentration limits for LLW disposal at Port Clarence have been calculated for each radionuclide listed in the permit application.

3.2 Radioactive Waste Inventory

132. The LLW that is expected to be available for disposal may arise from:

Non-nuclear industry sources for example, waste derived from hospitals, universities, the oil industry or other non-nuclear users of radioactive materials.

Nuclear industry sources for example, wastes derived from decommissioning of nuclear power stations and research centres.

133. The LLW that is expected to be disposed under the Port Clarence Permit will arise from within the UK with waste arising largely from the decommissioning and clean-up of nuclear industry sites, from production of titanium dioxide and from the oil and gas industry.

134. The waste will conform to the CFA which will include waste acceptance criteria (WAC) established by any new permit and, where required, the consigning organisation will have an appropriate transfer permit. The radionuclides included in the radiological assessments are listed in Table 6, along with their half-lives and daughters assumed to be in secular equilibrium. The permit will include an "Any other radionuclide" group to allow some flexibility for disposal of radionuclides that have not been listed explicitly.

135. When radionuclides decay they produce a daughter product that may be a stable atom, for example Po-210 has a half-life of 138 days and produces a stable daughter, Pb-206. In some cases the daughter product may also be radioactive and this can result in a sequence of radioactive daughters that is known as a decay chain. The uranium (U-238) and thorium (Th-232) series are the two most important decay chains. The longer lived radionuclides of these series are identified in Table 6. The short-lived daughters are not treated explicitly in calculations of radiological impact although their hazard is assessed by including their doses in the calculation of doses from a longer lived parent. The decay chains of interest are represented in Figures 11 to 14 below.

136. In Table 6 and taking U-238 as an example, three daughters are listed (Th-234, Pa-234m, Pa-234) that do not appear in column 1 and any dose conversion factors used for U-238 are the sum of values for each of these radionuclides. The longest half-life of these three daughters is 24.1 days (Th-234). The last column indicates that there is a further daughter U-234, it has a long half-life of 245,500 years, but this is included in column 1 and will have its own dose conversion factors. The daughter of U-234 is Th-230 and because this also has a long half-life (75,380 years) it is considered explicitly in column 1. Dose conversion factors are taken from (ICRP, 1996), (European Commission, 1995), (European Commission, 1993) and (US EPA, 2018). Half-lives are taken from the LLWR radiological handbook (LLWR Ltd, 2011a) or from the IAEA reference database where radionuclides are not included in the LLWR assessment.

Table 6 Radionuclides included in the radiological assessments

Radionuclide	Half-life (y)	Daughters assumed to be in secular equilibrium	Radioactive daughters considered explicitly
H-3	12.3		
C-14	$5.70\ 10^3$		
Cl-36	$3.01\ 10^5$		
Ca-41	$1.02\ 10^5$		
Mn-54	0.855		
Fe-55	2.74		

Radionuclide	Half-life (y)	Daughters assumed to be in secular equilibrium	Radioactive daughters considered explicitly
Co-60	5.27		
Ni-59	$1.01\ 10^5$		
Ni-63	100		
Zn-65	0.668		
Se-79	$2.95\ 10^5$		
Sr-90	28.8	Y-90	
Mo-93	$4.0\ 10^3$		
Zr-93	$1.53\ 10^6$		
Nb-93m	16.1		
Nb-94	$2.03\ 10^4$		
Tc-99	$2.11\ 10^5$		
Ru-106	1.02	Rh-106	
Ag-108m	418		
Ag-110m	0.684		
Cd-109	1.26		
Sb-125	2.76		
Sn-119m	0.802		
Sn-123	0.354		
Sn-126	$2.30\ 10^5$	Sb-126m, Sb-126	
Te-127m	0.290		
I-129	$1.57\ 10^7$		
Ba-133	10.5		
Cs-134	2.07		
Cs-135	$2.30\ 10^6$		
Cs-137	30.2	Ba-137m	
Ce-144	0.780		
Pm-147	2.62		
Sm-147	$1.06\ 10^{11}$		
Sm-151	90.0		
Eu-152	13.5		
Eu-154	8.59		
Eu-155	4.76		
Gd-153	0.658		
Pb-210*	22.2	Bi-210, Po-210	
Po-210*	0.379		
Ra-226*	$1.60\ 10^3$	Rn-222, Po-218, At-218, Pb-214, Bi-214, Po-214, Tl-210, Pb-210, Bi-210, Po-210	
Ra-228*	5.75	Ac-228, Th-228, Ra-224, Rn-220, Po-216, Pb-212, Bi-212, Po-212, Tl-208	
Ac-227	21.8	Th-227, Fr-223, Ra-223, Rn-219, Po-215, Pb-211, Bi-211, Tl-207	
Th-228	1.91	Ra-224, Rn-220, Po-216, Pb-212, Bi-212, Po-212, Tl-208	

Radionuclide	Half-life (y)	Daughters assumed to be in secular equilibrium	Radioactive daughters considered explicitly
Th-229	7.34 10^{3}	Ra-225, Ac-225, Fr-221, Ra-221, Rn-217, At-217, Bi-213, Po-213, Tl-209, Pb-209	
Th-230	7.54 10^{4}		Ra-226
Th-232*	1.41 10^{10}	Ra-228, Ac-228, Th-228, Ra-224, Rn-220, Po-216, Pb-212, Bi-212, Po-212, Tl-208	
Pa-231	3.28 10^{4}		Ac-227
U-232	68.9	Th-228, Ra-224, Rn-220, Po-216, Pb-212, Bi-212, Po-212, Tl-208	
U-233	1.59 10^{5}		Th-229
U-234	2.46 10^{5}		Th-230
U-235	7.04 10^{8}	Th-231	Pa-231
U-236	2.34 10^{7}		Th-232
U-238	4.47 10^{9}	Th-234, Pa-234m, Pa-234	U-234
Np-237	2.14 10^{6}	Pa-233	U-233
Pu-238	87.7		U-234
Pu-239	2.41 10^{4}	U-235m	U-235
Pu-240	6.56 10^{3}		U-236
Pu-241	14.4		Am-241
Pu-242	3.75 10^{5}		U-238
Pu-244	8.0 10^{7}	U-240, Np-240m	Pu-240
Am-241	432		Np-237
Am-242m*	141	Am-242, Np-238, Cm-242, Pu-242	Pu-238
Am-243	7.37 10^{3}	Np-239	Pu-239
Cm-242	0.446		Pu-238
Cm-243*	29.1	Am-243	Pu-239
Cm-244	18.1		Pu-240
Cm-245	8.50 10^{3}		Pu-241
Cm-246	4.76 10^{3}		Pu-242
Cm-248	3.48 10^{5}		Pu-244
* See paragraph 138			

137. Radionuclides with half-lives of less than three months or with half-lives significantly less than the parent radionuclide have not been explicitly assessed. Where such radionuclides arise from ingrowth, they are included through the assumption that they will be in secular equilibrium with the parent radionuclide, and the dose coefficients used are adjusted accordingly. The decay chains of coupled radionuclides are illustrated in Figures 5 to 8.

138. Short-lived daughters that are assumed to be in secular equilibrium with a longer-lived parent radionuclide have been omitted from the figures. Note that Figure 12 lists Ra-228 and Th-228 as being considered explicitly, this applies only to the Goldsim groundwater migration and radiological assessment models. In all other models Ra-228 and Th-228 are considered in secular equilibrium with the longer-lived parents. Also note that Figure 13 lists Pb-210 and Po-210 as being considered explicitly, this

applies only to the Goldsim groundwater migration and radiological assessment models. In all other models Pb-210 and Po-210 are considered in secular equilibrium with the long-lived parent (Ra-226). Figure 13 also lists Cm-242 and Pu-242 as being considered explicitly, this applies only to the Goldsim groundwater migration and radiological assessment models. In all other models Cm-242 and Pu-242 are considered in secular equilibrium with the long-lived parent (Am-242m). Figure 15 lists Am-243 as being considered explicitly, this applies only to the Goldsim groundwater migration and radiological assessment models. In all other models Am-243 is considered in secular equilibrium with the long-lived parent (Cm-243).

139. Secular equilibrium describes the state that is achieved when each radionuclide in a chain decays at the same rate that it is produced. For example, as pure U-238 begins to decay to Th-234, the amount of thorium and its activity increase. Eventually the rate of thorium decay equals its production and its concentration then remains constant. As Th-234 decays to Pa-234m, the concentration of Pa-234m and its activity rise until its production and decay rates are equal. When the production and decay rates of each radionuclide in the decay chain are equal, the chain has reached secular equilibrium. Secular equilibrium between a long-lived parent and a shorter-lived daughter radionuclide is achieved after approximately five half-lives of the daughter radionuclide. Hence Ra-226 and Pb-210 would approach secular equilibrium after approximately 60 years.

Figure 12 Decay system for Cm-248 and Cm-244

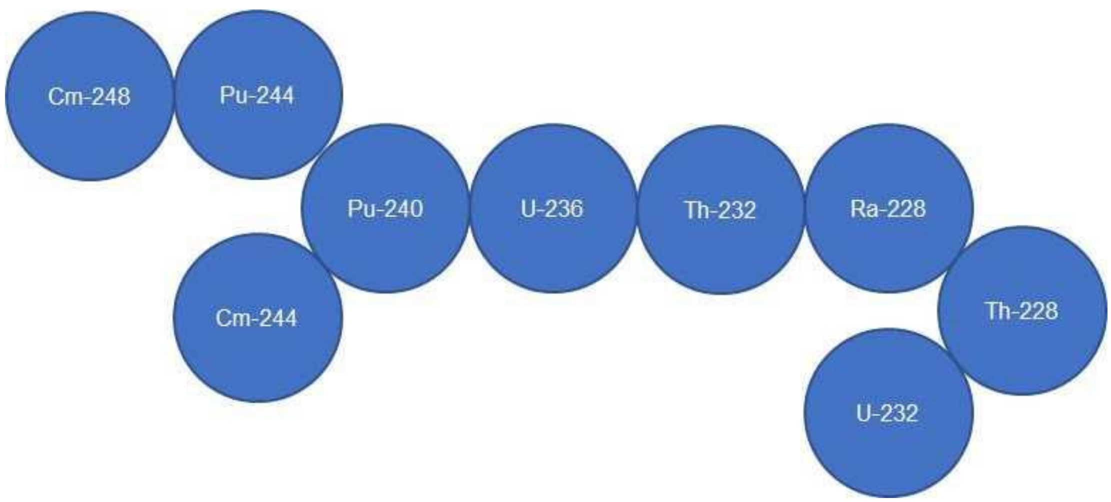


Figure 13 Decay system for Cm-246 and Am-242m

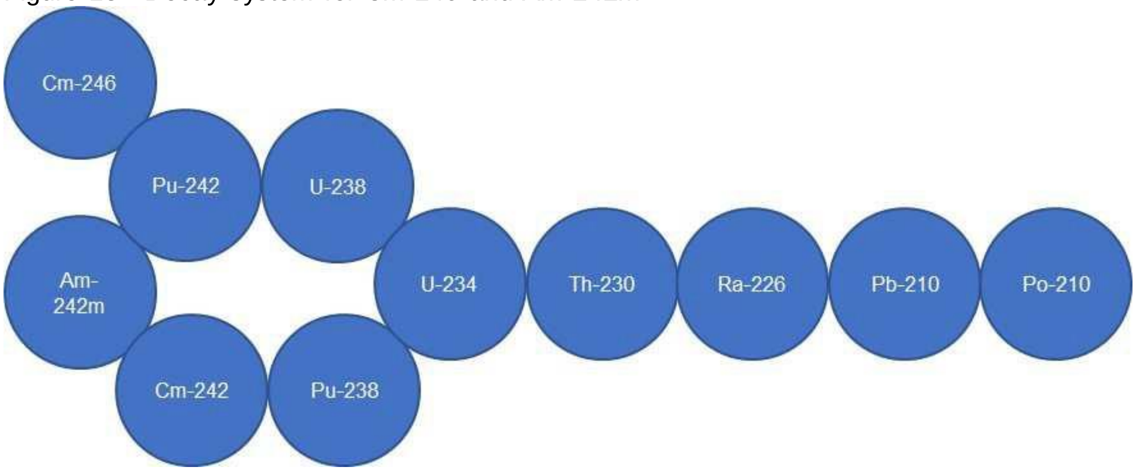


Figure 14 Decay system for Cm-245

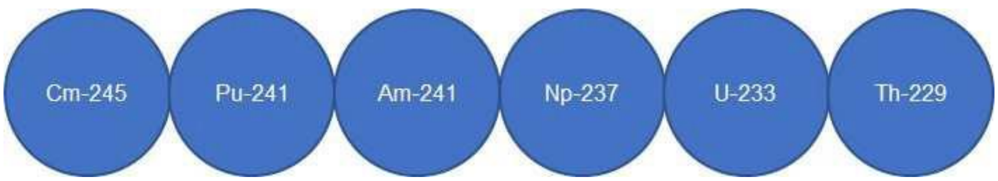
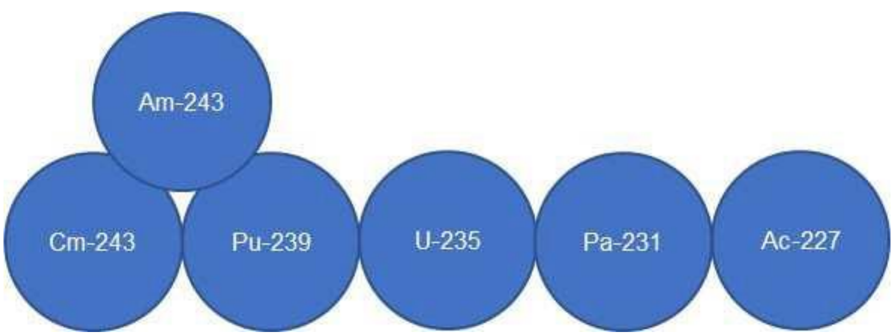


Figure 15 Decay system for Cm-243



140. In all of the assessment calculations, the quantities of long-lived daughters that have ingrown from specific parents or were directly disposed are distinguished. For example, the groundwater models consider seven categories of U-234, all with identical decay and sorption properties:

- U-234 directly disposed;

U-234 ingrown from Pu-238;

U-234 ingrown from U-238;

U-234 ingrown from Pu-242.

U-234 ingrown from Pu-242;

U-234 ingrown from Cm-242;

U-234 ingrown from Am-242m; and,

U-234 ingrown from Cm-246.

141. The future disposal inventory is not known in detail because waste streams for disposal will only be identified as a result of commercial agreements subsequent to receipt of the revised permit. In view of this uncertainty estimates of radiological impact are given based on 'illustrative inventories' for waste streams that might be typical of those contributing to the total impact from disposals at the facility. These estimates are presented in Appendix D. In developing the safety case two illustrative inventories have been used, these are for wastes disposed to the ENRMF and an illustrative NORM inventory based on the composition of a local industrial waste stream that has already been disposed at the Port Clarence site.

142. These calculations do not show the total impact of the whole facility, this will be dependent on the waste that is accepted for disposal. However, the calculations illustrate the dose that would arise from waste streams typical of those that might be disposed to the Port Clarence site.

143. As stated above it is not possible prior to near the time of receipt of the wastes to describe the specific form, amounts or types of wastes. Most commonly waste from the nuclear industry is rubble, soils, crushed concrete, bricks and metals that arise from demolition of buildings that were previously used for nuclear research or power generation. A large program of work to decommission the nuclear legacy sites created since the 1940's is currently underway in the UK that will generate significant volumes of LLW. The UK Nuclear Industry LLW strategy (NDA, 2016) and supporting inventories (NDA, 2016) provide detailed information on the potential types and nature of the wastes. During decommissioning, the hazards with the highest radioactivity are removed prior to demolition of structures. What remains after decommissioning is a mixture of construction materials/soils that can either be proven clean or which sometimes contain trace levels of radioactivity. Efforts are made to separate out radioactivity, to sort wastes, to recycle materials and to reuse materials. The wastes that remain with trace levels of radioactivity after these processes, and where it is BAT to dispose of to landfill, are typical of the wastes accepted at the ENRMF. It is expected that similar wastes would be sent to Port Clarence.

144. NORM waste contains radioactive substances that arise naturally in the environment and contain radionuclides of natural terrestrial and cosmic origin. NORM wastes are most commonly generated through processes that concentrate solid, liquid and gaseous NORM as a by-product (e.g. activities such as mining, the processing of minerals and earth materials, oil and gas operations, etc. see Table 7). The physical,

chemical and radiological characteristics of NORM wastes can vary markedly depending on the industrial process. NORM wastes generally fall into the LLW or very low level radioactive waste (VLLW) categories. The UK strategy for the management of NORM was published recently (DECC, 2014) and included data on the types of waste, tonnage and activity concentrations produced. Those waste requiring specialist disposal are listed in Table 7.

Table 7 Types of solid NORM waste produced in the UK requiring specialist disposal

Industry	Waste type	Approximate quantity in tonnes per year	Approximate total activity per year
Oil and gas – offshore	Scales and sludge. May be hazardous waste due to heavy metal and hydrocarbon content	~ 160	~ 4 GBq Ra-226, ~ 2 GBq Ra-228, ~ 0.3 GBq Pb-210
Oil and gas – onshore	Scales and sludge, May be hazardous wastedue to heavy metal and hydrocarbon content	< 20	< 0.05 GBq Ra-226, < 1 GBq Pb-210+
Titanium dioxide	Filter cloths	~ 10	~ 1 GBq Ra-226
China clay	Scale		
Zirconia industry	magnesium dross	~ 0.04	~232 MBq Th-232
Thorium coated lens manufacturer	Mixed solids	~ 1	~ 0.05 GBq Th-232
Contaminated land	Soil, building rubble, discrete items	Very variable	Very variable but anticipated to be less than 1 GBq Ra-226
Total		< 300 tonnes	< 6 GBq Ra-226, ~ 2 GBq Ra-228, ~ 1 GBq Pb-210, ~ 232 MBq Th-232

From (DECC, 2014)

145. Under the EPR (UK Government SI, 2016) a consignor can dispose of 5 10^{10} Bq y^{-1} of NORM waste containing up to 5 Bq g^{-1} to landfill under an exemption i.e. without requiring a Permit (i.e.10,000 t y^{-1} of NORM at 5 Bq g^{-1}). There are also provisions for disposal of NORM waste containing up to 10 Bq g^{-1} at a landfill site without the need for a Permit, subject to the prior submission of a safety case to the Environment Agency and the receipt of no objections from them.

146. The general nature of the waste inventory is described in the national inventories for radioactive waste (NDA, 2016). If the consigning site has established that disposal to landfill is the Best Available Technique (BAT), then subject to ensuring that the high levels of environmental protection afforded by the site are not compromised, radioactive wastes with elevated levels of total organic carbon content and the specified soluble contaminants will be accepted at the site for disposal.

147. It is recognised that many disposed wastes are heterogeneous in terms of the distribution of activity within packaged material. For waste that remains in a waste cell the safety case can be based on the assumption that the wastes are broadly homogeneous. Where intrusion occurs the safety case needs to consider radionuclides that may be distributed heterogeneously in some waste materials. Consideration has therefore been given to the potential impact of variable activity within a waste package (see Section E.6).

4 Authorisation of Disposal

4.1 Process by Agreement {R1}

148. The NS-GRA suggests that a developer is expected to enter into a voluntary agreement with the environment agencies to discuss a proposed facility and subsequent development (Requirement 1):

> "The developer should follow a process by agreement for developing a disposal facility for solid radioactive waste." (NS–GRA (UK Environment Agencies, 2009) para 5.2.3)

149. Early dialogue with the Environment Agency has been conducted. Discussions with the Environment Agency regarding the acceptance of LLW at the site date back to February 2018 and subsequent meetings have occurred on the 20th December 2018 and the 16th May 2019 at which Augean set out the principles of their approach and the programme for the application.

4.2 Dialogue with Local Communities and Others {R2}

150. The NS-GRA expects the developer to engage widely in discussion of the developing ESC (Requirement 2):

> "The developer should engage in dialogue with the planning authority, local community, other interested parties and the general public on its developing environmental safety case." (NS–GRA (UK Environment Agencies, 2009) para 5.7.1)

151. Augean has discussed the proposal to dispose of LLW at Port Clarence with Stockton on Tees Borough Council planning officers and environmental health officers (3rd April 2019). A communications strategy has been produced that includes a programme of dialogue with stakeholders including the planning authority and the local community. This has been developed based on the following principles:

to comply with Local Authority and Combined Authority Statements of Community Involvement as well as guidance from Central Government and the relevant Ministries, the nuclear industry and its representative bodies and Regulators;

to promote the fullest understanding and facts about the proposals and any potential impacts they may have to dispel any misunderstandings and misapprehensions at an early stage;

to communicate in a timely and responsive manner with all stakeholder groups in order to reassure, educate and inform them about the proposals directly so that they feel confident about the safety of the proposals;

to encourage dialogue and discussion about the proposals and allow the community to feedback their ideas, obtain clarifications where necessary and influence in a constructive manner;

to be clear to all stakeholders how they can become involved in the process; and,

to comply with the statutory obligations and procedures as imposed by the planning and permitting process.

152. Augean's approach is based on experience at the ENRMF but will be tailored to the needs of the local communities near Port Clarence based on advice from local elected representatives. The Planning Inspectorate noted that the consultations that had been carried out regarding ENRMF covered all aspects of the proposed development including the disposal of LLW. The Inspector concluded that there was extensive engagement between Augean and the local community. The Inspector was satisfied that the consultation requirements of the national policy for LLW management had been met (The Planning Inspectorate, 2013).

153. Consultation activities will include briefings for the local Member of Parliament, District Councillors and the Tees Valley Combined Authority. Augean will also host community consultation events, site tours and will establish a register of stakeholders. Throughout the consultation programme a careful record will be kept of all the activities and responses and collated into a Statement of Community Involvement, which will accompany the planning application.

154. Augean will report back to the local community via the register of stakeholders about the planning application and the environmental permit. Augean uses the register of stakeholders to contact those interested in the proposals via an electronic newsletter. This provides a good and responsive medium for offering further opportunities to visit the site, and explaining in a detailed way aspects of the scheme by giving further information about specific topics that may be of particular interest or concern raised during the consultation process.

155. On submission of the application for the permit variation Augean will inform the local community of the submission. A non-technical summary of the application proposals has been prepared for circulation in the community. Community consultation events and opportunities to visit the site will be organised for October 2019 at which the community can discuss the application with Augean and the company's expert advisors. The Environment Agency will be invited to take part in this event.

5 Management Requirements

5.1 Environmental Safety Case {R3}

156. This document has been designed to fulfil the requirement for an environmental safety case that is proportionate to the level of risk represented by the proposed waste disposal at Port Clarence. The supporting technical basis for the radiological assessments used to support the ESC is presented in Appendix E. The safety assessments and related safety arguments presented throughout the document are drawn together in the summary (see Section 8).

5.2 Environmental Safety Culture and Management System {R4}

157. The NS-GRA outlines a requirement for a positive environmental safety culture supported by an appropriate organisational structure and management systems (Requirement 4):

> "The developer/operator of a disposal facility for solid radioactive waste should foster and nurture a positive environmental safety culture at all times and should have a management system, organisational structure and resources sufficient to provide the following functions: (a) planning and control of work; (b) the application of sound science and good engineering practice; (c) provision of information; (d) documentation and record-keeping; (e) quality management." NS–GRA (UK Environment Agencies, 2009) para 6.2.5

158. Augean has an established effective management system and safety culture. The system ensures:

- Effective planning and control of work;
- Application of sound science and engineering practice;
- Safe acceptance and handling of waste;
- Maintenance and availability of comprehensive records and information; and,
- Quality management.

159. This system is subject to regular audit and inspection by internal independent compliance teams, external auditors including Public Health England (PHE), the British Standards Institute and customers, together with the Environment Agency. Augean has demonstrated that it is fully capable to assure environmental safety through its organisational structure, strong leadership and appropriate resourcing, competencies and culture. A summary of the business structure and management systems is provided below.

5.2.1 The Augean Business and Culture

160. Augean PLC, formed in 2004, is a UK-based specialist waste and resource management group. The group provides a wide range of services for difficult, hazardous and radioactive wastes through its treatment, transfer, landfill disposal and recycling operations. Over the past fifteen years the business has developed through a series of stages of acquisition, planning and development to establish a waste business operating to modern standards and responding to regulatory change.

161. The structure of the Management Board and areas of responsibility is shown in Figure 16.

162. Augean is committed to Corporate Social Responsibility (CSR) as demonstrated through the publication since 2006 annually of a CSR Report which measures their performance in respect of business, health and safety, their employees, their neighbours and the environment.

163. The Augean CSR Report is a record of company performance and how they are working together to improve that performance in respect of business values, health and safety, the environment and within our local communities. This annual exercise is a valuable discipline to help them demonstrate their commitment to responsible care, evaluate their performance against stated objectives and provide focus on their aspirations for the year ahead.

164. An essential element of their approach to business is their core business values supported by business principles.

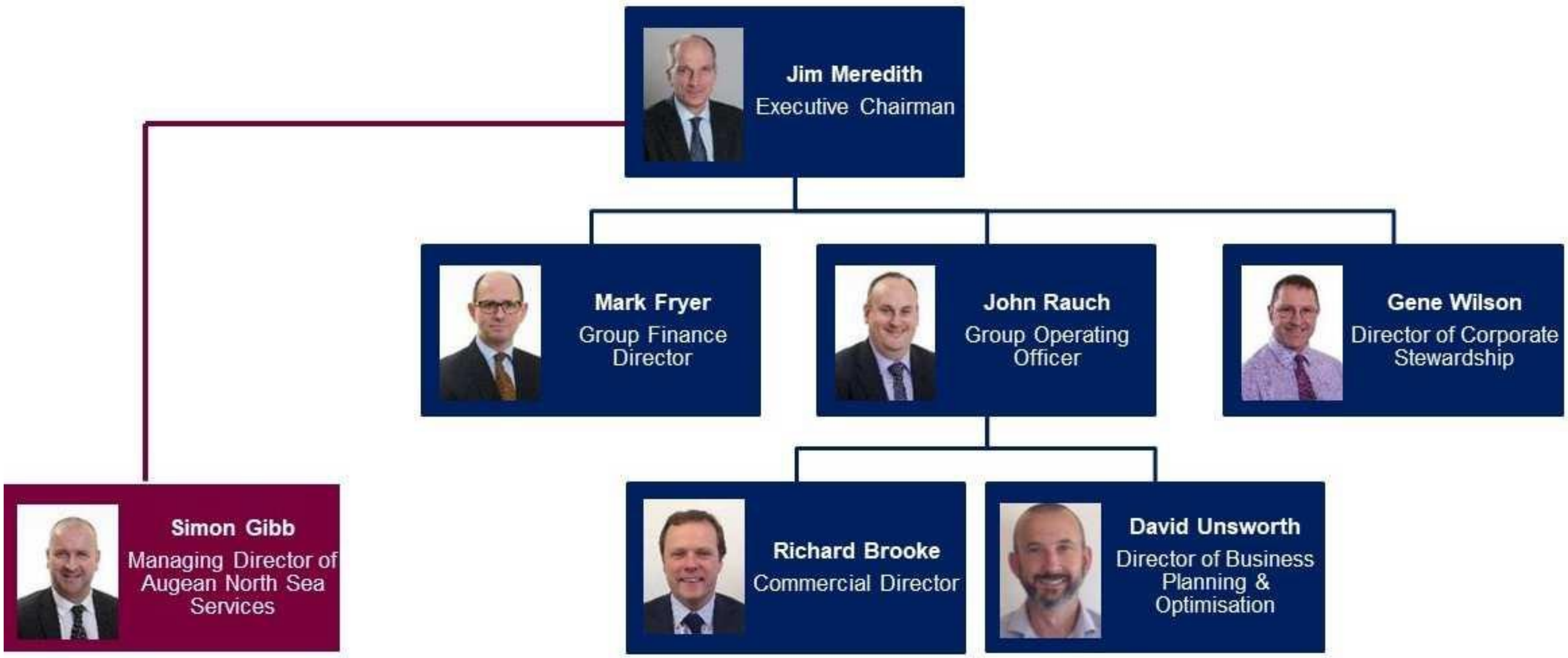
"Augean's core business values are:

- Respect – we show we value our people and others we work with;
- Integrity – we demonstrate we can be trusted;
- Teamwork – we work better together; and,
- Excellence – we strive to achieve our ambition.

Based on these values Augean operate on the following business principles:

- Priorities – we take action according to the priority: Safety, Compliance, Profit;
- Safety – we stop the job if we are not sure it is safe;
- Environmental responsibility – we respect the environment and take a planned approach to protecting it;
- Social and community responsibility – we invest time to build constructive relations with the communities in which we operate;
- Technical excellence – we value the expertise of our staff and use up-to-date techniques and equipment; and,
- Transparency – we are open and transparent in all that we do."

Figure 16 Augean Management Board



5.2.2 Management systems

165. Operational performance is maintained through a certified Integrated Management System (IMS) delivering protection of health and safety, both internally and externally, and the management, protection and improvement of the environment for nature and our local communities. The IMS is certified by the British Standards Institute to the following standards:

ISO 9001:2015 Quality management system;

ISO ISO 14001:2015 Environmental management system;

BS OHSAS 18001:2007 Health and safety management system; and,

PAS99:2012 Integrated management system.

166. Central to the IMS is the Health, Safety, Quality and Environment Policy statement which is presented at Appendix C.

167. Delivery of the policy objectives is set out in the Augean Business Manual which:

Defines roles of key positions in the organisation and provision of appropriate resources. This is further supported by specific job descriptions.

Identifies the importance of training and competence which is supported by Corporate training requirements procedure and lead by the Group Training Manager.

Identifies the provision of operational procedures.

Describes the approach to incidents and accidents by the provision of site-specific emergency plans.

Sets out the need for document control including record keeping.

Describes auditing of compliance with the IMS which is supplemented by monthly compliance inspection at all sites.

Includes systems for corrective and preventative action in the case of non-conformance.

168. The IMS provides a framework that considers the different aspects of the business and determines the impact of business activities on the workforce and the environment. Risk assessments have been conducted for all operational activities and where necessary to ensure adequate operational control procedures have been developed and implemented. Appendix C shows an overview of the IMS and lists the main corporate procedures within the system.

5.2.3 Corporate Reporting and Communication

169. The business has a range of mechanisms for developing policy, decision making and communication. Policy is usually determined at Management Board level. Policy decisions are communicated directly through the corporate structure and through a wide range of other mechanisms including Director Engagement Visits and presentations, training, safety campaigns and the monthly publication of Augean Update.

170. The outcome of auditing and inspection, near miss and safe act reporting, incident investigation and training are all reported to the Management Board on a monthly basis in a Compliance Report. The Compliance Report is reviewed each month at the Management Board meeting. More strategic and policy matters together with serious near miss and incidents are reviewed at the Quarterly Compliance Review meeting attended by the Management Board and Head of HSEQ together with invited site managers.

171. A series of operational fora operate within the business to develop and share best practice and to advise the Management Board on technical issues. These include:

Continuous improvement Group;

Radiation Safety Group;

Process Safety Group;

Industrial Services Group and,

Transport Managers Group.

5.2.4 Site organisation

172. The Port Clarence Site Manager is responsible for the quality, health and safety and environmental performance of the landfill sites. The Site Manager reports directly to the Management Board which is ultimately responsible for performance. The Site Manager at Port Clarence is a holder of a Certificate of Technical Competence for the management of hazardous and non-hazardous landfills. The Site Manager and Assistant Managers are trained Radiation Protection Supervisors (RPSs). The entire operating team receives specific training in the operating procedures relevant to their function.

173. Operational meetings are held weekly. Health and safety meetings are held quarterly and include all staff present on site. There are Health and Safety Representatives in the landfill, treatment and administrative areas of the site.

174. Augean employs a range of highly qualified professionals with expertise in environmental and health and safety legislation, environmental management, chemistry, ecology, planning, engineering and waste management. As necessary, expertise is outsourced from external consultants. The Company maintains a list of

approved consultants who are selected on the basis of qualification and experience and whose place on the list is dependent on good service.

175. Technical support and expertise is provided by Corporate Stewardship specifically the Health Safety and Environment Managers (HSEQ) who deal with Permitting issues and legislative compliance, the monitoring team that monitors the environmental impact of the site in all media and the site chemists who provide laboratory facilities and determine the suitability of waste for acceptance at the site. The HSEQ Managers undertake regular inspections of the site including compliance with Environmental and Radiological Permits. Periodic audits of procedures are undertaken in accordance with the IMS the frequency of which is determined on a risk basis. The HSEQ Managers report all inspections to the Director of Corporate Stewardship who is a member of the Management Board and advises the Board on health and safety and environment issues. All HSEQ Managers have received radiological training relevant to the operation of the Augean sites and are qualified RPSs.

176. Augean employs a dedicated Technical Assessment Team providing a centralised service to the business. The team comprises three experienced professionals and one graduate trainee. The purpose of this team is to assess waste streams, determine how the waste can be managed in accordance with the waste hierarchy and the suitability of the waste for acceptance at a specified site. The team tracks and monitors waste inputs, including radiological capacity, to site through computer software. Specifically, in respect of radioactive waste, the company employs a qualified radioactive waste advisor and a specialist Technical Assessor qualified as an RPS who are further supported on a consultancy basis by Active Collection Bureau, Abbot Consulting Ltd and Loughborough University. The assessment team is independent of the operational team and based at the Company Headquarters at Wetherby. The Technical Assessor collates waste characterisation information and undertakes the initial chemical and radiological evaluation of the suitability of waste for disposal at the site. The final approval for booking of the waste to the site is given by the Site Manager. The process for acceptance of waste is set out in the pre-acceptance and acceptance procedures.

177. To support the site and in accordance with the Ionising Radiation Regulations and to provide staff training as necessary Augean will retain the services of PHE or other suitably qualified organisations as Radioactive Waste Advisor and Radiation Protection Advisor. The main scope of the support provided by the PHE is:

Support during Permit transfer and variation;

Preparing a comprehensive Radiation Risk Assessment of the impact on employees at the site;

Local rules and procedures;

Training site staff; and,

Four site visits per annum to audit the waste handling operation, records and undertake additional monitoring.

5.2.5 Arrangements Specific to LLW Disposal Operations

178. The following arrangements are incorporated into the management system specific to LLW disposal operations:

A radiation protection plan and risk assessment as required by the Ionising Radiations Regulations, prepared by the site Radiological Protection Advisor (currently PHE). Local rules in accordance with the Ionising Radiations Regulations and the conditions of the Environmental Permit. Defined roles and responsibilities include the following:

- Radiation Protection Advisor,
- Radioactive Waste Advisor (PHE),
- Radiation Protection Supervisor(s), and,
- Dangerous Goods Safety Advisor (Class 7).

A procedure for the pre-acceptance of waste including the conditions for acceptance for LLW for use in contractual arrangements with consignors (LLW01, the CFA).

A procedure for the pre-acceptance of waste by the central technical team (LLW02).

A procedure for acceptance and the receipt of waste, assay, waste emplacement (including loose tipping), coverage, record keeping and general LLW disposal operations (LLW03).

A procedure for the quarantine of non-compliant waste packages received at Port Clarence (LLW04).

A procedure for monitoring employee doses and instructions for measuring X-Ray and Gamma Radiation dose rates during acceptance of LLW waste at Port Clarence (LLW05).

A procedure for routine and periodic health surveillance monitoring of site staff for contamination and exposure.

An emergency plan including response arrangements to identified fault scenarios including:

- Dropped load;
- Contamination discovery;
- Non-compliant load;
- Dose above threshold discovery; and,
- Potentially contaminated person or wound.

Procedures for environmental monitoring incorporated into the Monitoring and Action Plans (MAPs).

A procedure for handling asbestos bearing packages of LLW.

A procedure outlining actions to be taken if consignments are unable to reach the site entrance in order to minimise risks to staff, the site and wider community (LLW06).

5.2.6 Principles that would be applied to waste retrieval

179. Waste retrieval is not planned following emplacement and is not expected under all foreseeable circumstances. The Environment Agency has previously requested consideration of the principles that would be applied should a package of unsuitable waste be inadvertently deposited at the site.

180. For waste arriving in packages, given the robustness of the packaging and the method of placement it is considered that the containers will remain intact in the landfill for an extended period. The placement of the waste in robust containers in accurately recorded locations will facilitate recovery of waste if it is considered necessary. Detailed risk assessments would be undertaken and methods would be developed and agreed with the Environment Agency and the Radiation Protection Supervisor in advance of the exercise taking into account the specific circumstances of the removal but in principle the following approach would be taken:

identification of the location of the waste from the GPS records - this information also includes details of the types of hazardous waste deposited in the locality;

determination from GPS records the quantity and characteristics of waste that would need to be excavated to access the specific waste that must be removed;

identification of stockpiling areas for excavated material and standards for stocking;

consider the need for undertaking the operation under cover;

removal of the majority of soil and/or waste covering by machine and by hand where necessary;

monitor the emissions from the packaged waste to confirm that they remain less than 10 µSv h^{-1} at a distance of 1 m from the package (i.e. measure to confirm before it is moved);

in respect of bags locating of the carrying straps and then lifting out of the waste bag using the forks of a forklift truck;

in respect of drums use of drum handler attachments on a forklift truck to remove the waste drum;

in respect of ISO containers use of a crane;

if necessary the containers would be brushed down to remove extraneous adhered material;

in the unlikely event that any of the containers are compromised they would be repacked or over packed at the excavation area;

- the containers would be loaded onto a lorry in the working area;
- suitable personal protective equipment would be specified based on risk assessment and potential exposure would be monitored;
- removal of the material from the site in accordance with the relevant Transportation Regulations; and,
- replacement of wastes into the excavation using suitable cover material to infill interstices.

181. It is not envisaged that loose tipped waste will be retrieved. The activity concentration limit of loose tipped waste is specified and is lower than that proposed for packaged waste consignments.

6 Radiological Requirements

182. The NS-GRA specifies dose constraints to members of the public that may arise from the Port Clarence landfills during the period of authorisation, a risk guidance level after the period of authorisation and dose constraints for human intrusion. This section summarises the dose assessments that have been undertaken to support the ESC (detailed in Appendix E). The results are presented as effective doses (µSv y^{-1} or mSv y^{-1}) and a maximum inventory (MBq) of each radionuclide.

183. The radiological capacity (also called the relevant value in this report) is the radionuclide inventory of each radionuclide that can be disposed at Port Clarence that would not result in a dose greater than the relevant dose criterion from any of the exposure scenarios. It is therefore the minimum of the values calculated for specified exposure scenarios (see Appendix E). All calculations detailed in Appendix E are inherently cautious ensuring that the prospective dose is overestimated and, because the radiological capacity is inversely proportional to the dose, the radiological capacity is therefore minimised.

184. The radiological capacity of the Port Clarence landfills (values for both the hazardous and non-hazardous landfills) for each radionuclide is presented in Section 7.4.2 and these values, together with the sum of fractions approach, are used to control disposals. Calculating the fraction of the radiological capacity that has been used by each disposed radionuclide in turn and ensuring that the sum of fractions is ≤1.0 will ensure that the dose from all disposed radionuclides does not exceed the relevant dose criterion. Hence, the sum of fractions approach ensures that the dose criteria are not exceeded if a mix of radionuclides is disposed of. The 'relevant values' presented in Table 34 (Schedule 3 of the proposed Permit) are these radiological capacity values based on the dose criteria.

185. Note that whilst there is no site constraint on the amount of LLW tonnage that can be disposed to the site it is assumed for the purpose of the risk assessment that LLW will comprise no more than 20% of the waste tonnage disposed at the Port Clarence landfill.

186. The results of the dose assessments presented in Sections 6.1, 6.1.2.2 and 6.3 show the maximum inventory that could be disposed of each radionuclide, in each of the Port Clarence landfills.

187. Estimates of radiological impact based on 'illustrative inventories' for waste streams that might be typical of those contributing to the total impact from disposals at the facility have been produced. These estimates are presented in Appendix E.

6.1 Dose constraints during the period of authorisation {R5}

188. The NS-GRA specifies dose constraints for members of the public for the period of authorisation (Requirement 5):

> "During the period of authorisation of a disposal facility for solid radioactive waste, the effective dose from the facility to a representative member of the critical group should not exceed a source-related dose constraint and a site related dose constraint.
>
> The UK Government and Devolved Administrations have directed the environment agencies to have regard to the following maximum doses to individuals which may result from a defined source, for use at the planning stage in radiation protection:
>
> 0.3 mSv/y from any source from which radioactive discharges are made; or,
>
> 0.5 mSv/y from the discharges from any single site."
>
> (UK Environment Agencies, 2009), para 6.3.1 and 6.3.2

189. For the purpose of the assessments reported here Port Clarence landfill is considered to be a source from which radioactive discharges occur. The ESC uses the term "period of authorisation" to cover the time when active management controls are maintained and the Permit remains in force. This period is assumed to last until 2130 in these assessments (50 years operation followed by 60 years post closure). Post-closure or after the period of authorisation refers to the time when the permit has been revoked and there is no active management or control at the site (2130 onwards is assumed in these assessments although the period of authorisation may be much longer).

190. Public Health England (PHE; formerly the Health Protection Agency, HPA) recommends a lower annual dose constraint for members of the public of 0.15 mSv (milli Sievert) for a new facility and the GRA notes that PHE has recommended that this lower value is applied to a new disposal facility (HPA, 2009). However, the GRA does not formally adopt this recommendation, and this lower dose constraint has not been adopted in the recent update of the Environmental Permitting Regulations. Therefore, it is not considered further.

191. For workers the legal dose limit is 20 mSv/year, and the criterion used for the safety case for Port Clarence is 1 mSv y^{-1}, which is the same as the current legal dose limit for the public. This is an operational criterion and is not used to set the radiological capacity of the landfill because the exposure arises in a manner unrelated to the total capacity of the site. This criterion does affect some of the authorisation conditions, particularly the external dose limits on packages. This criterion will be used for radiation protection purposes during operation of the facility.

192. Doses and risks need to be assessed for a range of hypothetical exposure groups in order to identify those at greatest risks at a given time. The present-day land use can be used to inform calculations of the impact during the period of authorisation. Throughout this report the term "scenario" is used to describe a situation or class of situations leading to future exposures.

193. The radiological assessment has considered a range of potential scenarios. A review of generic guidance and existing publicly available ESCs identified a set of scenarios that are discussed in detail in Appendix E and those considered for Port Clarence for the period of authorisation are summarised in Table 8. In cases where a scenario has not been assessed, because it will not or is very unlikely to occur at Port Clarence, the reasons for this are discussed. The scenarios discussed below consider both workers and members of the public during the period of authorisation and these are divided into two broad categories – those that are likely to occur and those that are unlikely to occur i.e. have a low likelihood of occurrence. None of these scenarios constrain the amount of radioactivity that can be disposed of at Port Clarence since this is constrained by calculations relating to the period after authorisation.

194. There is no abstraction of drinking water near the Port Clarence site due to saline intrusion from the estuary (Jones, et al., 2014). There are no public water supplies in the north-east from the Sherwood Sandstone Group that underlies the site (Allen, et al., 1997). It was agreed with the Environment Agency in December 2018 that the groundwater pathway would not result in exposure during the period of authorisation and is not therefore considered further for this period.

Table 8 Summary of radiological assessment scenarios during the period of authorisation

Scenario	Exposed group
Period of Authorisation – likely to occur	
Direct exposure	Worker
Loose tipping	Worker
	Member of public
Leachate processing off-site at treatment works	Treatment worker
	Angler
	Farming family
Leachate processing using Reed bed	Treatment worker
Release to atmosphere	Member of public
Release to groundwater*	Member of public
Cell excavation*	Worker
Period of Authorisation – unlikely to occur	
Dropped load	Worker
Wound exposure	Worker
Leachate spillage	Farming family
Landfill fire	Member of public
Barrier failure*	Member of public
Aircraft impact*	Member of public

* Not explicitly assessed.

6.1.1 Dose assessments for the period of authorisation: expected to occur

6.1.1.1 Direct exposure: waste handling

195. Doses from direct exposure while handling waste are based on calculations that were performed for the ENRMF, and experience at ENRMF, since these are directly relevant to Port Clarence.

196. Radiation risks to employees from normal operations were last reviewed by the PHE for the ENRMF in 2017 (Jakes, 2017). A conservative estimate of the dose to ENRMF workers for disposal of wastes containing up to 200 Bq g^{-1} as a result of three work activities suggests an annual dose of about 0.79 mSv if the same worker undertook waste receipt, monitoring, transfer and placement in the landfill and worked in the covered waste area. PHE considered it unlikely that the same person would be exposed during all the listed work activities. An assessment of exposure resulting from a wound concluded that internal doses from a contaminated wound would be very unlikely to exceed 1 mSv in practice.

197. The external radiation exposure to workers from their occupancy near to a waste package prior to disposal was also assessed by the UKAEA (Augean, 2009). UKAEA considered the external radiation dose for a series of cases and package types. The hypothetical worst case was identified to be a flexible type waste container with 200 Bq g^{-1} of Co-60. This was an unlikely case and another case was also included to illustrate more typical exposures. The hypothetical worst case dose identified a dose rate of 14.5 µSv h^{-1} measured at a distance of 1 m from the package face. A dose rate of 10 µSv h^{-1} is used at the ENRMF as an acceptance criterion to limit total exposure below 1 mSv and constrains the contents of the package to this limit. The same dose rate criterion will be applied at Port Clarence and included in the CFA.

198. Assessments have been presented (Augean, 2009), showing the dose to a member of the public standing at a distance in direct line of sight of a waste package/shipment. The maximum dose rate at 50 metres is estimated to be 4 10^{-3} µSv h^{-1} for a package containing 200 Bq g^{-1}. If the person stands in that location for 8 hours per day and there is waste at the maximum activity in that location every day then the person would receive 12 µSv y^{-1}; the corresponding dose at a distance of 100 m would be 3 µSv y^{-1}. These are low doses and the calculations are very conservative.

199. The ENRMF assessments used a maximum activity concentration of 200 Bq g^{-1} for each radionuclide. The approach at Port Clarence is to calculate activity concentration limits for disposal of each radionuclide at Port Clarence landfill and then apply the sum of fractions for a mix of radionuclides. In addition, the dose rate criterion of 10 µSv h^{-1} at a distance of 1 m from the package will be applied and this will further constrain the activity concentration of some radionuclides that can be accepted at Port Clarence.

200. The external dose to workers during the operational phase will be managed through occupational radiation dose protection practices, hence the external dose assessment for waste handling has not been used to constrain the overall radiological capacity of the site.

6.1.1.2 Direct exposure: waste emplacement and cell excavation

201. Waste will be emplaced in the landfill and immediately covered. The advice of the radiation protection advisor at the ENRMF is that the maximum radiation dose 1 m above the covered waste should be less than 2 µSv h^{-1} in order to ensure the occupational dose is considerably less than the dose criterion of 1 mSv y^{-1}. The same dose rate criterion is adopted for Port Clarence.

202. The external radiation exposure of workers in the vicinity of the emplaced waste after it has been covered was assessed by the UKAEA (Augean, 2009) for the ENRMF. The assessment demonstrates that for most cases a 0.3 m thick cover layer will more than achieve the specified dose rate. For the worst case of waste containing Co-60, at 200 Bq g^{-1}, a cover layer of 0.7 m is required to reduce the dose rate.

203. At Port Clarence a minimum cover layer of 0.3 m will be adopted and if the dose rate 1 m above the covered waste is greater than 2 µSv h^{-1} then further cover will be added in order to achieve the dose rate. The minimum cover layer of 0.3 m is adequate to ensure daily physical protection of the waste. This condition will be specified in the site operating procedures.

204. Direct exposure is also calculated at the time of site closure and reported in Section 6.2.1.1.

205. Additional "as low as reasonably achievable" (ALARA) precautions will be adopted:

- all wastes will be handled by machines;
- the only people on foot are those unstrapping loads and undertaking health physics monitoring; and,
- workplace monitoring will confirm actual doses and enable dose limitation to be managed.

206. Workplace monitoring at the ENRMF has been undertaken continuously since 2011 and to date has shown no measurable doses.

207. Cell excavations are not assessed in the ESC. Any excavations will be undertaken with full knowledge of where waste is placed within each cell and appropriate precautions will be taken. Installation of the landfill cap requires landfill workers to locate the side liner of a waste cell. Operating procedures at Port Clarence will require at least 2 m of non-radioactive waste to be placed between the side liner and LLW to make certain that workers do not come into contact with packages or loose tipped LLW when the landfill is permanently capped.

208. The external dose to workers during the operational phase will be managed through occupational radiation dose protection practices, hence the external dose assessment for waste emplacement has not been used to constrain the overall radiological capacity of the site.

209. This scenario is one of the scenarios used to determine the proposed radionuclide activity concentration limits for packaged wastes (see Section 7.4.2.3 for further details).

6.1.1.3 Impact due to loose tipping LLW

210. Loose tipping will occasionally be undertaken where necessary and subject to a BAT assessment. Loose tipping could have implications for onsite and offsite doses during operations i.e. during the period of authorisation. Post-closure scenarios are not

affected by loose tipping because the containers are ignored in terms of the fate of disposed activity in the ESC.

211. PHE has provided a worker assessment for loose tipping of NORM waste at the ENRMF (PHE, 2017) using cautious assumptions about dust generation and an activity concentration twice the average for the site (20 Bq g^{-1}). This assessment indicates the dominant exposure pathway is due to dust inhalation of actinides. The highest estimated doses were for Ac-227 and Th-229. In most cases it is expected that the waste will be damp and therefore give rise to little airborne dust, or if dry and dusty, local dust suppression (water spray) will be used to minimise airborne dust. In reality therefore, internal doses are likely to be lower than those estimated, it was considered reasonable to assume that, as a worst case, annual internal doses of the order of 0.2 mSv per year might be associated with loose tipping LLW operations where the average activity concentration is 20 Bq g^{-1}.

212. The ESC has considered worker and public exposure from a dust plume created when tipping loose waste (see sub-section E.3.4). The dose assessment is very cautious and takes no account of operating procedures that might apply to loose tipped waste to prevent dust emission. However, it is assumed that the current practice of immediately covering radioactive waste is maintained. Optimisation considerations may for example include dust suppression requirements or tipping the LLW into a trench that has been dug in the non-radioactive waste within a cell, as is the practice at Clifton Marsh (Eden, 2010) and not tipping during windy conditions. Members of the exposed group are assumed to be adult, a child or an infant and to be exposed as a result of inhalation of contaminated dust.

213. In all cases the limiting exposure is to a worker and is due to inhalation of actinides. The radionuclides that are most limiting are listed in Table 9 based on a cut-off at 100 Bq g^{-1}. The dose to the public when the activity concentration is limited by the worker dose is always less than 0.2 µSv y^{-1}.

214. Doses to the public are also less than 20 µSv y^{-1} when exposed to an activity concentration of 200 Bq g^{-1}, see Table 68.

Table 9 Limiting concentrations for loose tipping based on worker exposure

Radionuclide	Limiting specific activity (Bq g^{-1}) (worker dose of 1 mSv y^{-1})
Ac-227	2.1
Cm-248	3.3
Th-229	4.6
Th-232	7.0
Pa-231	8.4
Pu-240	9.8
Pu-239	9.8

Radionuclide	Limiting specific activity (Bq g^{-1}) (worker dose of 1 mSv y^{-1})
Am-242m	10.2
Pu-244	10.7
Pu-242	10.7
Pu-238	10.7
Th-230	11.8
Cm-245	11.9
Cm-246	12.0
Am-243	12.3
Am-241	12.3
U-232	14.6
Cm-243	17.0
Ra-228	19.8
Cm-244	20.7
Np-237	23.6
Th-228	27.0
Ra-226	60.4

215. The dose to workers during the operational phase will be managed through occupational radiation dose protection practices, hence the dose assessment for loose tipping waste has not been used to constrain the overall radiological capacity of the site.

216. This scenario is one of the scenarios used to determine the proposed radionuclide activity concentration limits for loose tipped wastes (see Section 7.4.2.3 for further details).

6.1.1.4 Impact due to leachate treatment

217. The permit application involves no specific authorised liquid discharge routes. Leachate is currently used at the on-site soil treatment facility or treated off-site at a suitable treatment facility. Any discharges from Port Clarence will be subject to permitting.

218. Radionuclide activity in leachate would however be monitored on a regular basis. This will ensure that the workers at the off-site treatment facility would not be exposed as a result of undeclared radioactivity in the leachate sent for treatment. Monitoring experience at the ENRMF has not detected any significant radioactivity in ENRMF leachate.

219. An assessment has been made of the radiological impact arising from treatment of contaminated leachate. The dose criteria used in the assessment are 1 mSv y^{-1} for workers at the on-site facility and 0.3 mSv y^{-1} for doses to public and workers at the off-site facility. In the assessment of ENRMF leachate treatment (Eden NE, 2015b) the dose to workers was used by the Environment Agency to constrain Co-60 disposal and the worker dose calculations are therefore repeated here for that reason.

220. Under normal circumstances leachate generated in the landfill is treated on site through the waste stabilisation plant (about 20,000 m^3 y^{-1}). This process binds the leachate in the stabilisation matrix. The stabilised material is then disposed of in the landfill. In the event that the capacity of the stabilisation plant is insufficient to accommodate the amount of leachate that must be removed from the landfill (for example during plant maintenance) the excess leachate is sent to a suitable treatment works which currently is the Billingham Reed Beds (Scott Bros. Ltd) but could also be sent to Bran Sands Industrial Effluent Treatment Works (Northumbrian Water Limited. Under normal operating circumstances it is necessary to send approximately 2,600 m^3 y^{-1} of leachate for off-site treatment.

221. Use of leachate at the on-site soil treatment facility is covered by the local assessment for the treatment facility, for compliance with the Ionising Radiation Regulations (IRR), and is not therefore addressed here. An assessment has been undertaken to determine the potential impact of off-site leachate management. Output from a GoldSim groundwater model of the site provides an estimate of the maximum leachate activity concentration and this is used to assess the potential doses arising from leachate treatment. The calculations are conservative because they do not take into account sorption within waste materials whereas in reality the waste received at Port Clarence is likely to provide sorption sites within waste cells.

222. The radiological assessment is based on the Environment Agency initial radiological assessment methodology [IRAM, (Environment Agency, 2006b)]. The IRAM for a sewage treatment works is used here as a proxy for a hazardous waste processing facility taking into account an appropriate total input flow rate. The Reed Bed assessment considers contamination of the total area of the Reed Beds (49,000 m^2) and accumulation over 7 years which is the anticipated operating life of the beds. The treated leachate is then discharged to the estuary via Billingham Beck. A complete assessment to support an application for authorised discharges of leachate to the reed beds would also need to consider their disposal.

223. The flux of radionuclides to off-site treatment (Bq y^{-1}) uses the peak leachate activity concentrations (per MBq input to the landfill) during the active control period (60 years after capping) and the leachate export rate (2,647 m^3 y^{-1}) from the site. The ingrowth of daughters is modelled using GoldSim and the activity concentrations of the daughters are propagated through the model and the dose contributions summed.

224. The radionuclides where doses from leachate treatment could limit the radiological capacity are shown in Table 10. The Treatment Facility worker would limit the capacity in most cases where capacity would be limited by the Reed Bed worker.

Table 10 Dose estimated for exposure from the treatment of leachate offsite

Radionuclide	Radiological capacity (MBq)	Treatment facility worker		Reed Bed worker	
		Dose rate ($\mu Sv\ y^{-1}\ MBq^{-1}$)	Dose from disposal of radiological capacity ($\mu Sv\ y^{-1}$)	Dose rate ($\mu Sv\ y^{-1}\ MBq^{-1}$)	Dose from disposal of radiological capacity ($\mu Sv\ y^{-1}$)
Ba-133	$1.67\ 10^{7}$	$1.79\ 10^{-5}$	$3.00\ 10^{2}$	$1.65\ 10^{-6}$	$2.75\ 10^{1}$
Sb-125	$2.59\ 10^{8}$	$1.16\ 10^{-6}$	$3.00\ 10^{2}$	$4.48\ 10^{-9}$	$1.16\ 10^{0}$
Co-60	$2.69\ 10^{8}$	$1.12\ 10^{-6}$	$3.00\ 10^{2}$	$8.22\ 10^{-9}$	$2.21\ 10^{0}$
Ag-110m	$4.01\ 10^{8}$	$7.48\ 10^{-7}$	$3.00\ 10^{2}$	$6.58\ 10^{-10}$	$2.64\ 10^{-1}$
Eu-154	$4.22\ 10^{8}$	$7.10\ 10^{-7}$	$3.00\ 10^{2}$	$1.32\ 10^{-8}$	$5.59\ 10^{0}$
Eu-152	$4.49\ 10^{8}$	$6.68\ 10^{-7}$	$3.00\ 10^{2}$	$1.88\ 10^{-8}$	$8.45\ 10^{0}$
Ac-227	$1.43\ 10^{9}$	$2.10\ 10^{-7}$	$3.00\ 10^{2}$	$9.13\ 10^{-10}$	$1.30\ 10^{0}$
Th-228	$1.79\ 10^{9}$	$1.67\ 10^{-7}$	$3.00\ 10^{2}$	$3.81\ 10^{-10}$	$6.83\ 10^{-1}$
Cs-134	$3.53\ 10^{9}$	$8.51\ 10^{-8}$	$3.00\ 10^{2}$	$6.21\ 10^{-10}$	$2.19\ 10^{0}$
Mn-54	$6.22\ 10^{9}$	$4.82\ 10^{-8}$	$3.00\ 10^{2}$	$9.23\ 10^{-11}$	$5.75\ 10^{-1}$
Zn-65	$8.33\ 10^{9}$	$3.60\ 10^{-8}$	$3.00\ 10^{2}$	$5.43\ 10^{-11}$	$4.52\ 10^{-1}$
Ra-228	$8.37\ 10^{9}$	$3.58\ 10^{-8}$	$3.00\ 10^{2}$	$1.74\ 10^{-9}$	$1.45\ 10^{1}$
Eu-155	$1.90\ 10^{10}$	$1.58\ 10^{-8}$	$3.00\ 10^{2}$	$1.65\ 10^{-10}$	$3.12\ 10^{0}$
Ru-106	$2.02\ 10^{10}$	$1.49\ 10^{-8}$	$3.00\ 10^{2}$	$1.37\ 10^{-10}$	$2.77\ 10^{0}$
Gd-153	$6.54\ 10^{10}$	$4.59\ 10^{-9}$	$3.00\ 10^{2}$	$6.82\ 10^{-12}$	$4.46\ 10^{-1}$
Ce-144	$4.60\ 10^{11}$	$6.52\ 10^{-10}$	$3.00\ 10^{2}$	$1.10\ 10^{-12}$	$5.05\ 10^{-1}$
Cd-109	$8.26\ 10^{11}$	$3.63\ 10^{-10}$	$3.00\ 10^{2}$	$3.90\ 10^{-12}$	$3.22\ 10^{0}$
Sn-123	$2.03\ 10^{12}$	$1.48\ 10^{-10}$	$3.00\ 10^{2}$	$1.19\ 10^{-13}$	$2.42\ 10^{-1}$

225. The calculations of doses from leachate treatment are very conservative and assume no retention by the waste and an instantaneous deposit of the radiological capacity. There is no allowance for radioactive decay of short half-life radionuclides.

226. This pathway has not been used to limit radiological capacity because leachate disposal is controlled by Augean and a discharge permit would be required to transfer radioactively contaminated leachate. Operational experience at the ENRMF shows that the assessment model assumptions concerning leachate concentrations are very cautious and should not be used to limit exposure. However, the calculations are used to develop the trigger levels for leachate monitoring described in Section 7.5.4.

6.1.1.5 Impact due to atmospheric releases

227. The permit application involves no specific permitted gaseous discharge routes. However, the inadvertent release of gases during operations may expose landfill workers on the site and public exposure to gas may also occur but at some distance from the source (Appendix E, Sub-section E.3.5). The gas pathway considers radioactive carbon, tritium and radon. The aim is to restrict chemical and biological processes occurring within the hazardous waste landfill once disposal has taken place and there are limits on the total organics in waste disposed in the hazardous landfill to reduce the prospect of C-14 and H-3 releases. No waste is accepted in liquid form, waste must not be corrosive, oxidising or flammable, it should not contain ion exchange resins or complexing agents and hazardous waste leaching criteria apply to the non-radioactive content of LLW where practicable. These conditions reduce the likelihood

that rapid gaseous release will occur in the hazardous landfill and hence the assumptions used in the calculations are very conservative. The release of gas from the non-hazardous landfill has been considered, although disposal of organics is limited in practice because it is not BAT.

228. The calculations assume that waste is covered on a daily basis to a depth of 0.3 m, and covered again within 2 months, there is no radioactive decay and members of the public are always present in the downwind direction resulting in the highest dose (Appendix E, Sub-section E.3.5.1). Similar assumptions are used for workers but they are assumed to be at the point of discharge with dilution by the average wind speed. The carbon-based peak gas release rates were calculated based on the work for the ENRMF ESC (Eden NE, 2015a) and used a model of landfill gas evolution (GasSim). Doses are based on the peak rate of gas production following disposal of the inventory. The doses in Table 11 are from disposals at the radiological capacity.

Table 11 Dose estimated for exposure from gas released during operations

Radionuclide	Radiological capacity (MBq)	Dose* (µSv y^{-1})	
		Worker	Public
H-3	6.43 10^9	1.62 10^2	7.12 10^1
C-14	1.87 10^8	1.62 10^2	7.12 10^1
Ra-226**	3.89 10^6	1.37 10^1	1.00 10^0

*Based on the peak release rate following disposal of the radiological capacity given in Column 1.

** Dose arises from radon gas.

229. Doses from exposure to gas when each radionuclide is disposed at the radiological capacity (see Table 11) are significantly below the site criterion for workers (1 mSv y^{-1}) and the public dose constraint (0.3 mSv y^{-1}). The dose estimates indicate that the highest doses are from H-3 exposure for both a worker and an adult member of the public. The calculated peak dose to an adult member of the public using the radionuclide proportions currently disposed at the ENRMF is 32 µSv y^{-1}.

6.1.2 Dose assessments for the period of authorisation: unlikely to occur

230. A number of events that are unlikely to occur during the period of authorisation have been considered (Table 8). Assessments have been undertaken for dropped waste containers and a leachate spillage during transport to the leachate treatment facility. A fire in a waste cell is considered very unlikely but have been considered as what-if assessments. The gradual deterioration of the HDPE liner is expected to occur and is considered in the groundwater risk assessments. Wound exposure is already addressed in the operational safety case (see Section E.3.9).

231. The maximum doses arising from a dropped container and leachate spillage are given in Table 13 and Table 12, respectively. In the first case the doses depend on the specific activity of waste and for the leachate spillage the doses depend on the activity concentration in the leachate: this is based on disposal at the radiological capacity.

6.1.2.1 Potential impact from a dropped load

232. The dropped load assessment calculations assume that the bag is filled with a loose dry material that disperses readily, that the package fails and that the worker does not respond correctly. These are highly conservative assumptions. The activity concentration in the load is assumed to be 200 Bq g^{-1} and the load is 1 t.

233. The results of the dropped load dose assessment meet the site criterion for workers for all radionuclides except Ac-227 (1.9 mSv) and Cm-248 (1.2 mSv); all doses to the public are below 10 µSv except Ac-227 (16 µSv). The national LLW inventory reports a total of 1.1 MBq of Ac-227 and Cm-228 (BEIS and NDA, 2017), which is less than the total used in each case for this assessment (200 MBq). Hence, both are very unlikely to be present at 200 Bq g^{-1} in a single package given their low occurrence and the maximum doses from a dropped load would be at least a factor of 100 smaller than that given in the table.

234. A key measure to mitigate dropped load dispersion events is to use waste containers that withstand or substantially withstand accidental drops during handling. Where drums are used these will be rated under existing dangerous good transport regulations for radioactive material to withstand a drop test. Flexible containers may only be used where this is acceptable under dangerous goods transport regulations and these regulations specify isotope specific limits designed to ensure public safety.

235. This scenario has not been used to constrain the radiological capacity because it has a low probability of occurrence and is independent of the total tonnage and total activity received at Port Clarence.

236. This scenario is one of the scenarios used to determine the proposed radionuclide activity concentration limits for packaged wastes and for loose tipped wastes (see Section 7.4.2.3 for further details).

Table 12 Doses from a dropped bag

Radionuclide	Dose due to dropped bag*		
	Worker (mSv)	Public (mSv)	Public receptor
Ac-227**	$1.90\ 10^{0}$	$1.56\ 10^{-2}$	Infant
Cm-248**	$1.20\ 10^{0}$	$6.14\ 10^{-3}$	Infant
Th-229	$8.54\ 10^{-1}$	$5.24\ 10^{-3}$	Infant
Th-232	$5.65\ 10^{-1}$	$4.04\ 10^{-3}$	Infant
Pa-231	$4.67\ 10^{-1}$	$2.17\ 10^{-3}$	Infant
Pu-240	$4.00\ 10^{-1}$	$1.89\ 10^{-3}$	Infant
Pu-239	$4.00\ 10^{-1}$	$1.89\ 10^{-3}$	Infant
Am-242m	$3.86\ 10^{-1}$	$1.89\ 10^{-3}$	Infant

Radionuclide	Dose due to dropped bag*		
	Worker (mSv)	Public (mSv)	Public receptor
Pu-244	$3.67\ 10^{-1}$	$1.79\ 10^{-3}$	Infant
Pu-242	$3.67\ 10^{-1}$	$1.79\ 10^{-3}$	Infant
Pu-238	$3.67\ 10^{-1}$	$1.79\ 10^{-3}$	Infant
Th-230	$3.33\ 10^{-1}$	$1.89\ 10^{-3}$	Infant
Cm-245	$3.30\ 10^{-1}$	$1.70\ 10^{-3}$	Infant
Cm-246	$3.27\ 10^{-1}$	$1.70\ 10^{-3}$	Infant
Am-243	$3.20\ 10^{-1}$	$1.61\ 10^{-3}$	Infant
Am-241	$3.20\ 10^{-1}$	$1.70\ 10^{-3}$	Infant
U-232	$2.69\ 10^{-1}$	$2.43\ 10^{-3}$	Infant
Cm-243	$2.31\ 10^{-1}$	$1.42\ 10^{-3}$	Infant
Ra-228	$1.99\ 10^{-1}$	$1.96\ 10^{-3}$	Infant
Cm-244	$1.90\ 10^{-1}$	$1.23\ 10^{-3}$	Infant

* Based on 200 Bq g^{-1} and 200 MBq in package

** National LLW inventory of Ac-227 and Cm-228 is only 1.1 MBq in total, see text

6.1.2.2 Worker exposure through a wound

237. Radionuclides can enter the body via wounds and absorption through intact skin. This is not a reasonably foreseeable scenario under normal circumstances. However, it is a possible accident scenario.

238. Material likely to be entering a wound would be dust or grit, which are not soluble. As such, using the NCRP 'fragment' category dose coefficient is the most realistic. The highest doses result from Pu-239, Pu-240, Th-232, Pu-238 and Th-230. For all radionuclides for which data is available, doses when using the fragment coefficient are less than 1 mSv even if the activity concentration in the waste is increased to 5000 Bq g^{-1}. Details of the calculations are given in E.3.9.

6.1.2.3 Potential impact from leachate spillage

239. It is expected that a spillage of landfill leachate will be subject to mitigation measures based on a detailed assessment of any ground contamination. Doses to site workers would be kept within site constraints. However, leachate that enters water resources would become diluted and effective mitigation measures would be more difficult to achieve. The assessment of leachate spillage therefore focusses on pathways related to the use of water resources (drinking, irrigation, livestock and angling). The leachate activity concentration used in the calculations is the maximum observed during the period of authorisation based on output from the GoldSim model and assuming disposal at the radiological capacity.

240. The greatest radionuclide specific doses arising from disposing of the radiological capacity are presented in Table 13 all with a dose of 300 µSv. The event has a low probability of occurring and clean-up actions would be taken to mitigate the event. The scenario does constrain the radiological capacity without mitigation measures.

Table 13 Doses from a leachate spillage

Radionuclide	Radiological capacity	Dose due to leachate spillage*	
		Dose to a farming family (µSv)	Public receptor
Mn-54	1.12 10^{13}	3.00 10^{2}	infant
Fe-55	1.86 10^{13}	3.00 10^{2}	infant
Co-60	3.58 10^{11}	3.00 10^{2}	infant
Zn-65	8.95 10^{11}	3.00 10^{2}	infant
Ru-106	9.14 10^{11}	3.00 10^{2}	infant
Ag-110m	6.41 10^{12}	3.00 10^{2}	infant
Cd-109	1.04 10^{12}	3.00 10^{2}	infant
Sb-125	4.17 10^{11}	3.00 10^{2}	infant
Sn-119m	8.43 10^{12}	3.00 10^{2}	infant
Sn-123	2.97 10^{12}	3.00 10^{2}	infant
Te-127m	4.07 10^{12}	3.00 10^{2}	infant
Ba-133	7.18 10^{9}	3.00 10^{2}	child
Cs-134	1.01 10^{11}	3.00 10^{2}	Adult
Ce-144	4.81 10^{12}	3.00 10^{2}	infant
Pm-147	2.14 10^{13}	3.00 10^{2}	infant
Eu-155	8.81 10^{12}	3.00 10^{2}	infant
Gd-153	4.83 10^{13}	3.00 10^{2}	infant
Po-210	6.17 10^{9}	3.00 10^{2}	infant
Ra-228	2.25 10^{10}	3.00 10^{2}	child
Ac-227	3.04 10^{9}	3.00 10^{2}	infant
Th-228	1.72 10^{11}	3.00 10^{2}	infant

6.1.2.4 Landfill fire

241. This scenario is only relevant to the non-hazardous landfill. Details of the calculations are described in Section E.3.6.2 and the dose assuming two fires occur in a year are given in Table 78. This scenario is used in the radiological capacity calculations for the non-hazardous landfill.

6.2 Risk guidance level after the period of authorisation {R6}

242. The NS-GRA provides guidance on the level of risk to be applied after the period of authorisation (Requirement 6):

> "After the period of authorisation, the assessed radiological risk from a disposal facility to a person representative of those at greatest risk should be consistent with a risk guidance level of 10^{-6} per year (i.e. 1 in a million per year)." (UK Environment Agencies, 2009), para 6.3.10

243. Based on the recommended risk to dose conversion factor of 0.06 per Sv (HPA, 2009), and assuming that the event is certain to occur, the risk guidance level corresponds to a dose of approximately 20 µSv y^{-1}. For situations where the probability of receiving a dose is less than one, doses could be greater than 20 µSv y^{-1} while still maintaining consistency with the risk guidance level and, for situations where the probability is very much less than one, doses could be very much greater than 20 µSv y^{-1}. Where the probability is less than 1 justification for any adopted value is required.

244. The NS-GRA does not lay down an absolute requirement for the risk guidance level to be met. The value of 10^{-6} y^{-1} (per year) is consistent with HSE advice that this is "a very low level of risk" above which people may be prepared to tolerate risks in order to secure benefits and below which risks are broadly accepted (HSE, 2001). The "risk guidance level" does not apply to human intrusion scenarios as these have a specific dose guidance level (see Section 6.3).

245. This ESC provides a quantitative assessment of the potential future effects of the contamination that can be compared with the risk criterion, using systematically developed and justified, site-specific mathematical models. A cautious best estimate approach is adopted when selecting parameter values and the models themselves are cautious.

246. The results of the assessments relating to longer term impacts, after the period of authorisation (post-closure), are described in Appendix E, Section E.4. The radiological assessment has considered a range of potential scenarios and these are summarised in Table 14. In cases where a scenario has not been explicitly assessed, because it will not or is very unlikely to occur at Port Clarence, the reasons for this are discussed. The scenarios discussed below are divided into two broad categories – those that are likely to occur and those that are unlikely to occur (i.e. scenarios which have a low likelihood of occurrence). The dose assessment considers exposure of members of the public after the period of authorisation.

Table 14 Summary of radiological assessment scenarios considered after the period of authorisation (excluding intrusion scenarios and non-human biota)

Scenario	Exposed group
After the Period of Authorisation – likely to occur	
Recreational user	Member of public
Site erosion	Member of public
Inundation from sea*	Member of public
After the Period of Authorisation – unlikely to occur	
Groundwater abstraction	Farming family
Bathtubbing	Farming family
Gas release and external	Site resident
Site re-engineering*	Worker
Other unlikely events*	

* Not explicitly assessed.

247. The detailed results of the assessments for the post-closure period are presented in Appendix E.4. The effects of very long-term climate change on site erosion and

inundation from the sea are considered in the natural evolution of the site (see sub-section 2.9). Future glaciation would have similar or lesser effects than the "residential intrusion scenario" considered in Appendix E.5.6. The list in Table 14 includes a category of "Other unlikely events" which covers seismic events, transport accidents and a criticality event. The reasons why these events have not been assessed in detail are given in Appendix E.4.

6.2.1 Dose assessments after the period of authorisation – expected to occur

6.2.1.1 Impact on recreational users due to gas releases and external radiation

248. The intended end use of the site includes woodland, scrub and grassland with paths. An assessment is therefore made of the doses to a member of the public who spends time walking over the restored site for 2 h d^{-1} (hours per day) and is exposed to gases released from the waste and receives external exposure from buried waste packages. The results are calculated at the time of closure and after 60 years (the assumed period of authorisation in the aftercare or post-closure period). The assessment includes the effects of radioactive decay and ingrowth upon the calculated doses. Doses from radon gas are shown under Ra-226.

249. Table 15 presents the radionuclide specific doses arising from disposing of the radiological capacity where the calculated dose is greater than 10^{-19} µSv y^{-1}. The highest doses are from H-3, Ni-59 and Nb-93m at closure and these limit the radiological capacity of the site. The peak dose will always be lower than this due to application of the sum of fractions approach.

250. The assumptions concerning gas release in this period are very conservative and this results in overstating gas doses to recreational users of the site.

Table 15 Doses to recreational users of the restored site at the time of closure and 60 years after closure

Radionuclide	Radiological capacity (MBq)	At closure		60 years after closure	
		Dose per unit disposal (µSv y^{-1} MBq^{-1})	Dose at capacity (µSv y^{-1})	Dose per unit disposal (µSv y^{-1} MBq^{-1})	Dose at capacity (µSv y^{-1})
H-3	$6.43\ 10^{9}$	$3.11\ 10^{-9}$	$2.00\ 10^{1}$	$7.43\ 10^{-11}$	$4.78\ 10^{-1}$
C-14	$1.87\ 10^{8}$	$1.07\ 10^{-7}$	$2.00\ 10^{1}$	$3.23\ 10^{-8}$	$6.05\ 10^{0}$
Mn-54	$1.12\ 10^{13}$	$5.35\ 10^{-19}$	$5.99\ 10^{-6}$		
Co-60	$3.58\ 10^{11}$	$6.04\ 10^{-17}$	$2.16\ 10^{-5}$		
Zn-65	$8.95\ 10^{11}$	$3.81\ 10^{-18}$	$3.41\ 10^{-6}$		
Mo-93	$1.44\ 10^{9}$	$2.24\ 10^{-9}$	$3.23\ 10^{0}$	$4.14\ 10^{-9}$	$5.96\ 10^{0}$
Nb-93m	$5.06\ 10^{10}$	$3.95\ 10^{-10}$	$2.00\ 10^{1}$	$5.60\ 10^{-11}$	$2.83\ 10^{0}$
Nb-94	$6.09\ 10^{6}$	$5.54\ 10^{-19}$	$3.38\ 10^{-12}$	$1.03\ 10^{-18}$	$6.29\ 10^{-12}$
Ag-110m	$6.41\ 10^{12}$	$3.82\ 10^{-18}$	$2.45\ 10^{-5}$		
Sn-126	$4.60\ 10^{6}$	$1.26\ 10^{-19}$	$5.80\ 10^{-13}$	$2.36\ 10^{-19}$	$1.08\ 10^{-12}$
Cs-134	$1.01\ 10^{11}$	$2.21\ 10^{-19}$	$2.23\ 10^{-8}$		

Radionuclide	Radiological capacity (MBq)	At closure		60 years after closure	
		Dose per unit disposal (µSv y^{-1} MBq^{-1})	Dose at capacity (µSv y^{-1})	Dose per unit disposal (µSv y^{-1} MBq^{-1})	Dose at capacity (µSv y^{-1})
Eu-152	$8.05\ 10^{9}$	$2.49\ 10^{-18}$	$2.00\ 10^{-8}$	$2.15\ 10^{-19}$	$1.73\ 10^{-9}$
Eu-154	$4.18\ 10^{10}$	$3.46\ 10^{-18}$	$1.45\ 10^{-7}$		
Ra-226	$3.89\ 10^{6}$	$8.93\ 10^{-17}$	$3.47\ 10^{-10}$	$1.26\ 10^{-16}$	$4.90\ 10^{-10}$
Ra-228	$2.25\ 10^{10}$	$3.09\ 10^{-15}$	$6.96\ 10^{-5}$	$4.17\ 10^{-18}$	$9.39\ 10^{-8}$
Th-228	$1.72\ 10^{11}$	$1.95\ 10^{-15}$	$3.35\ 10^{-4}$		
Th-229	$2.88\ 10^{7}$	$5.16\ 10^{-18}$	$1.49\ 10^{-10}$	$9.58\ 10^{-18}$	$2.76\ 10^{-10}$
Th-232	$7.95\ 10^{6}$	$1.16\ 10^{-15}$	$9.18\ 10^{-9}$	$2.16\ 10^{-15}$	$1.71\ 10^{-8}$
U-232	$4.04\ 10^{8}$	$1.73\ 10^{-19}$	$6.97\ 10^{-11}$	$1.76\ 10^{-19}$	$7.11\ 10^{-11}$

6.2.1.2 Impact due to the erosion of landfill

251. The landfill site has been reclaimed from salt marsh and mudflats over many decades through the deposition of wastes, clinker and slag deposits from industries including gas works, lime works, chlorine works, soda works, blast furnaces and salt evaporating pans (Augean, 2014). The landfill restoration profile rises above the floodplain and in the existing plan there are two waste cells that overlap with the projected flood level used for planning purposes (see Section 2.3 and Figure 10).

252. It is possible that local or national policies maintaining shipping access and managing flood defences could change and impact the future evolution of the estuary. If dredging activities stopped there would be accumulation of sediments and further development of salt marshes and mudflats. The sediment deposits and sea level rise would impact flooding rather than erosion at the Port Clarence site.

253. Although it is considered unlikely to occur, erosion of the landfill has been assessed using cautious assumptions. Access to the site on a regular basis may not be possible once erosion starts due to the inundation of low lying land that surrounds the site. However, it is assumed that erosion starts about 2540 years after closure and scenarios consider both recreational use of the site and release to the estuary.

254. The intended end use of the site includes public access to scrub and grassland with paths. An assessment is therefore made of the doses to a member of the public who spends time walking over the restored site and it is assumed that this continues once erosion starts to impact the site (see Appendix E, Section E.4.5). We have partitioned time spent close to the eroding materials by assuming a daily walk of 1 hour, passing the exposed face once, assuming a face length of 1 km and walking at 5 km h^{-1}. The walker inadvertently ingests soil, inhales dust and receives an external exposure from exposed waste.

255. Table 16 presents the dose rate per MBq (µSv y^{-1} MBq^{-1}) calculated from the assessment at the time of erosion (2,540 years after site closure) for 16 radionuclides. This scenario limits disposal of these 11 radionuclides and doses arising from disposing of the radiological capacity are therefore 20 µSv y^{-1} for these radionuclides.

Table 16 Radiological capacity limited by doses to a walker due to erosion of landfill

Radionuclide	Radiological capacity (MBq)	Dose per unit disposal ($\mu Sv\ y^{-1}\ MBq^{-1}$)	Dose at radiological capacity ($\mu Sv\ y^{-1}$)
Nb-94	$6.09\ 10^{6}$	$3.28\ 10^{-6}$	20
Sn-126	$4.60\ 10^{6}$	$4.35\ 10^{-6}$	20
Th-229	$2.88\ 10^{7}$	$6.95\ 10^{-7}$	20
Th-232	$7.95\ 10^{6}$	$2.52\ 10^{-6}$	20
U-233	$1.02\ 10^{8}$	$1.96\ 10^{-7}$	20
U-235	$6.93\ 10^{7}$	$2.89\ 10^{-7}$	20
Pu-239	$1.55\ 10^{8}$	$1.29\ 10^{-7}$	20
Pu-240	$1.89\ 10^{8}$	$1.06\ 10^{-7}$	20
Pu-242	$1.58\ 10^{8}$	$1.26\ 10^{-7}$	20
Pu-244	$1.26\ 10^{8}$	$1.59\ 10^{-7}$	20
Am-243	$1.46\ 10^{8}$	$1.37\ 10^{-7}$	20

256. The erosion of the landfill to sea uses PC-CREAM 08 to derive the dose per unit activity following release into the estuary and then being washed out to sea. The dose per unit release (DPUR) has been calculated using PC-CREAM 08 with the default habit data. In these scoping calculations it is cautiously assumed that all radionuclides within the landfill mass are completely soluble. The erosion rate (0.1 m y^{-1}) used (Blott, et al., 2013) is cautious (the erosion rate of 72% of the coast in England and Wales is less than 0.1 m y^{-1}) and it is assumed to apply to the shortest cross section of the landfill (about 310 m) to derive an annual loss rate for LLW to the estuary (0.03% per annum).

257. The assessment considered a constant discharge over a period of 1, 5, 50 and 500 years. The approach does not allow for radioactive decay of the source over the release period and therefore will result in overestimates of the DPUR for radionuclides with a shorter half life than the release period. For each release period, the DPUR varies with time. We have cautiously selected the maximum DPUR for each release period and then selected the highest DPUR from the four release periods. We have cautiously applied the maximum DPUR over this period.

258. The assessment considers the consumption of crustaceans, fish, molluscs and seaweed, external irradiation from beaches and fishing equipment and sea spray inhalation. The results for this scenario are presented in Table 17 for the 10 radionuclides giving the highest dose rates ($\mu Sv\ y^{-1}\ MBq^{-1}$). Table 17 also gives the dose rate based on disposing of the radiological capacity ($\mu Sv\ y^{-1}$).

Table 17 Peak doses due to erosion of landfill to sea

Radionuclide	Radiological capacity (MBq)	Dose per unit disposal ($\mu Sv\ y^{-1}\ MBq^{-1}$)	Dose at capacity ($\mu Sv\ y^{-1}$)
U-234	$1.45\ 10^{8}$	$1.38\ 10^{-7}$	20
Th-230	$1.98\ 10^{6}$	$1.01\ 10^{-5}$	20
Ra-226	$3.89\ 10^{6}$	$5.14\ 10^{-6}$	20
Zr-93	$3.12\ 10^{11}$	$6.42\ 10^{-11}$	20
Se-79	$8.98\ 10^{8}$	$1.87\ 10^{-8}$	17
Ni-59	$1.95\ 10^{11}$	$6.24\ 10^{-11}$	12
Mo-93	$1.44\ 10^{9}$	$5.76\ 10^{-9}$	8
Pu-244	$1.26\ 10^{8}$	$3.47\ 10^{-8}$	4
Pu-242	$1.58\ 10^{8}$	$2.06\ 10^{-8}$	3
Pu-240	$1.89\ 10^{8}$	$1.65\ 10^{-8}$	3

259. Erosion to sea would restrict the radiological disposal capacity at Port Clarence for four radionuclides (U-234, Th-230, Ra-226 and Zr-93).

6.2.1.3 Impact due to inundation from the sea

260. The effects of very long term climate change are assessed due to the location of the site close to the Tees Estuary. Consideration has also been given to the timescale over which sea level rise could occur (see Section 2.9) leading to the potential erosion of the site. Future glaciation would have similar or lesser effects than the “residential intrusion scenario” considered in Section E.5.6 since it could also remove the cap but it would occur much later (e.g. 10,000s of years in the future).

261. With sea level rise the area surrounding the landfill is likely in due course to be subject to periodic flooding. At some stage the peak flood height will begin to overlap the basal liner and water may enter the base of the landfill. However, the bathtubbing and the groundwater scenarios are both assumed to occur earlier and would have similar or greater effects than inundation. This pathway has not therefore been considered further.

6.2.2 After the Period of Authorisation – unlikely to occur

262. The following scenarios (water abstraction and bathtubbing) are unlikely to occur.

6.2.2.1 Water abstraction

263. The abstraction of potable water is not known to occur from the aquifer beneath the Port Clarence site. The groundwater is not potable due to saline intrusion and would also not be suitable for irrigation or livestock. This scenario is therefore considered as

a 'what if' scenario and is not used to limit the radiological capacity because water cannot be used for irrigation or animal consumption.

264. The groundwater risk assessment takes into account gradual deterioration of the HDPE waste cell liner (see Appendix E, Section E.4.3). This assumes a doubling time every 100 years for the HDPE component of the liner defects that allow a flux of water from the waste cells to the unsaturated zone beneath the waste cells and subsequently to the groundwater.

265. Water abstraction from a well 100m from the boundary of the site was modelled using GoldSim and annual doses were calculated from drinking contaminated water and from the use of water for irrigation of crops and livestock. The activity concentration at the well varies over time, generally rising to a peak and then subsequently reducing. The peak activity concentration was used to derive the annual dose and hence these values are peak annual doses occurring at different times post closure.

266. The results for selected radionuclides are given in Table 18. The complete set of results is presented in Appendix E, Table 120. Since this scenario has not been used to limit the radiological capacity, some doses from disposal of the entire radiological capacity would exceed the dose limit for members of the public were this scenario to be considered credible. The peak dose will always be lower than this due to application of the sum of fractions approach.

Table 18 Peak doses due to groundwater abstraction after the period of authorisation

Radionuclide	Radiological capacity (MBq)	Drinking water pathway dose per unit disposal (µSv y^{-1} MBq^{-1})	Irrigation pathway dose per unit disposal (µSv y^{-1} MBq^{-1})	Total dose per unit disposal (µSv y^{-1} MBq^{-1})	Time of Max (y)	Dose at capacity (µSv y^{-1})
Tc-99	$6.12\ 10^{8}$	$3.61\ 10^{-6}$	$2.15\ 10^{-5}$	$2.51\ 10^{-5}$	$1.09\ 10^{3}$	$1.53\ 10^{4}$
I-129	$3.01\ 10^{8}$	$2.82\ 10^{-6}$	$2.48\ 10^{-5}$	$2.76\ 10^{-5}$	$1.98\ 10^{4}$	$8.31\ 10^{3}$
Cl-36	$1.56\ 10^{8}$	$3.34\ 10^{-6}$	$2.26\ 10^{-5}$	$2.59\ 10^{-5}$	$1.50\ 10^{3}$	$4.05\ 10^{3}$
Ca-41	$5.77\ 10^{9}$	$5.21\ 10^{-9}$	$5.29\ 10^{-8}$	$5.81\ 10^{-8}$	$2.07\ 10^{4}$	$3.35\ 10^{2}$
Np-237	$1.42\ 10^{7}$	$4.47\ 10^{-7}$	$3.43\ 10^{-6}$	$3.88\ 10^{-6}$	$8.18\ 10^{4}$	$5.51\ 10^{1}$
U-238	$1.60\ 10^{9}$	$5.07\ 10^{-10}$	$5.02\ 10^{-9}$	$5.52\ 10^{-9}$	$1.00\ 10^{5}$	$8.86\ 10^{0}$
U-236	$1.48\ 10^{9}$	$2.84\ 10^{-10}$	$2.29\ 10^{-9}$	$2.57\ 10^{-9}$	$1.00\ 10^{5}$	$3.81\ 10^{0}$
Se-79	$8.98\ 10^{8}$	$4.82\ 10^{-11}$	$2.89\ 10^{-9}$	$2.93\ 10^{-9}$	$1.00\ 10^{5}$	$2.64\ 10^{0}$
U-234	$1.45\ 10^{8}$	$9.23\ 10^{-10}$	$8.61\ 10^{-9}$	$9.53\ 10^{-9}$	$1.00\ 10^{5}$	$1.38\ 10^{0}$
U-235	$6.93\ 10^{7}$	$6.31\ 10^{-10}$	$7.00\ 10^{-9}$	$7.63\ 10^{-9}$	$1.00\ 10^{5}$	$5.29\ 10^{-1}$
U-233	$1.02\ 10^{8}$	$3.27\ 10^{-10}$	$3.10\ 10^{-9}$	$3.42\ 10^{-9}$	$1.00\ 10^{5}$	$3.50\ 10^{-1}$
Pu-241	$9.39\ 10^{9}$	$2.76\ 10^{-12}$	$2.11\ 10^{-11}$	$2.38\ 10^{-11}$	$1.24\ 10^{2}$	$2.24\ 10^{-1}$
Am-241	$3.03\ 10^{8}$	$8.33\ 10^{-11}$	$6.40\ 10^{-10}$	$7.23\ 10^{-10}$	$2.59\ 10^{3}$	$2.19\ 10^{-1}$
Cm-245	$1.26\ 10^{7}$	$1.47\ 10^{-9}$	$1.13\ 10^{-8}$	$1.28\ 10^{-8}$	$4.89\ 10^{4}$	$1.61\ 10^{-1}$
Mo-93	$1.44\ 10^{9}$	$3.45\ 10^{-12}$	$5.59\ 10^{-11}$	$5.93\ 10^{-11}$	$1.66\ 10^{4}$	$8.53\ 10^{-2}$
Pu-238	$7.56\ 10^{8}$	$3.28\ 10^{-13}$	$2.94\ 10^{-12}$	$3.27\ 10^{-12}$	$5.97\ 10^{2}$	$2.47\ 10^{-3}$
C-14	$1.87\ 10^{8}$	$2.24\ 10^{-13}$	$3.13\ 10^{-12}$	$3.36\ 10^{-12}$	$2.01\ 10^{4}$	$6.29\ 10^{-4}$
Pu-244	$1.26\ 10^{8}$	$1.23\ 10^{-13}$	$7.75\ 10^{-13}$	$8.98\ 10^{-13}$	$1.00\ 10^{5}$	$1.13\ 10^{-4}$

Radionuclide	Radiological capacity (MBq)	Drinking water pathway dose per unit disposal ($\mu Sv\ y^{-1}\ MBq^{-1}$)	Irrigation pathway dose per unit disposal ($\mu Sv\ y^{-1}\ MBq^{-1}$)	Total dose per unit disposal ($\mu Sv\ y^{-1}\ MBq^{-1}$)	Time of Max (y)	Dose at capacity ($\mu Sv\ y^{-1}$)
Am-242m	$1.75\ 10^{7}$	$4.62\ 10^{-13}$	$4.14\ 10^{-12}$	$4.60\ 10^{-12}$	$9.68\ 10^{2}$	$8.04\ 10^{-5}$
Pu-240	$1.89\ 10^{8}$	0	$3.53\ 10^{-13}$	$3.53\ 10^{-13}$	$3.63\ 10^{4}$	$6.66\ 10^{-5}$

267. Table 18 also shows that the time at which the peak dose occurs in the future varies from 1000 years to 100,000 years, depending on the radionuclide. The GoldSim calculations are evaluated to 100,000 years.

268. The variability in time to peak dose means that the sum of fractions approach will be overly cautious. For example the peak dose for Tc-99 occurs at 1000 years, but the dose due to I-129 at that time will be less than that shown in Table 18 as the peak has not yet occurred. The peak dose to an individual, summed over radionuclides at any particular time, could be evaluated for a known inventory once disposals have occurred and this could be used to determine a more accurate estimate of the residual disposal capacity at intermediate stages before the site closes.

6.2.2.2 Bathtubbing

269. Calculations to show the impact of bathtubbing have been undertaken (Appendix E, Section E.4.5). Bathtubbing involves degradation of the cap so that the infiltration of water into the landfill is greater than the percolation through the liner, leading to saturation of a waste cell and overtopping of the side liner. The design of the waste cells at Port Clarence is shown in Figure 11. However, the cap design includes a geosynthetic clay layer and restoration soil, materials that will not degrade. The restoration programme includes areas of open water adjacent to the landfill area with aquatic marginal vegetation, scrub, wet meadow and ruderal grassland with small hollows, banks and ridges suitable for nature conservation use.

270. It is assumed that drainage of leachate from the top of the side liner to standing water adjacent to the site could occur. It is unlikely that the site or its immediate surroundings will be developed for housing, nevertheless another scenario is considered in which the overtopping is assumed to contaminate soil below the garden of a house that has been built adjacent to the landfill. Vegetables are assumed to be grown in the garden. This is the approach adopted for the ENRMF (Eden NE, 2015a).

271. As leachate level monitoring will continue following completion of filling, capping and placement of the restoration materials, leachate levels will be controlled as necessary so that compliance limits are not exceeded. The control of leachate levels at the site will continue until it is considered by the Environment Agency that the landfill is unlikely to present a significant risk to the environment if leachate management ceases. The Environmental Permit for landfill sites cannot be surrendered until the Environment Agency consider that the site no longer presents a potential significant risk to the environment and human health including groundwater. On this basis the potential for overtopping of leachate at a stage when the leachate could have an unacceptable

impact on the environment is very unlikely to occur. Accordingly the bathtubbing event is considered very unlikely to occur in practice. Nevertheless the impact of bathtubbing is considered at a time after closure determined by GoldSim. The time corresponds to 135 years after closure and is the point in time the groundwater model suggests overtopping could occur if leachate management has ceased.

272. Two scenarios are considered. The first scenario assumes direct transfer of overtopping leachate to open water on the site and exposure of a fisherman through fish consumption. No account is taken of potential interaction with soil during drainage or silts at the bottom of the water body. It is assumed that freshwater inputs to the waterbody are equivalent to the average rainfall (574.2 mm m^{-2}). The second assumes that an area (3 ha) adjacent to the site is subject to leachate released due to bathtubbing; this is a small area relative to the size of the landfill and all activity is assumed to accumulate in the affected area. Seepage will occur at the top of the side liner and this will be at least 1 m below restored ground levels. It is also assumed that 1% of the activity introduced at depth (>1 m) reaches the cultivated surface soils (Shaw, et al., 2004). The remainder is assumed to drain to sub-strata. No account is taken of potential dilution by rain falling in the surrounding area and draining to the same point. The doses are calculated for a household.

273. The results for the bathtubbing scenarios are presented in Table 19 for the radionuclides giving the highest doses (µSv y^{-1}) based on disposing of the radiological capacity.

Table 19 Peak doses due to bathtubbing/flooding after the period of authorisation.

Radionuclide	Radiological capacity (MBq)	Resident		Fish consumer	
		Dose per unit disposal (µSv y^{-1} MBq^{-1})	Dose at capacity (µSv y^{-1})	Dose per unit disposal (µSv y^{-1} MBq^{-1})	Dose at capacity (µSv y^{-1})
U-238	1.60 10^{9}	7.01 10^{-8}	1.12 10^{2}	2.63 10^{-14}	4.22 10^{-5}
Pu-244	1.26 10^{8}	8.46 10^{-7}	1.06 10^{2}	8.20 10^{-15}	1.03 10^{-6}
U-233	1.02 10^{8}	1.02 10^{-6}	1.05 10^{2}	2.54 10^{-14}	2.60 10^{-6}
U-236	1.48 10^{9}	6.67 10^{-8}	9.87 10^{1}	2.36 10^{-14}	3.49 10^{-5}
U-235	6.93 10^{7}	1.19 10^{-6}	8.22 10^{1}	2.40 10^{-14}	1.66 10^{-6}
Pu-242	1.58 10^{8}	4.52 10^{-7}	7.16 10^{1}	7.84 10^{-15}	1.24 10^{-6}
Pu-239	1.55 10^{8}	4.12 10^{-7}	6.41 10^{1}	8.25 10^{-15}	1.28 10^{-6}
Pu-240	1.89 10^{8}	3.04 10^{-7}	5.74 10^{1}	8.26 10^{-15}	1.56 10^{-6}
Am-243	1.46 10^{8}	2.54 10^{-7}	3.71 10^{1}	1.55 10^{-14}	2.27 10^{-6}
Pa-231	1.36 10^{7}	2.22 10^{-6}	3.01 10^{1}	2.36 10^{-14}	3.20 10^{-7}
Se-79	8.98 10^{8}	3.23 10^{-8}	2.90 10^{1}	3.48 10^{-13}	3.13 10^{-4}
U-234	1.45 10^{8}	2.00 10^{-7}	2.90 10^{1}	2.36 10^{-14}	3.42 10^{-6}
Sm-147	4.81 10^{8}	5.56 10^{-8}	2.67 10^{1}	1.64 10^{-14}	7.87 10^{-6}
Cm-248	1.45 10^{7}	1.38 10^{-6}	2.01 10^{1}	4.37 10^{-13}	6.35 10^{-6}

274. Bathtubbing would restrict the disposal capacity of Port Clarence for these radionuclides. The greatest doses are for isotopes of Uranium and Plutonium.

6.2.2.3 Gas release

275. The development of the site for residential purposes is very unlikely due to the slope of the restored site, location in an industrial area, a risk of potential flooding of the surrounding low lying areas alongside potential changes due to sea level rise and growing nature conservation interests. Hence, dose to residential user of site from gas release is not considered further.

6.2.2.4 Site re-engineering

276. A site re-engineering/remediation scenario was included in the SNIFFER methodology to cover the situation where a site operator has no records of radioactive waste disposals or their location, possibly because they were disposed of under earlier VLLW authorisations, and excavates waste during final site restoration works. In the case of Port Clarence records would be maintained as a condition of the Permit. Any remediation work would be done with the knowledge that there was radioactive material on the site and it can be assumed that appropriate precautions against exposure would be adopted. Site rules also prevent any disposal of radioactive waste within 2 m of basal liners and within 1 m of the top of the cell. Hence this scenario is not considered in the ESC.

6.3 Human intrusion after the period of authorisation {R7}

277. The NS-GRA provides dose guidance levels to be used for assessments of human intrusion after the period of authorisation (Requirement 7):

> "The developer/operator of a near-surface disposal facility should assess the potential consequences of human intrusion into the facility after the period of authorisation on the basis that it is likely to occur. The developer/operator should, however, consider and implement any practical measures that might reduce the chance of its happening. The assessed effective dose to any person during and after the assumed intrusion should not exceed a dose guidance level in the range of around 3 mSv/year to around 20 mSv/year. Values towards the lower end of this range are applicable to assessed exposures continuing over a period of years (prolonged exposures), while values towards the upper end of the range are applicable to assessed exposures that are only short term (transitory exposures)." (UK Environment Agencies, 2009), para 6.3.36

278. The NS-GRA defines human intrusion as any human action that accesses the waste or that damages a barrier providing an environmental safety function after the period of authorisation.

279. The NS-GRA (paragraph 6.3.41) requires assessment of future human intrusion into the facility assuming that either the intruder does not have prior knowledge of the disposal facility, or that the intruder has knowledge of the existence of underground workings but does not understand what they contain. It is not necessary to assess intrusions undertaken with full knowledge of the existence, location, nature and contents of the disposal facility; the environment agencies take the view that a society that preserves full knowledge of the disposal facility will be capable itself of exercising

proper control over any intrusions into the disposal system. Therefore, the human actions that must be assessed are deliberate acts, for example, to excavate a void or recover materials, but where the intruder is uninformed or oblivious to the radiological hazard. The standard against which human intrusion into a near-surface disposal facility should be assessed is specified in terms of dose, not risk, because the environment agencies believe that the likelihood of human intrusion cannot reliably be assessed in terms of a probability (NS-GRA (UK Environment Agencies, 2009), para 6.3.38).

280. The NS-GRA dose guidance level of 3 mSv y^{-1} to 20 mSv y^{-1} indicates the standard of environmental safety to be achieved. The guidance levels should not be interpreted as limits and are the same as the levels given in advice issued by the HPA in their publication on the disposal of solid radioactive waste (HPA, 2009).

281. The lower dose criterion of 3 mSv y^{-1} is applied in this ESC for prolonged exposure resulting from human intrusion. Doses in this section are presented as mSv.

6.3.1 Dose assessments following intrusion after the period of authorisation

282. The results of the assessments relating to intrusion, after the period of authorisation (post-closure), are described in Appendix E, Section E.5. The radiological assessment has considered a range of potential scenarios and these are summarised in Table 20. The scenarios discussed below consider both workers and members of the public.

Table 20 Summary of radiological assessment scenarios following intrusion after the period of authorisation

Scenario	Exposed group	Time after closure
Drilling operative	Worker	60 years
Trial pit excavation	Worker	60 years
Gas release and external exposure	Site resident	150 years
Excavation for housing	Excavation worker and Resident	150 years
Excavation for smallholder	Farming family	200 years
Site re-engineering or removal	not explicitly assessed	

6.3.2 Dose to workers excavating the site

283. The exposure of workers who excavate waste at the site has been assessed over two timeframes. It is assumed that small excavations, e.g. trial pit and borehole, may occur at the site in the short term after closure (60 years) and that larger excavations, e.g. for housing or for smallholding, may occur in the longer term (150 or 200 years). LLW, other waste and cover material are assumed to be excavated. If the LLW is disposed of at a depth greater than 5 m then it would not be extracted or disturbed by the trial pits or large excavations and the resulting doses to workers excavating at the site would be zero. It is assumed that a single drilling engineer is involved in 5 boreholes

(Hicks & Baldwin, 2011), i.e. the potential dose arising from 5 intrusion events is calculated.

284. The results for the twelve radionuclides giving the largest impacts are summarised in Table 21 alongside the potential dose arising from disposing of the radiological capacity. The doses to a trial pit excavator (see full results in Appendix E, Table 135) are always lower than for borehole drilling so these are not listed in Table 21 (see full results in Appendix E, Table 133). The doses to a worker excavating for smallholding are always lower than for excavation for housing so these are also not listed in Table 21 (see full results in Appendix E, Table 137).

285. The dose (and hence derived quantities such as the radiological capacity) to the worker in the human intrusion scenarios depends upon the duration of exposure and the activity concentration in the excavated waste. Both of the scenarios presented in Table 21 use exposure times of 80 hours per year to contaminated material and hence it would be expected that the doses would be identical. However, the excavation for housing (150 years) is assumed to occur later than the borehole drilling scenario (60 years) and radioactive decay and ingrowth modifies the doses accordingly.

Table 21 Highest doses to workers excavating at the site for each time period

Radionuclide	Radiological capacity (MBq)	Borehole drilling (60y)		Excavation for housing (150y)	
		Dose per unit disposal (mSv MBq^{-1})	Dose from capacity (mSv)	Dose per unit disposal (mSv MBq^{-1})	Dose from capacity (mSv)
Co-60	$3.58\ 10^{11}$	$2.46\ 10^{-12}$	$8.81\ 10^{-1}$	$1.78\ 10^{-17}$	$6.38\ 10^{-6}$
Ag-108m	$2.65\ 10^{8}$	$3.54\ 10^{-9}$	$9.39\ 10^{-1}$	$3.05\ 10^{-9}$	$8.09\ 10^{-1}$
Cs-137	$9.69\ 10^{8}$	$3.48\ 10^{-10}$	$3.37\ 10^{-1}$	$4.40\ 10^{-11}$	$4.27\ 10^{-2}$
Eu-152	$8.05\ 10^{9}$	$1.32\ 10^{-10}$	$1.06\ 10^{0}$	$1.31\ 10^{-12}$	$1.06\ 10^{-2}$
Eu-154	$4.18\ 10^{10}$	$2.46\ 10^{-11}$	$1.03\ 10^{0}$	$1.73\ 10^{-14}$	$7.24\ 10^{-4}$
Ac-227	$3.04\ 10^{9}$	$8.88\ 10^{-10}$	$2.70\ 10^{0}$	$5.06\ 10^{-11}$	$1.54\ 10^{-1}$
Pu-238	$7.56\ 10^{8}$	$6.42\ 10^{-10}$	$4.85\ 10^{-1}$	$3.15\ 10^{-10}$	$2.38\ 10^{-1}$
Pu-239	$1.55\ 10^{8}$	$1.12\ 10^{-9}$	$1.75\ 10^{-1}$	$1.12\ 10^{-9}$	$1.74\ 10^{-1}$
Pu-240	$1.89\ 10^{8}$	$1.12\ 10^{-9}$	$2.11\ 10^{-1}$	$1.11\ 10^{-9}$	$2.09\ 10^{-1}$
Pu-241	$9.39\ 10^{9}$	$2.82\ 10^{-11}$	$2.65\ 10^{-1}$	$2.49\ 10^{-11}$	$2.34\ 10^{-1}$
Pu-242	$1.58\ 10^{8}$	$1.03\ 10^{-9}$	$1.64\ 10^{-1}$	$1.03\ 10^{-9}$	$1.64\ 10^{-1}$
Am-241	$3.03\ 10^{8}$	$8.34\ 10^{-10}$	$2.52\ 10^{-1}$	$7.22\ 10^{-10}$	$2.18\ 10^{-1}$
Am-243	$1.46\ 10^{8}$	$9.55\ 10^{-10}$	$1.39\ 10^{-1}$	$9.49\ 10^{-10}$	$1.39\ 10^{-1}$
Cm-242	$1.48\ 10^{11}$	$3.28\ 10^{-12}$	$4.85\ 10^{-1}$	$1.61\ 10^{-12}$	$2.38\ 10^{-1}$

286. The highest doses occur for Ac-227 with a dose of about 2.7 mSv for disposal of about 3,000 TBq at the site (radiological capacity calculations are presented in Section 7.4). These calculated doses are below the dose guidance level for intrusion. Other scenarios constrain the radiological capacity at the Port Clarence landfill.

287. The trial pit excavation scenario is one of the scenarios used to determine the proposed radionuclide activity concentration limits for packaged wastes (see Section 7.4.2.3 for further details).

6.3.3 Doses to site residents (intact cap)

288. The scenario where housing is built on the site but leaves the cap intact is discussed here. The scenario where housing is built on the site but the cap and some waste have been excavated is discussed in section 6.3.4. The complete results for site residents arising from gas released from the wastes and through external irradiation are presented in Appendix E (see Table 143). Note that these results include the effects of radioactive decay and ingrowth after 150 years (the assumed time between site closure and the approval of housing development on the site) upon the calculated doses. This is a very cautious assessment because housing is very unlikely to be constructed on reclaimed land that has been subjected to land raise in the estuary, particularly because it is clearly obvious that the landform is not natural.

289. The ten highest doses are shown below and are dominated by the gas pathway (Table 22). In the case of Ra-226, the dominant pathway is inhalation of radon gas and results are given for wastes containing two different Ra-226 activity concentrations, reflecting the emplacement strategy. Wastes containing up to 200 Bq g^{-1} of Ra-226 (labelled high content) are disposed of at a depth greater than 5 m and the resulting doses from radon are insignificant because the radon decays in the soil before it reaches the surface. Waste containing Ra-226 activity concentrations of <5 Bq g^{-1} can be disposed of at any depth (labelled low content) and results in a dose from the radon gas that is generated from decay of Ra-226 in wastes within 5 m of the restored surface. The impact of disposing of Ra-226 at depth (below 5 m) is discussed further in Section 6.3.5.

290. The highest dose per unit disposal is from C-14 and all doses are below the dose guidance level for intrusion. The gas model is very conservative since it makes no allowance for the impact on gas migration of either an intact cap or the concrete raft on which the house is built. These physical barriers will reduce gas migration and doses significantly. This scenario does not constrain the radiological capacity.

Table 22 Site resident exposure – cap intact

Radionuclide	Radiological capacity (MBq)	Dose (mSv y^{-1} MBq^{-1})			Dose from maximum inventory (mSv y^{-1})
		Gas*	External	Total	
C-14	$1.87\ 10^{8}$	$2.11\ 10^{-9}$	$2.76\ 10^{-69}$	$2.11\ 10^{-9}$	$3.95\ 10^{-1}$
Mo-93	$1.44\ 10^{9}$		$8.30\ 10^{-12}$	$8.30\ 10^{-12}$	$1.19\ 10^{-2}$
H-3	$6.43\ 10^{9}$	$1.62\ 10^{-13}$		$1.62\ 10^{-13}$	$1.04\ 10^{-3}$
Nb-93m	$5.06\ 10^{10}$		$2.38\ 10^{-15}$	$2.38\ 10^{-15}$	$1.21\ 10^{-4}$
Ra-226** (high content)	$3.89\ 10^{6}$	$4.68\ 10^{-14}$	$3.74\ 10^{-33}$	$4.68\ 10^{-14}$	$1.82\ 10^{-7}$
Th-232	$7.95\ 10^{6}$		$4.39\ 10^{-18}$	$4.39\ 10^{-18}$	$3.49\ 10^{-11}$
Th-229	$2.88\ 10^{7}$		$1.93\ 10^{-20}$	$1.93\ 10^{-20}$	$5.56\ 10^{-13}$
U-232	$4.04\ 10^{8}$		$1.45\ 10^{-22}$	$1.45\ 10^{-22}$	$5.85\ 10^{-14}$

Radionuclide	Radiological capacity (MBq)	Dose (mSv y^{-1} MBq^{-1})			Dose from maximum inventory (mSv y^{-1})
		Gas*	External	Total	
Ag-108m	2.65 10^{8}		1.34 10^{-22}	1.34 10^{-22}	3.55 10^{-14}
Th-230	1.98 10^{6}		1.54 10^{-20}	1.54 10^{-20}	3.05 10^{-14}

* Conservative estimate ignoring the effect of the cap

** The gas dose shown for Ra-226 is from the release of Rn-222.

6.3.4 Doses to site occupants at 150 or 200 years (cap excavated)

291. This section considers the doses to site occupants after excavation works have removed the cap and some of the waste. The dose rates to residents on the site following construction of houses 150 years after the period of authorization (section E.5.6) and to a smallholder on the site 200 years after the period of authorization (section E.5.8), are summarised in Table 23 for the ten radionuclides giving rise to the highest doses at the radiological capacity for each scenario. The table also includes waste containing two different Ra-226 activity concentrations to indicate the doses from placement at different depths. The doses shown in Table 23 for Ra-226 (high content), i.e. up to 200 Bq g^{-1}, are due to radon coming from a depth of 4 m: it is assumed that the placement of Ra-226 (high content) below the intrusion depth (i.e. 5 m below the surface), followed by excavation of a depth of 1 m across the site, would leave 4 m of cover in place. It is assumed that wastes containing Ra-226 up to 5 Bq g^{-1} could be disposed of without restriction on the depth of disposal in the landfill. It is assumed that there is dilution of this low content Ra-226 as a result of the excavation (a dilution factor of 0.096 is used). The sensitivity of the intrusion doses and radon release to the radium placement depth within the landfills is discussed below (see Section 6.3.5).

Table 23 Doses to site residents after 150 years or smallholders after 200 years

Radionuclide	Radiological capacity (MBq)	Resident (150 y)		Smallholder (200 y)	
		Dose per MBq (mSv y^{-1} MBq^{-1})	Dose from the maximum inventory (mSv y^{-1})	Dose per MBq (mSv y^{-1} MBq^{-1})	Dose from the maximum inventory (mSv y^{-1})
Cl-36	1.56 10^{8}	1.60 10^{-9}	0.3	1.92 10^{-8}	3.0
Ca-41	5.77 10^{9}	2.44 10^{-11}	0.1	6.21 10^{-11}	0.4
Ni-59	1.95 10^{11}	5.44 10^{-13}	0.1	5.92 10^{-12}	1.2
Ni-63	2.42 10^{11}	4.76 10^{-13}	0.1	3.67 10^{-12}	0.9
Se-79	8.98 10^{8}	1.43 10^{-9}	1.3	3.34 10^{-9}	3.0
Mo-93	1.44 10^{9}	2.11 10^{-10}	0.3	2.04 10^{-9}	2.9
Zr-93	3.12 10^{11}	1.05 10^{-12}	0.3	2.03 10^{-12}	0.6
Tc-99	6.12 10^{8}	2.44 10^{-9}	1.5	4.90 10^{-9}	3.0

Radionuclide	Radiological capacity (MBq)	Resident (150 y)		Smallholder (200 y)	
		Dose per MBq (mSv y^{-1} MBq^{-1})	Dose from the maximum inventory (mSv y^{-1})	Dose per MBq (mSv y^{-1} MBq^{-1})	Dose from the maximum inventory (mSv y^{-1})
Ag-108m	2.65 10^{8}	1.01 10^{-9}	0.3	1.08 10^{-9}	0.3
I-129	3.01 10^{8}	1.97 10^{-9}	0.6	9.97 10^{-9}	3.0
Ra-226* (high content)	3.89 10^{6}	1.15 10^{-14}	4.48 10^{-8}	8.22 10^{-9}	3.20 10^{-2}

* Assuming that wastes containing significant activity concentrations of Ra-226 are 5m below the restored surface

292. For the smallholder, the calculations apply critical group consumption rates to the two foodstuffs that give the greatest contribution to the dose, and mean consumption rates to all other foodstuffs. The two foodstuffs giving the highest dose rate varies from radionuclide to radionuclide, for example for U-232 and the higher atomic number actinides they are root vegetables and green vegetables. There are also a small number of radionuclides where animal products are included in the two foodstuffs resulting in the highest dose rates (e.g. Cl-36, Ca-41 and Mo-93). For the resident, the calculations assume that the consumption rate of root vegetables and green vegetables grown in the garden is 50% of the mean consumption rate, a conservative assumption for a household resident where most food is purchased rather than grown on site.

293. The assessment calculations presented for the smallholding scenario also include a gas contribution based on gas migration from underlying waste and in the case of radon from excavated waste remaining directly under the house. The average timescale for gas release of H-3 and C-14 used were 50 y and 900 y, respectively.

6.3.5 Dose to site occupant from Radium when building on waste/spoil mix

294. The site occupant scenario was also evaluated assuming that there was no radium emplacement strategy placing significant radium bearing wastes at a particular depth. Hence, it assumed that a house was built on Ra-226 contaminated waste or spoil excavated from the site. This scenario is described in Appendix E (Section E.5.7) and results are presented in Table 148. Specifying that wastes containing > 5 Bq g^{-1} Ra-226 are disposed of below the excavation depth will ensure that the average activity concentration in any excavated wastes would meet the dose criterion. This scenario does not consider exposure to the wastes remaining in the site since this is addressed above. Hence, this scenario does not impose a restriction on the Ra-226 activity concentration in the waste below the excavated depth.

295. Since the scenario is only relevant if a dwelling is built on a spoil/waste mixture containing radium bearing waste, waste emplacement strategies within waste cells can be employed to ensure that waste containing > 5 Bq g^{-1} radium is not excavated from the site. If it is cautiously assumed that the maximum depth of any human intrusion

event is 5 m, then ensuring that waste containing >5 Bq g^{-1} (significant radium bearing waste) is placed at depths greater than this will prevent mixing of the waste with excavated spoil, and in these circumstances, this scenario is no longer credible. Hence waste emplacement strategies (i.e. placing significant radium bearing wastes no less than 5 m below the restored surface of the waste cells) are applied for radium bearing wastes at Port Clarence.

296. The possibility of radon migration from buried radium bearing wastes through the remaining cell-filling material is also considered. This is the same type of calculation as considered in Appendix E, Section E.3.5, but considering migration of radon through cell-filling material (i.e. soil, soil-like waste and other non-radium bearing wastes) instead of considering radon migration through the intact cap. The assessment assumes that all the radon gas only has on average to migrate through 4 m of cover material and ignores the effect of house foundations and impermeable membranes designed to prevent radon ingress. If all radium bearing wastes were placed at depths of greater than 5 m, then this would result in radon migrating through at least 4 m of cell-filling material and as the thickness increases, i.e. the cover depth increases, the dose from radon declines due to radioactive decay during migration. Therefore, the assessment represents a very cautious estimate of the dose since significant radium bearing wastes will be placed at various depths from 5 m below the restored surface.

6.4 Heterogeneity of waste

297. The waste that is expected to be sent to Port Clarence for disposal may not be uniformly distributed throughout the consignment. A series of scenarios have therefore been considered to look at the potential dose that could arise from different types of waste that may be sent to the site for disposal. These assessments are independent of whether disposal occurs to the hazardous or non-hazardous landfill and are uncertain to occur but have been assumed to have a probability of occurrence equal to unity. In this section the disposal of large items, discrete (smaller) items and particles are considered (see Table 24).

Table 24 Summary of radiological assessment scenarios for different waste forms

Scenario	Exposed group
Exposure to heterogeneously contaminated large objects following intrusion or erosion	Worker/ Member of public
Exposure to discrete items following erosion	Member of public
Exposure to particles following erosion	Member of public

6.4.1 Large items

298. Concrete slabs or blocks from decommissioning buildings and rubble from demolition of buildings used for the storage or conditioning of radioactive wastes may become contaminated. Such contamination may be restricted to the surface layers of the concrete, but the depth of penetration will depend on the nature of the waste or conditioning process (e.g. wet or dry facilities), the period of time the facility was in

use, the building material (and any surface treatment such as painting or other sealants) and the chemical properties of the radionuclide fingerprint. Best practice is to remove the contaminated surface layer of the building before demolition and dispose of it separately from the rest of the building material, so avoiding significant inhomogeneity in the waste.

299. Characterisation of wastes is always subject to some uncertainty. Wastes can be homogenised or representatively sampled to obtain an overall averaged activity concentration. To determine activity distributions within heterogeneously contaminated wastes they can be sub-sampled or, for large items, cores can be extracted and the depth of contamination, or depth profiles of contamination, can be determined. However, this can be a laborious and expensive undertaking, and considerable uncertainty may remain if there is spatial as well as penetrative heterogeneity in the activity distribution.

300. To consider the potential effects of a range of assumptions regarding the distribution of activity within wastes, the ESC considers some example heterogeneous large items and demolition rubble. This is the same approach used for the ENRMF ESC. A number of different cases are considered, including: a hypothetical concrete block contaminated with Cs-137; concrete blocks from decommissioning (with different radionuclide fingerprints); and, rubble and crushed concrete from building demolition (with different radionuclide fingerprints). Sensitivity to assumed depth profiles for distribution of activity is explored (see Appendix E, Section E.6.1).

301. Drilling through waste or exposure of waste (through natural processes of erosion or through deliberate human activity) could lead to exposure to heterogeneously contaminated material through external exposure or inhalation of dust or inadvertent ingestion of dust. The contamination is assumed to be in the exposed top surface 1 cm of the item.

Intrusion

302. The assessment considers the case where one or more boreholes drilled on the site after the end of the period of authorisation may penetrate the contaminated items and waste is retrieved for laboratory analysis. The driller may handle the retrieved core leading to both an organ dose (skin on the hand) and a whole-body effective dose. In addition, dust from the core may be inhaled and inadvertent ingestion may occur. The principal considerations in determining the resulting dose are time spent handling or in proximity to the core and, for determining the whole-body effective dose, the averaged distance from the core.

303. The dose at 60 years is compared to the human intrusion dose guidance values of 3 to 20 mSv (with the lower value being applicable for doses that may occur over extended periods). The doses from the example large items were all well below this.

Erosion

304. A hypothetical date for ‘natural’ erosion exposing the waste was used to illustrate the impact of erosion followed by exposure of a site occupier to the contaminated surface.

Erosion is not expected to happen until around the year 4500 at the earliest and therefore the hypothetical date was 2,000 years post closure. Extrapolating the dose out to 2,000 years gives a dose estimate of 0.03 mSv y^{-1} (dominated by the ingestion and inhalation of dust containing Pu-239 for the example waste item). This dose is equivalent to an annual risk of around 1.5 10^{-6}. Given the grossly conservative nature of the assumption that the contaminated surface 1 cm is uniformly exposed, it is considered that this risk is broadly consistent with the risk guidance criterion of 10^{-6} for the post-closure period.

6.4.2 Discrete items

305. This scenario is included due to the possibility that the site will be eroded by the sea, and walkers along the bank of the estuary near the site may then come into contact with discrete items of waste that have become exposed. Erosion is not expected to happen until around the year 4500 at the earliest. This scenario is not used to constrain landfill capacity. However, it places limits on the radioactivity of specific discrete items within consignments.

306. LLW Repository Ltd (LLWR Ltd, 2013) define ‘discrete items’ as “a distinct item of waste that, by its characteristics, is recognisable as unusual or not of natural origin and could be a focus of interest, out of curiosity or potential for recovery and recycling/re-use of materials should the waste item be exposed after repository closure.” This definition is adopted in this assessment.

307. Examples of discrete items given by LLWR (LLWR Ltd, 2013) are hand tools, engineered items and equipment of durable materials (such as may be disposed with other wastes in drums for grouting or high-force compaction, or directly to a Disposal Container); grouted drums or pucks from high-force compaction; and large metal items, e.g. steel beams and plates, pipework, shielding, heavy equipment and flasks (but not general scrap metal) such as may be disposed directly to a Disposal Container.

308. A discrete item has the potential to modify the behaviour of a person that encounters it, i.e. it is visible and therefore an individual may deliberately go towards and inspect, or (if small enough) pick up the item. This is different from the standard assessment calculations in which the estuary bank user carries out activities on the bank without regard to the presence of the waste or the radioactive hazard it may pose. Thus, two situations can be envisaged: a casual encounter with a single item and a situation where a person deliberately seeks out, collects, takes away or disrupts discrete items. However, the future behaviour of people that might lead to them encountering radioactive discrete items uncovered by natural disruptive processes cannot be predicted, and so the probability of exposure cannot be quantified. In this respect, the exposure situation is similar to that of inadvertent human intrusion. Exposure to discrete items exposed by natural processes is specifically addressed in Requirement R12 of the Environment agencies GRR ((Environment Agencies, 2018)), which specifies that the results of illustrative calculations are compared with the dose guidance level for inadvertent human intrusion (3 mSv to 20 mSv); however this guidance relates to the clean-up of nuclear licensed sites, and does not apply to waste disposal sites.

309. The dose criteria used in this assessment is the effective dose of 20 µSv y^{-1}, which corresponds to the risk guidance level specified in the GRA, assuming a probability of unity. This is appropriate for an assessment of the dose as a result of a casual encounter with a single item. The results of the dose calculations are used to determine limits on the activity on discrete items that can be accepted for disposal at Port Clarence. The proposed Discrete Item Limits will provide adequate protection to a potential future estuary bank user.The radionuclide groups and discrete item limits for each group are given in Table 25 and Table 26, respectively.

Table 25 Radionuclide groups for Discrete Item Limits at Port Clarence

Parameter	Radionuclides
Group a	Nb-94 Sn-126 Ra-226 Th-229 Th-230 Th-232 Pa-231 Pu-244 Cm-248
Group b	Ag-108m I-129 U-232 U-233 U-235 U-238 Np-237 Pu-239 Pu-240 Pu-242 Am-243 Cm-245 Cm-246
Group c	Cl-36 Se-79 Sm-147 U-234 U-236 Pu-238 Am-241 Am-242m
Group d	C-14 Ca-41 Sr-90 Mo-93 Zr-93 Tc-99 Cs-135 Cs-137 Pb-210 Ac-227 Pu-241 Cm-243 Cm-244
Group e	H-3 Mn-54 Fe-55 Co-60 Ni-59 Ni-63 Zn-65 Nb-93m Ru-106 Ag-110m Cd-109 Sb-125 Sn-119m Sn-123 Te-127m Ba-133 Cs-134 Ce-144 Pm-147 Sm-151 Eu-152 Eu-154 Eu-155 Gd-153 Po-210 Ra-228 Th-228 Cm-242

Table 26 Discrete Item Limits for Port Clarence

	Weight 1 kg or less	Weight between 1 and 100 kg	Weight 100 kg or greater
Group a	0.0001 GBq	0.1 GBq te^{-1}	0.01 GBq
Group b	0.001 GBq	1 GBq te^{-1}	0.1 GBq
Group c	0.01 GBq	10 GBq te^{-1}	1 GBq
Group d	0.1 GBq	100 GBq te^{-1}	10 GBq
Group e	1 GBq	1000 GBq te^{-1}	100 GBq

Sum of fractions for discrete item limits

310. In the first instance, waste consignors should determine whether any items within a consignment should be classified as a discrete item. Guidance on what can be classified as a discrete item can be obtained by consulting LLW Repository Ltd's

Discrete Item Library (LLWR Ltd, 2019). Waste consignors would also contact Augean Ltd for guidance.

311. Based on the activity of each radionuclide on the item and the Discrete Item Limits for the item, a Sum of Fractions approach to determine acceptability of that item should then be used.

312. The Sum of Fractions is given by:

$$\text{SoF} = \frac{Q_a}{L_a} + \frac{Q_b}{L_b} + \frac{Q_c}{L_c} + \frac{Q_d}{L_d} + \frac{Q_e}{L_e},$$

where Q_n is the total activity of group n radionuclides on the item and L_n is the Port Clarence Discrete Item Limit for that group (given in Table 26).

313. If a radionuclide is known to be present on an item, is not listed in Table 25 and has a half-life greater than 200 years then the radionuclide should be cautiously assigned to Group a. Otherwise it should be assigned to Group e, unless it decays to an alpha-emitting daughter with a half-life a few tens to hundreds of time the parent half-life, in which case ingrown progeny are liable to determine the impact at 2400 years.

314. If this Sum of Fraction is less than one, the item is acceptable for disposal within a consignment at Port Clarence, subject to meeting other Waste Acceptance Criteria and the consignment specific activity limits (Bq g^{-1}).

6.4.3 Particles

315. Assessments have been undertaken to calculate the dose that could occur from the disposal of waste containing radioactive particles at Port Clarence. Radioactive particles are small items that could be as small as a grain of sand that could be incorporated in a radioactive waste stream or package. The possibility that future intrusion events could lead to unintentional recovery of, and exposure to, radioactive particles is considered. Migration of particles in groundwater or uptake from soil into the food chain is not considered credible.

316. The methodology for assessing the dose implications of excavating waste materials that include particles is described in Appendix E (Section E.6.3).

317. The methodology for assessing the dose implications of exposure to waste materials that include particles following erosion is described in Appendix E (Section E.6.4).

318. It is not possible to determine generic waste acceptance criteria for waste containing particles as the characteristics of the particle (e.g. nuclides, size, solubility) will be specific to the consignment. Therefore waste containing particles will be considered on a case by case basis.

319. Decisions regarding acceptance for waste containing high activity particles can be made by comparison of the results of dose calculations for the activity on the particle

with the NS-GRA intrusion dose guidance level. The ingestion dose and external (whole body) dose are therefore compared to the annual dose guidance level of 3 to 20 mSv. The exposure is regarded as a 'one-off' event and hence the appropriate dose guidance value would lie towards the upper end of the range cited.The dose from contact with the skin is compared with the 50 mSv annual dose limit for the equivalent dose to skin for members of the public, as specified in the NS-GRA. Wastes that do not meet these dose guidance levels are not accepted without specific approval from the Environment Agency. Demonstration that the disposal route adopted represents BAT would also be required.

320. The waste acceptance procedure is therefore described by the following steps:

Use the particle assessment spreadsheet tool to assess the dose from the type of particle in the waste.

Identify the package and consignment activity concentration limits relevant to the nuclides in the package.

For ESC radionuclides where the ingestion dose is less than 3 mSv, the external dose to whole body is less than 3 mSv, the skin dose due to external exposure is less than 50 mSv, and the package and consignment meet their respective activity concentration limits, a consignment of particles may be disposed of without consulting the Environment Agency.

Where the ingestion dose is between 3 mSv and 20 mSv or the external dose to whole body is between 3 mSv and 20 mSv, then the Environment Agency should be consulted.

Where the ingestion dose is above 20 mSv or the external dose to whole body is above 20 mSv or the skin dose due to external exposure is above 50 mSv the consignment would not be acceptable for disposal.

For radionuclides not considered in the ESC or where alternative f1 values or low solubility are proposed then the Environment Agency should be consulted.

6.5 Optimisation {R8}

6.5.1 Introduction

321. The NS-GRA requires that radiological risks are as low as reasonably achievable (Requirement 8):

> The choice of waste acceptance criteria, how the selected site is used and the design, construction, operation, closure and post-closure management of the disposal facility should ensure that radiological risks to members of the public, both during the period of authorisation and afterwards, are as low as reasonably

achievable (ALARA), taking into account economic and societal factors. (UK Environment Agencies, 2009), para 6.3.56

322. The requirement for optimisation in relation to radiological risk may be considered at three levels.

The design of the Port Clarence landfills is consistent with best practice and regulatory requirements for the disposal of hazardous and non-hazardous, as appropriate and may therefore be considered to be optimised.

We have considered a number of specific ways in which the management and the design of the site may be enhanced to achieve an optimised solution for the disposal of radioactive wastes.

Waste consignors are required to manage wastes in a manner consistent with BAT and must demonstrate that disposal to Port Clarence is an optimal solution and hence consistent with BAT.

323. The first two aspects are discussed below, noting that the third is a matter for consignors.

324. Key aspects of the design of the Port Clarence landfills include the following.

A full containment landfill engineering system designed to meet the requirements of the EU Landfill Directive which is BAT. This requires a basal lining system with, or equivalent to having, a hydraulic conductivity of 1 10^{-9} ms^{-1} or lower and a thickness of no less than 1 m or alternative engineering system which provides a level of environmental protection which meets the groundwater quality criteria set in the EU Groundwater Directives. For the basal liner, the non-hazardous landfill incorporates a 1 m thick layer of reworked, engineered clay (1.5 m for the hazardous landfill) with a maximum hydraulic conductivity of 1 10^{-9} ms^{-1} and a 2 mm HDPE synthetic liner. The sidewalls are formed from low permeability engineered clay materials with the HDPE liner placed over these.

A low permeability cap consisting of a regulation layer of 300 mm of soil or clay over the waste, a geosynthetic clay liner, a geotextile protection layer, and at least one metre of restoration soil cover.

Arrangements for the management of leachate.

Arrangements for dealing with landfill gases.

Ancillary systems such as vehicle cleaning equipment.

A systematic approach to monitoring surface water, groundwater and environmental impacts.

The landfill site will be restored to areas of woodland, scrub and grassland with short turf grassland, ruderal grassland, areas of open water, aquatic marginal vegetation and wet meadow in the wider site, so that it is suitable for nature conservation use with public access.

Operational arrangements for site construction, operation, closure, restoration and aftercare.

325. These design attributes and arrangements accord with the Environmental Permitting Regulations. The standard design and approach set out in these regulations, which are the basis of the implemented design and approach at the Port Clarence, are the output of an extensive process. The design features and arrangements provide an appropriate strategy to limit the environmental impacts arising from non-radioactive contaminants. In the context of the assumed timescales and approach to landfill risk assessment, these measures will also be effective in limiting the environmental impacts arising from radioactive contaminants. In this sense, the design of the facility may be considered to have been optimised with respect to the release of radioactive contaminants and the arising radiological impacts.

326. As the design of the facility is already recognised as consistent with good practice for landfills meeting BAT and the hazards associated with the proposed disposals of radioactive waste are low (and meet the relevant guidance levels), a detailed and systematic analysis of alternative design and management strategies for the facility has not been undertaken. Rather, the focus has been on consideration of a number of specific alternatives that arise if radioactive wastes are to be disposed. These are discussed in the following subsections.

6.5.2 Alternative strategies for waste emplacement

327. Most large scale human intrusion events (see Section 6.3) only disturb the ground to a limited depth of a few metres and hence if the radioactive waste is placed below that depth then such intrusion events will not disturb it. This is particularly important for radium-bearing wastes, which can give rise to doses from radon if buildings are constructed on waste that has been distributed on the surface as a result of a human intrusion event. Strategies that place the majority of the radioactive waste below the intrusion depth e.g. below 5 m of the restored surface will reduce doses from intrusion.

328. Intrusion doses are dependent on the activity concentration in the material that is excavated and therefore waste emplacement strategies that result in wastes with lower activity concentrations being placed within the top of the site (within the intrusion depth) or co-disposal of radioactive and non-radioactive wastes within this depth will also minimise doses from intrusion.

329. The doses from the other scenarios depend on the total activity in the landfill site and are therefore not affected significantly by waste emplacement strategies relating to depth of disposal.

330. It is therefore proposed that wastes with significant radium content above 5 Bq/g should be emplaced under at least 5 m of cover. Waste emplacement strategies for other radioactive wastes would be considered if required, bearing in mind the current sequence of cell filling and the importance of intrusion scenarios compared with other exposure scenarios for the radionuclides in the wastes.

6.5.3 Operational strategies

331. A number of approaches have been implemented to manage and optimise potential radiological impacts during operations. Some of the key approaches are discussed in the following paragraphs.

332. The waste packages reduce the probability of doses during operations, reduce leaching post-closure and increase the prospect of the waste being recognised as hazardous during future intrusion. The activity concentration associated with loose tipped waste is limited to a lower value so that disposals cannot result in unacceptable doses. Dust suppression is used where required.

333. The limit on putrescible materials accepted at the hazardous landfill ensures that microbial activity is minimised and gaseous release from microbial action or from fire leading to a dose is also minimised.

334. Augean requires the surface of waste packages to be clean to ensure dusts do not represent a hazard. Wastes placed in the landfill are also covered daily to reduce external exposure. A check is also undertaken on dose measurements at 1 m above the surface of the covered LLW, to ensure exposure of less than 2 μSv hr^{-1}. The depth of cover will be increased if necessary to ensure that this limit is not exceeded. These precautions will provide additional confidence that no specific protective measures are needed for workers at the site who are closest to the LLW and will provide additional confidence that anyone off site also is suitably protected.

335. Operational constraints have been put in place to restrict the placement of waste in a landfill cell, placing non-radioactive waste to a specified depth at the base (2 m), sides (2 m) and top (1 m) of a cell. This creates a barrier between the LLW and the side liner of a waste cell which will need to be located when the cell is capped. It also means that all LLW will be 2.3 m or greater below the restored surface of the site. An additional limitation is proposed for wastes with significant radium contamination. Such wastes will be disposed at least 5 m below the restored surface of the site. This places radium below a reasonable excavation intrusion depth and reduces the potential dose due to radon gas release from material extracted from the landfill during intrusion.

336. The profiling of the restored surface will encourage surface runoff, preventing the development of puddles and reducing infiltration. The geographical position of the site means that it is unlikely to see any housing development at the site.

6.6 Environmental radioactivity {R9}

337. A radiological assessment of the potential effects on non-human biota (NHB) from the disposal of LLW at Port Clarence has been undertaken using the ERICA (Environmental Risk from Ionising Contaminants: Assessment and Management) Assessment Tool. The ERICA tool is a software system that has a structure based upon the tiered ERICA Integrated Approach to assessing the radiological risk to terrestrial, freshwater and marine biota. The most recent update was uploaded in June 2019, and that is the version of the tool used in this assessment.

The ERICA toolkit allows consideration of three ecosystems: terrestrial, freshwater and marine. All these ecosystems are applicable to the environment surrounding the Port Clarence site and are considered in the ESC. Within these ecosystems, the ERICA tool considers a range of organisms and wildlife groups as shown in Table 27.

Table 27 Wildlife groups considered in the ERICA tool

Terrestrial	Freshwater	Marine
Amphibian	Amphibian	Benthic Fish
Annelid	Benthic fish	Bird
Arthropod - detritivorous	Bird	Crustacean
Bird	Crustacean	Macroalgae
Flying insects	Insect larvae	Mammal
Grasses and herbs	Mammal	Mollusc - bivalve
Lichen and bryophytes	Mollusc – bivalve	Pelagic fish
Mammal large	Mollusc – gastropod	Phytoplankton
Mammal small – burrowing	Pelagic fish	Polychaete Worm
Mollusc - gastropod	Phytoplankton	Reptile
Reptile	Reptile	Sea Anemones &True Coral
Shrub	Vascular plant	Vascular Plant
Tree	Zooplankton	Zooplankton

338. During the operational and active management phases, radioactivity could be released to the biosphere as gas (e.g. landfill gas production may result in C-14 labelled carbon dioxide or tritiated hydrogen gas), or in discharges from leachate treatment facilities. After the period of authorisation, the majority of releases of radioactivity are likely to be associated with groundwater or as a result of intrusion into the waste.

339. Input data for the NHB dose assessment are radioactivity concentrations in soil and air (terrestrial ecosystem assessment) and water or sediment (freshwater and marine ecosystem assessment). The activity concentrations of radionuclides in soil and water are calculated using the same approaches underlying the dose calculations to the public.

340. The impact on burrowing animals that dig into the waste is also considered.

6.6.1 Marine ecosystem

341. An assessment of a marine ecosystem was considered to be representative of the estuary close to the Port Clarence site. Tier 1 assessment was performed, with Tier 2 for Ca-41. All risk quotients are well below 1, therefore NHB in the estuary are considered to be sufficiently protected.

6.6.2 Freshwater ecosystem

342. There is an existing freshwater pond at the north-west corner of the site and further ponds are planned, as shown in Figure 7. Radionuclides may be transferred to these

bodies from the landfill via by water that has become contaminated assuming that leachate from the landfill overtops the liner (the bathtubbing scenario, see subsection 6.2.2.2).

343. The activity concentration in the pond was cautiously assumed to be equal to the peak activity in water in the GoldSim 'topsoil' compartment for each radionuclide, calculated using the GoldSim model (see Subsection E.4.3.5), reduced by the following factors:

A factor of 100 to account for transport to the upper soil layers, as discussed in paragraph 888.

A factor of 10 to account for losses between the overflow point and the pond, and dilution in pond water. This factor was determined by modelling transport from the overflow point to the existing pond. There was a reduction in activity concentration in the pond compared to the topsoil compartment at the bathtubbing point that varied from a factor of 10 to a factor of 1 10^{13}. and much more than 10 for some radionuclides, depending on their mobility. A factor of 10 was conservatively used in the assessment.

344. A Tier 2 assessment was carried out to determine the risk quotients for each radionuclide for all organisms based on a screening level of 10 µGy h-1. The most restrictive organism was selected.

345. For U-234, the dose rate is slightly larger than 40 µGy h^{-1}. Since the factor required to reduce the dose rate to 40 is 1.07 and the dose arises from the bathtubbing scenario, the radiological capacity for U-234 was not adjusted.

6.6.3 Terrestrial ecosystem

346. Peak radionuclide concentrations in soil for the terrestrial ecosystem assessment were taken from the GoldSim results for the bathtubbing scenario (see Section E.4.3.8). For C-14 and H-3, activity concentrations in air (Bq/m^3) from the gas operations scenario were also used to calculate doses to NHB. The soil and air concentrations for each radionuclide were then scaled to account for the maximum inventory of each radionuclide. Activity concentrations for radionuclides that were ingrown through radioactive decay were calculated separately.

347. The ERICA assessment tool was then used to calculate a risk quotient for each radionuclide, using the Tier 1 assessment. It was found that a Tier 2 assessment was required as dose rates were too high for some of the Tier 1.

348. The dose rates from U-236 and U-238 are slightly larger than 40 µGy h-1, with rates of 48 µGy h^{-1} and 52 µGy h^{-1} respectively. U-238 is limited to an activity concentration of 200 Bq g^{-1}, as discussed in Subsection 7.4.2.2. Using this activity concentration, the total amount of U-238 activity that could be placed within Port Clarence is less than the capacity calculated based on exposure scenarios. When this lower total activity is used to calculate the dose rate, the dose rate from U-238 reduces to 8.2 µGy h^{-1}. Hence, no adjustment is needed to the radiological capacity of U-238.

349. U-236 is a minor constituent of LLW and the typical content is a factor of 10 less than that of U-238 (see Table 45). Hence, based on a realistic waste composition, terrestrial non-human biota are sufficiently protected.

6.6.4 Animals burrowing into landfill

350. The assessment undertaken for burrowing animals using the ERICA model is generic and applies to burrowing species that could burrow deep enough to reach the LLW (at least 2.3 m below the surface). Badger tunnels can be four metres deep, though most are less than one metre deep. Rabbit warrens can be up to 3 m deep. Hence it is appropriate to consider rabbits and badgers in the assessment and the results calculated for rabbits are assumed to be applicable to badgers. Other burrowing animals (mice, voles, moles) have a maximum burrow depth that is less than 1 m and therefore will not burrow into the waste.

351. We note that in their review of the ENRMF ESC, the EA commented that it would be precautionary to apply radiological capacity reduction factors based on the ERICA Tier 2 assessment for burrowing animals.

352. A Tier 2 assessment was carried out within ERICA to calculate a risk quotient for each radionuclide for burrowing mammals.

353. There are 26 radionuclides for which the dose rate to the burrowing mammal is greater than 40 µGy h^{-1}, by up to two orders of magnitude. As such, the radiological capacities were reduced to ensure that dose rates to burrowing mammals would be below 40 µGy h^{-1}. This ensures that burrowing mammals will be sufficiently protected.

354. The alternative is to ensure that wastes containing these radionuclides is buried at a depth below the surface that is greater than 4 m. This will ensure that rabbit warrens or badger tunnels will not enter the waste. The radiological capacity without this reduction is considered as a sensitivity Appendix E.

7 Technical Requirements

355. In this section protection against non-radiological hazards at the site is considered. The section then considers the development of the site and the operational aspects of non-hazardous waste, hazardous waste and LLW operations. Waste acceptance criteria and conditions that would apply to LLW disposals are considered. The last part of this section looks at site monitoring.

7.1 Protection against non-radiological hazards {R10}

356. The NS-GRA includes a requirement that the ESC demonstrates that adequate protection against non-radiological hazards is achieved (Requirement 10):

> "The developer/operator of a disposal facility for solid radioactive waste should demonstrate that the disposal system provides adequate protection against non-radiological hazards." (UK Environment Agencies, 2009) para 6.4.1

357. Paragraph 6.4.2 of Requirement 10 states that:

> "Some waste disposed of at a facility receiving radioactive waste may be potentially harmful wholly or partly because of its non-radioactive properties. There are nationally acceptable standards for disposing of hazardous waste. However, these standards may not be suitable to apply directly to waste that presents both radiological and non-radiological hazards. Accordingly, these standards need not necessarily be applied, but a level of protection should be provided against the non-radiological hazards that is no less stringent than would be provided if the standards were applied."

358. The Port Clarence landfill sites are already the subject of Environmental Permits issued and regulated by the Environment Agency which will continue in force for the period over which radioactive waste is deposited. Accordingly all the standards and controls that apply to the disposal of non-radioactive wastes will be applied to the radioactive wastes. The radioactive and non-radioactive wastes will be deposited in the same engineered cells within the boundaries of the currently consented Environmental Permits.

359. The landfill cells are designed to accept hazardous wastes and non-hazardous wastes and the adequacy of the designs is demonstrated through compliance with environmental protection legislation, stability risk assessments, hydrogeological risk assessments, landfill gas risk assessments and amenity impact risk assessments. The controls over the construction of the landfill engineering and landfill cells is specified in a Construction Quality Assurance Plan which is approved by the Environment Agency and construction works are subject to CQA Supervision with the provision of a CQA Verification Report to confirm that each aspect of the cell construction has been carried out in accordance with the specification. The operational procedures including waste pre-acceptance and acceptance, waste placement, site monitoring and site completion and restoration are all controlled through procedures which are implemented through

the Augean Integrated Management System which is necessary as part of the Environmental Permits.

360. The site pre-acceptance and acceptance procedures ensure that no explosive, flammable, corrosive, oxidising or infectious wastes are accepted at the site. The hazardous wastes accepted at the hazardous waste landfill site are largely hazardous due to harmful, toxic, carcinogenic, irritant or eco-toxic properties. The established procedures for the safe handling and disposal of the non-radioactive hazardous and non-hazardous wastes accepted at the site are similar to those necessary for the handling of LLW and enhance rather than conflict with them.

361. The arrangements for construction design, waste acceptance, groundwater protection, landfill gas management, leachate management, landfill stability, pollution prevention, nuisance prevention, construction quality assurance, maintenance, landfill capping, site restoration, operations, waste handling/placement, security, emergency and accident management plans, monitoring, closure, aftercare and surrender are all the subject of review and regulation by the Environment Agency under the existing Environmental Permits and will continue to be applied. The Environment Agency would not have issued the Environmental Permits for the existing landfill sites if they were not satisfied that suitable environmental management controls were designed and implemented at the site in order that there are no unacceptable impacts on the environment or human health as a result of the landfill disposal activities.

362. The characteristics of the radioactive wastes introduce no additional non-radiological hazards beyond those already assessed and controlled through the designs and procedures implemented through the existing Environmental Permits for the landfill sites. Disposed LLW will otherwise be compliant with Augean's waste acceptance procedure specified in site procedure LLW01 (see Section 7.4.3) relating to the non-radioactive properties of the waste (i.e. the proposal is for the disposal of radioactive wastes that would be classified as inert, non-hazardous or hazardous in terms of their content of non-radioactive materials). The impact of non-radioactive properties of the LLW waste are therefore covered by the HRA assessments.

363. An outline of the key landfill engineering features follows:

A full containment landfill engineering system designed to meet the requirements of the EU Landfill Directive. For the basal liner and side wall liner, the non-hazardous landfill incorporates a 1 m thick layer of engineered low permeability clay with a maximum hydraulic conductivity of 1 10^{-9} ms^{-1} and a 2 mm HDPE synthetic liner. The engineered clay layer is 1.5 m thick for the hazardous waste cells.;

A low permeability cap consisting of a 300 mm regulation layer, a geosynthetic clay liner, a geotextile protection layer and at least one metre of restoration soil cover;

Ancillary systems such as vehicle cleaning equipment;

A surface water, groundwater, gas and environmental monitoring system;

The landfill site will be restored to areas of grassland, scrub and woodland and the wider site will be restored to areas of open water, aquatic marginal vegetation, scrub, wet meadow and ruderal grassland with small hollows, banks and ridges suitable for nature conservation use and permissive public access; and,

Operational arrangements for site construction, operation, closure, restoration and aftercare.

The features and arrangements are not described in detail in this document (see Augean (2014) and references therein).

7.2 Site investigation {R11}

364. The NS-GRA includes a requirement that a site investigation has been undertaken (Requirement 11):

> "The developer/operator of a disposal facility for solid radioactive waste should carry out a programme of site investigation and site characterisation to provide information for the environmental safety case and to support facility design and construction." (UK Environment Agencies, 2009) para 6.4.6

365. The site has been the subject of a number of site investigations to support environmental impacts assessments and site permits. These have characterised the geological and hydrogeological setting of the site and associated development. A summary of the results of site investigations are presented in the HRA (MJCA, 2019a).

366. A baseline survey has been undertaken for background levels of radioactivity in materials on the site. The results from that survey are presented in Appendix B.

7.3 Use of site and facility design, construction, operation and closure {R12}

367. The NS-GRA includes a requirement concerning the management of the facility from design through to closure (Requirement 12):

> "The developer/operator of a disposal facility for solid radioactive waste should make sure that the site is used and the facility is designed, constructed, operated and capable of closure so as to avoid unacceptable effects on the performance of the disposal system." (UK Environment Agencies, 2009) para 6.4.16

368. The design, construction and operation of the site is in accordance with the Landfill Directive as described in Section 2.4 of this report. The Landfill Directive requires that the site provides long term protection of the environment. The risk assessments reported in the HRA show that the site will provide an appropriate level of containment for tens of thousands of years. The site uses conventional landfill rather than novel technologies, which provides confidence in the engineered solution.

369. The Environmental Permit for waste landfill sites cannot be surrendered until the Environment Agency is satisfied that:

the site has ceased accepting waste;

relevant closure procedures have been complied with;

an appropriate period of aftercare has passed to allow the waste to stabilise and to gather evidence to demonstrate that the active pollution control measures are no longer necessary; and,

the deposits of waste are in a satisfactory state that, if left undisturbed, will not cause pollution of the environment or harm to human health.

370. Following closure and into the aftercare phase Augean will continue to manage the site in accordance with the Permit. In accordance with the Landfill Directive and the Environmental Permitting Regulations Augean has agreed with the Environment Agency an approach to providing funds for the aftercare of the site in the event that Augean ceases to exist.

7.3.1 LLW operations

371. Most of the LLW that will be accepted at the site will be at a level of activity that can be transported without the need for any specified packaging or containment. Augean have determined that they will specify that all consignors should send LLW to Port Clarence in ISO containers, drums or double skinned bags except in special circumstances where BAT dictates otherwise. Articles that are too large to be placed in containers will be wrapped. It will be a requirement that the activity measured at 1 m from each package face must not exceed 10 μSv hr^{-1} (micro Sieverts per hour). Where loose tipping is proposed, the activity concentration must meet the more restrictive limits specified in the Permit, the waste must be covered and the 10 μSv hr^{-1} (micro Sieverts per hour) dose rate at 1 m from the waste must be met.

372. Additional precautions will be implemented after the waste is deposited in a landfill cell and has been covered by suitable non-LLW material. Measurements will be made above the surface of the cover material to confirm that the activity measured at 1 m above the surface of the covered LLW would result in an exposure of less than 2 μSv hr^{-1}. The depth of cover will be increased if necessary to ensure that this limit is not exceeded. These precautions will provide additional confidence that no specific protective measures are needed for workers at the site who are closest to the LLW and will provide additional confidence that anyone off site also is suitably protected.

373. Prior to agreement that each specific LLW consignment can be accepted at the site, Augean will require a range of information from the consignor, including detailed characterisation information regarding the physical nature, the chemistry and radioactive content of the waste together with information regarding the quantity, form and proposed packaging of the material. Augean will need to be provided with a copy of the relevant Environment Agency Authorisation or Environmental Permit for the disposal of the waste from the source site. The information will be assessed by Augean Technical Assessors and the site management to determine if the material is suitable

for disposal at the site and is consistent with the conditions of the Environmental Permit. On approval by the Technical Assessor and site management, the consignor will be permitted to make a booking to deliver the waste to the site. The consignor will be advised of the delivery requirements for the waste, including an external exposure limit of 10 µSv hr^{-1} at a 1 m distance from each package.

374. The LLW will be transported to the site in accordance with relevant transport regulations that apply to the radioactive wastes. The regulations are established to control the risks to vehicle drivers and risks from for example transport accidents that could result in waste spillage. Due to the limited amount of radioactivity in the LLW that can be accepted at the site, most wastes will not need any form of special packaging or shielding during handling or transport. However, as noted above, for ease of handling and in order to minimise the potential for spillage, Augean will oblige waste producers to ensure that waste is transported in enclosed containers such as drums, bulk bags or other containers. Similarly, waste with very low activity concentrations (as specified in the permit) could be loose tipped and must be transported in enclosed skips or trucks. Some large items of waste such as metal sheeting or concrete slabs may not be transported in containers but will be wrapped.

375. Prior to the delivery of wastes the timetable and details of the waste will be pre-notified to the site in accordance with the transportation regulations and pre-acceptance checks will be carried out to confirm the suitability of the waste for deposition at the site. Augean will audit the consigning facilities routinely to confirm that the characterisation and packaging procedures are followed. The detailed procedures will be consistent with the requirements of any Environmental Permit issued by the Environment Agency.

376. On arrival at the site and prior to acceptance onto a landfill cell, the RPS will confirm that the characterisation information which accompanies the waste load is adequate, conforms to the pre-acceptance information and that the load is acceptable for deposition at the site. Wastes arriving at the landfill will be subject to a physical check on the integrity of packaging and monitoring to check that the external radiation dose is no more than 10 µSv hr^{-1} at a distance of 1 m from the package. The packages will not be opened or sampled at the site in order to minimise unnecessary exposure. Waste that will be loose tipped will be subject to the external radiation dose check and a physical check to identify whether dust suppression measures will be required.

377. Procedures have been set out to cover the unlikely event that unacceptable wastes arrive at the site. If the wastes can be returned safely to the consignor, they will be refused acceptance at the site and returned to their source. If they may not be safe to return to the sender, quarantine measures will be implemented and the Environment Agency will be notified immediately. The detailed procedures for quarantine are specified in accordance with the radiation protection plan for the site, which is established in accordance with the Environmental Permit and to meet the requirements of the Ionising Radiation Regulations. LLW will not be accumulated intentionally. Waste for disposal will be placed in a landfill cell as soon as practicable after inspection on arrival at Port Clarence and within a maximum of 24 h following acceptance for disposal at the Port Clarence site.

378. Once the waste has been accepted and can be deposited, the delivery vehicle will travel along the internal haul roads to an unloading point adjacent to an active landfill area. The waste packages will be lifted from the delivery vehicles using mechanical handling machines such as fork-lift trucks and placed in the landfill. For waste that will be loose tipped into the landfill, the delivery vehicle will be positioned by the delivery driver as instructed by Augean staff and the driver will activate the tipping as instructed by Augean staff. The waste will be disposed of in the operational working cell or cells and will be placed alongside other waste. The disposal of radioactive waste will take place only under the supervision of an RPS who will be responsible for the operation of the plant at the disposal face.

379. LLW is not placed within 2 m from the base of the cell and the perimeter seal. No LLW is placed within the top metre of the waste in each cell. Wastes containing significant activity concentrations of Ra-226 (i.e.>5 Bq/g) will be placed at least 5 m below the final restored surface (see Appendix E, Section E.5.5.2).

380. Immediately after placement, the deposited LLW will be covered with a minimum thickness of 300 mm of suitable cover material over all exposed surfaces. The radiation levels at 1 m above the top of the cover material will be measured to check conformance with the specified dose rate of 2 μSv hr^{-1}. If the radiation level exceeds the specified dose rate, additional cover will be placed as necessary until the specified dose rate is achieved.

381. As the predicted doses of radiation to which workers at the site will be exposed are below those specified under the Ionising Radiation Regulations 1999 no workers will be defined as Classified Persons in accordance with the regulations. Specific personal protective equipment additional to the standard equipment used and worn by workers at a hazardous waste landfill site will not be necessary during normal site operations. Passive dosimeters will be worn by staff working in the LLW reception and disposal areas as reassurance to confirm that the exposures received are in accordance with the predictions.

NORM Acceptance

382. Port Clarence accepts Type 2 NORM waste under the provisions of the exemption from the requirement to have a permit in through compliance with Section 6 of Part 6 to Schedule 23 of the EPR2016. Following confirmation that the characterisation information is in order, the NORM waste is loose tipped into the working cell. The exposed surface is covered at the end of the working day in accordance with normal landfill procedures.

383. Type 2 NORM waste will not be used as covering material for LLW accepted at Port Clarence under the Permit.

7.4 Waste acceptance criteria {R13}

384. The NS-GRA includes a requirement that the developer/operator of the facility makes sure that the waste accepted for disposal is consistent with the ESC and demonstrates

that there are procedures in place to make sure that these criteria are met before waste is emplaced in the facility (Requirement 13).

> "The developer/operator of a disposal facility for solid radioactive waste should establish waste acceptance criteria consistent with the assumptions made in the environmental safety case and with the requirements for transport and handling, and demonstrate that these can be applied during operations at the facility." (UK Environment Agencies, 2009) para 6.4.26

7.4.1 Introduction

385. It is important that only wastes that meet regulatory criteria are accepted for disposal at the Port Clarence site. Calculations are presented in Appendix E that determine a set of radionuclide-specific limits and Section 7.4.2 discusses how these are used as part of a waste acceptance process. This includes the radiological capacity of the site and limits on the activity concentration in the wastes. Conditions that are placed on waste consignors and specific controls for waste receipt at the Port Clarence site are addressed in Section 7.4.3 and 7.4.4.

7.4.2 Determining Radiological Capacity

7.4.2.1 Methodology

386. Radioactive waste that would be disposed at Port Clarence must be consistent with limits specified in the permit and in the last few years new permits have included activity concentrations, tonnage limits and a radiological capacity.

387. For most scenarios, it is reasonable to take the view that for each radionuclide the total radiation dose is proportional to the total inventory disposed. When contaminants are transported in groundwater or leachate is discharged to a sewer, for example, it is likely that substantial mixing will occur so members of an exposed group are exposed to activity concentrations in environmental media that are a function of an average of those in the landfill. However, for certain cases, it is more reasonable to consider the radiation dose to be proportional to the average activity concentration over some smaller volume of the landfill. This will be true, for example, as a result of growing vegetables on a small plot of contaminated soil where the contamination may derive from only a portion of the disposed waste. This is reasonable because these scenarios involve disruption of the waste and the cap; the exposure mechanism is also likely to result in further mixing of the waste.

388. To account for the possibility that there could be dose contributions from more than one radionuclide at once, a limit is applied that constrains the contribution from each individual radionuclide. This is the radiological capacity. This radiological capacity ensures that the dose and risk criteria are met. The 'sum of fractions' approach is then used to limit the inventory of each radionuclide in the site to ensure that the dose criteria are met.

389. The radiological capacity for each radionuclide is calculated by considering each scenario in turn and deriving the scenario radiological capacity. The radiological capacity is the minimum value over all the scenarios.

390. At Port Clarence there are two landfills, the landfill for non-hazardous waste and the landfill for hazardous waste. Hence, combined effects also need to be considered. We have assumed that the receptor for the hazardous landfill scenario is the same as the receptor for the non-hazardous landfill, for all scenarios. Hence the combined inventory is used in the sum of fractions approach.

Sum of fractions approach

391. A limit, L_{Rn} is defined for each radionuclide corresponding to the total activity within either the hazardous or non-hazardous landfills separately at which the radiation dose from that radionuclide would be equal to the regulatory criterion. The adopted limit is the lowest value calculated from the specified assessment scenarios and is called the radiological capacity.

392. The sum of fractions approach restricts the disposed activity of waste containing radionuclides Rn such that:

$$\sum_{Rn} \frac{I_{Rn}}{L_{Rn}} \leq 1$$

with:

I_{Rn} is the inventory of radionuclide Rn (TBq); and,

L_{Rn} is the limiting radiological capacity for radionuclide Rn (TBq).

393. The radionuclide inventory in the site will be assessed using this sum of fractions and no further radioactive waste will be accepted once the sum equals 1. This is a standard approach, as described in an IAEA technical document (IAEA, 2003) and used in other permits (e.g. CD7914 for the Lillyhall landfill site or FB3598 for the ENRMF).

Scenario radiological capacities

394. The dose and risk criteria used to determine the radiological capacity of the Port Clarence landfills depends on the scenario being considered. In principle, these can be identified as:

for site workers, the dose criteria are the site criterion of 1 mSv y^{-1} (see Section 6.1);

for the public a dose constraint of 300 µSv y^{-1} during the period of authorisation for all exposure pathways other than contamination of groundwater and 20 µSv y^{-1} for exposures based on leachate entering groundwater (see Section 6.1);

in the post-authorisation period a risk criterion of 10^{-6} y^{-1} for the public is indicated in the NS-GRA and this can be considered equivalent to a dose rate of around 20 µSv y^{-1} (see Section 6.2.2); and,

for human intrusion in the post-authorisation period a dose guidance level of 3 mSv y^{-1} is used for prolonged exposure (see Section 6.3).

395. The radiological capacity is the total activity that can be disposed without exceeding the dose criteria specified above.

396. All assessments are based on a disposal of 1 MBq and the results presented as dose per megabecquerel (mSv MBq^{-1} or µSv MBq^{-1}) calculated for each radionuclide considered under each scenario. The appropriate dose criterion divided by the dose per megabecquerel provides the radiological capacity ($L_{Rn, Scenario}$) for a given scenario as:

$$L_{Rn,Scenario} = \frac{Dose_{crit}}{Dose_{Rn,Scenario}}$$

with:

$L_{Rn, Scenario}$ is the scenario capacity for radionuclide Rn (MBq), also referred to as the scenario radiological capacity;

$Dose_{crit}$ is the scenario dose criterion (µSv y^{-1} or mSv y^{-1}); and,

$Dose_{Rn, Scenario}$ is the calculated scenario dose for radionuclide Rn (µSv MBq^{-1} or mSv MBq^{-1}).

397. The limiting (minimum) scenario capacity for each radionuclide is the radiological capacity, the value L_{Rn} in paragraph 388 that is used in the sum of fractions.

398. Port Clarence has two landfills. A radiological capacity is derived for the whole site assuming that it is either a hazardous landfill, or a non-hazardous landfill. The capacity of the non-hazardous landfill takes account of two additional scenarios: a landfill fire and collection of landfill gas for energy production.

399. The radiological capacity for each radionuclide is presented in the tables of results for each scenario.

400. The calculations for a future resident living on a waste/spoil mix implies a limit on the specific activity of Ra-226 bearing wastes that are disposed of within 5 m of the restored surface of the site. This has been incorporated as a waste emplacement strategy for wastes containing > 5 Bq g^{-1} of Ra-226.

Application of the radiological capacity to waste acceptance

401. The total inventory in the site (the sum of the LLW disposed of in the hazardous landfill and the LLW disposed of in the non-hazardous landfill) needs to be controlled in order to ensure protection of humans and the environment from the combined effects. The

approach is to take each scenario in turn and to calculate the sum of fractions for that scenario. If each sum of fractions is less than 1 then the waste can be accepted. The sum of fractions for each scenario includes the contribution from the inventory in the hazardous landfill and the contribution from the inventory in the non-hazardous landfill. An example of the approach is given in Appendix D.

7.4.2.2 Radiological Capacity

402. The radiological capacities of the Port Clarence landfills are presented in three tables showing the limiting scenarios:

Table 28	Scenario radiological capacity calculations for intrusion and recreational use
Table 29	Scenario radiological capacity calculations for site erosion and leachate spillage
Table 31	Scenario radiological capacity for fire (non-hazardous landfill only) and burrowing mammals

403. Each table lists scenarios with a dose per unit disposal (µSv MBq^{-1}) and the scenario radiological capacity ($L_{Rn,\ Scenario}$) calculated as shown above for each radionuclide. For the dose arising from a groundwater pathway, a cut-off at 10^{-13} µSv MBq^{-1} is applied and the capacity is shown as "greater than" indicating the dose per unit disposal is very small. Two values are given for Ra-226 where appropriate: one for wastes containing significant activity concentrations of Ra-226 (>5 Bq g^{-1}) that are buried 5 m below the restored surface, and one for wastes containing small activity concentrations of Ra-226 that could be buried within 5 m of the restored surface.

404. The limiting scenarios are not combined but used as a set to limit disposals. Applying the sum of fractions approach to each scenario in turn allows Augean to understand the radiological impact of the LLW proposed for disposal. The radiological capacities from the limiting scenarios (excluding burrowing mammals) are summarised in Table 31. These scenario radiological capacity values are proposed for inclusion in the Environment Agency permit and would be applied using the sum of fractions approach to each scenario in turn. This approach will ensure that estimated radiation doses arising from the disposed inventory will never exceed the regulatory criteria whatever the radionuclide mix in the inventory of LLW disposed.

405. The screening value for dose to biota is not intended to represent a limit but they have been applied in this way in order to determine the scenario radiological capacity for burrowing mammals. A waste emplacement strategy would be employed to remove the need to determine the sum of fractions for burrowing mammals (the sum of fractions is not relevant if the waste is below the burrowing depth).

In addition to the limits set out in Table 31, it is proposed that a category of "Other radionuclides" is included. This category would correspond to radionuclides with half-lives greater than 3 months and that are not otherwise identified in Table 6. This category would be assigned a scenario radiological capacity equal to the lowest capacity in the list in Table 31 for the respective landfills.

Table 28 Scenario radiological capacity calculations for intrusion and recreational use

Radionuclide	Intrusion - Smallholder (60y) All ages, Ra-226 at 5m depth		Intrusion - Borehole excavator (60y) - worker Ra-226 at 5m depth		Gas + Ext. (Recreational 0y) All ages Ra-226 at 5m depth	
	Dose per MBq ($\mu Sv\ y^{-1}\ MBq^{-1}$)	Scenario Radiological Capacity (MBq)	Dose per MBq ($\mu Sv\ y^{-1}\ MBq^{-1}$)	Scenario Radiological Capacity (MBq)	Dose per MBq ($\mu Sv\ y^{-1}\ MBq^{-1}$)	Scenario Radiological Capacity (MBq)
H-3	$2.96\ 10^{-8}$	$1.01\ 10^{11}$	$1.77\ 10^{-13}$	$1.69\ 10^{16}$	$3.11\ 10^{-9}$	$6.43\ 10^{9}$
C-14	$1.29\ 10^{-5}$	$2.33\ 10^{8}$	$1.77\ 10^{-10}$	$1.70\ 10^{13}$	$1.07\ 10^{-7}$	$1.87\ 10^{8}$ (1)
Cl-36	$1.92\ 10^{-5}$	$1.56\ 10^{8}$	$1.33\ 10^{-9}$	$2.25\ 10^{12}$	$3.80\ 10^{-29}$	$5.27\ 10^{29}$
Ca-41	$6.21\ 10^{-8}$	$4.83\ 10^{10}$	$3.15\ 10^{-11}$	$9.53\ 10^{13}$	0	nd
Mn-54	$6.88\ 10^{-28}$	$4.36\ 10^{30}$	$1.55\ 10^{-27}$	$1.94\ 10^{30}$	$5.35\ 10^{-19}$	$3.74\ 10^{19}$
Fe-55	$2.58\ 10^{-16}$	$1.16\ 10^{19}$	$1.54\ 10^{-17}$	$1.94\ 10^{20}$	0	nd
Co-60	$9.61\ 10^{-10}$	$3.12\ 10^{12}$	$2.46\ 10^{-9}$	$1.22\ 10^{12}$	$6.04\ 10^{-17}$	$3.31\ 10^{17}$
Ni-59	$5.93\ 10^{-9}$	$5.06\ 10^{11}$	$2.41\ 10^{-11}$	$1.24\ 10^{14}$	0	nd
Ni-63	$9.67\ 10^{-9}$	$3.10\ 10^{11}$	$2.37\ 10^{-11}$	$1.27\ 10^{14}$	0	nd
Zn-65	$2.22\ 10^{-33}$	$1.35\ 10^{36}$	$1.35\ 10^{-33}$	$2.22\ 10^{36}$	$3.81\ 10^{-18}$	$5.24\ 10^{18}$
Se-79	$3.34\ 10^{-6}$	$8.98\ 10^{8}$	$5.61\ 10^{-10}$	$5.35\ 10^{12}$	$8.49\ 10^{-65}$	$2.36\ 10^{65}$
Sr-90	$7.83\ 10^{-6}$	$3.83\ 10^{8}$	$3.93\ 10^{-9}$	$7.64\ 10^{11}$	$3.22\ 10^{-26}$	$6.21\ 10^{26}$
Mo-93	$2.09\ 10^{-6}$	$1.44\ 10^{9}$	$7.43\ 10^{-10}$	$4.04\ 10^{12}$	$2.24\ 10^{-9}$	$8.92\ 10^{9}$
Zr-93	$2.03\ 10^{-9}$	$1.48\ 10^{12}$	$4.14\ 10^{-10}$	$7.24\ 10^{12}$	0	nd
Nb-93m	$7.62\ 10^{-11}$	$3.94\ 10^{13}$	$5.91\ 10^{-12}$	$5.07\ 10^{14}$	$3.95\ 10^{-10}$	$5.06\ 10^{10}$
Nb-94	$1.51\ 10^{-6}$	$1.98\ 10^{9}$	$3.91\ 10^{-6}$	$7.66\ 10^{8}$	$5.54\ 10^{-19}$	$3.61\ 10^{19}$
Tc-99	$4.90\ 10^{-6}$	$6.12\ 10^{8}$	$3.22\ 10^{-10}$	$9.32\ 10^{12}$	$1.64\ 10^{-48}$	$1.22\ 10^{49}$
Ru-106	$7.40\ 10^{-25}$	$4.05\ 10^{27}$	$1.16\ 10^{-24}$	$2.59\ 10^{27}$	$9.80\ 10^{-21}$	$2.04\ 10^{21}$
Ag-108m	$1.36\ 10^{-6}$	$2.20\ 10^{9}$	$3.54\ 10^{-6}$	$8.48\ 10^{8}$	$4.52\ 10^{-20}$	$4.42\ 10^{20}$
Ag-110m	$1.05\ 10^{-32}$	$2.86\ 10^{35}$	$2.73\ 10^{-32}$	$1.10\ 10^{35}$	$3.82\ 10^{-18}$	$5.23\ 10^{18}$
Cd-109	$6.65\ 10^{-21}$	$4.51\ 10^{23}$	$3.21\ 10^{-23}$	$9.35\ 10^{25}$	$3.41\ 10^{-49}$	$5.87\ 10^{49}$
Sb-125	$1.10\ 10^{-13}$	$2.73\ 10^{16}$	$2.82\ 10^{-13}$	$1.06\ 10^{16}$	$3.84\ 10^{-21}$	$5.20\ 10^{21}$

Radionuclide	Intrusion - Smallholder (60y) All ages, Ra-226 at 5m depth		Intrusion - Borehole excavator (60y) - worker Ra-226 at 5m depth		Gas + Ext. (Recreational 0y) All ages Ra-226 at 5m depth	
	Dose per MBq ($\mu Sv\ y^{-1}\ MBq^{-1}$)	Scenario Radiological Capacity (MBq)	Dose per MBq ($\mu Sv\ y^{-1}\ MBq^{-1}$)	Scenario Radiological Capacity (MBq)	Dose per MBq ($\mu Sv\ y^{-1}\ MBq^{-1}$)	Scenario Radiological Capacity (MBq)
Sn-119m	$1.17\ 10^{-30}$	$2.56\ 10^{33}$	$4.10\ 10^{-32}$	$7.31\ 10^{34}$	0	nd
Sn-123	$2.12\ 10^{-58}$	$1.41\ 10^{61}$	$1.82\ 10^{-59}$	$1.65\ 10^{62}$	$1.06\ 10^{-20}$	$1.89\ 10^{21}$
Sn-126	$2.04\ 10^{-6}$	$1.47\ 10^{9}$	$4.80\ 10^{-6}$	$6.25\ 10^{8}$	$1.26\ 10^{-19}$	$1.58\ 10^{20}$
Te-127m	$2.10\ 10^{-68}$	$1.43\ 10^{71}$	$1.81\ 10^{-71}$	$1.66\ 10^{74}$	$6.76\ 10^{-39}$	$2.96\ 10^{39}$
I-129	$9.97\ 10^{-6}$	$3.01\ 10^{8}$	$2.29\ 10^{-8}$	$1.31\ 10^{11}$	$1.04\ 10^{-138}$	$1.92\ 10^{139}$
Ba-133	$5.98\ 10^{-9}$	$5.02\ 10^{11}$	$1.54\ 10^{-8}$	$1.95\ 10^{11}$	$9.28\ 10^{-24}$	$2.16\ 10^{24}$
Cs-134	$3.51\ 10^{-15}$	$8.54\ 10^{17}$	$6.88\ 10^{-15}$	$4.36\ 10^{17}$	$2.21\ 10^{-19}$	$9.05\ 10^{19}$
Cs-135	$5.10\ 10^{-8}$	$5.88\ 10^{10}$	$4.43\ 10^{-10}$	$6.77\ 10^{12}$	$4.67\ 10^{-57}$	$4.28\ 10^{57}$
Cs-137	$2.17\ 10^{-7}$	$1.38\ 10^{10}$	$3.48\ 10^{-7}$	$8.61\ 10^{9}$	$4.47\ 10^{-20}$	$4.47\ 10^{20}$
Ce-144	$9.04\ 10^{-32}$	$3.32\ 10^{34}$	$2.15\ 10^{-31}$	$1.40\ 10^{34}$	$5.50\ 10^{-35}$	$3.63\ 10^{35}$
Pm-147	$1.04\ 10^{-16}$	$2.89\ 10^{19}$	$1.91\ 10^{-17}$	$1.57\ 10^{20}$	$1.12\ 10^{-47}$	$1.79\ 10^{48}$
Sm-147	$4.18\ 10^{-8}$	$7.17\ 10^{10}$	$9.46\ 10^{-8}$	$3.17\ 10^{10}$	0	nd
Sm-151	$1.15\ 10^{-10}$	$2.61\ 10^{13}$	$3.33\ 10^{-11}$	$9.00\ 10^{13}$	0	nd
Eu-152	$5.07\ 10^{-8}$	$5.92\ 10^{10}$	$1.32\ 10^{-7}$	$2.28\ 10^{10}$	$2.49\ 10^{-18}$	$8.04\ 10^{18}$
Eu-154	$9.48\ 10^{-9}$	$3.16\ 10^{11}$	$2.46\ 10^{-8}$	$1.22\ 10^{11}$	$3.46\ 10^{-18}$	$5.78\ 10^{18}$
Eu-155	$4.62\ 10^{-12}$	$6.49\ 10^{14}$	$1.19\ 10^{-11}$	$2.52\ 10^{14}$	$1.58\ 10^{-40}$	$1.26\ 10^{41}$
Gd-153	$1.38\ 10^{-35}$	$2.17\ 10^{38}$	$3.59\ 10^{-35}$	$8.36\ 10^{37}$	$2.12\ 10^{-42}$	$9.46\ 10^{42}$
Pb-210	$2.25\ 10^{-6}$	$1.33\ 10^{9}$	$5.99\ 10^{-8}$	$5.00\ 10^{10}$	$3.30\ 10^{-22}$	$6.07\ 10^{22}$
Po-210	$4.93\ 10^{-54}$	$6.08\ 10^{56}$	$4.87\ 10^{-55}$	$6.16\ 10^{57}$	$2.82\ 10^{-24}$	$7.08\ 10^{24}$
Ra-226	$1.31\ 10^{-4}$	$3.08\ 10^{13}$	$5.99\ 10^{-6}$	$5.01\ 10^{8}$	$8.28\ 10^{-14}$	$2.42\ 10^{14}$
Ra-228	$3.17\ 10^{-8}$	$9.46\ 10^{10}$	$5.22\ 10^{-9}$	$5.75\ 10^{11}$	$3.09\ 10^{-15}$	$6.46\ 10^{15}$
Ac-227	$1.43\ 10^{-7}$	$2.10\ 10^{10}$	$8.88\ 10^{-7}$	$3.38\ 10^{9}$	$1.21\ 10^{-20}$	$1.66\ 10^{21}$
Th-228	$5.94\ 10^{-16}$	$5.05\ 10^{18}$	$1.63\ 10^{-15}$	$1.84\ 10^{18}$	$1.95\ 10^{-15}$	$1.03\ 10^{16}$
Th-229	$5.80\ 10^{-7}$	$5.17\ 10^{9}$	$3.04\ 10^{-6}$	$9.86\ 10^{8}$	$5.16\ 10^{-18}$	$3.87\ 10^{18}$
Th-230	$1.97\ 10^{-6}$	$1.53\ 10^{9}$	$1.07\ 10^{-6}$	$2.81\ 10^{9}$	$2.56\ 10^{-38}$	$7.80\ 10^{38}$

Radionuclide	Intrusion - Smallholder (60y) All ages, Ra-226 at 5m depth		Intrusion - Borehole excavator (60y) - worker Ra-226 at 5m depth		Gas + Ext. (Recreational 0y) All ages Ra-226 at 5m depth	
	Dose per MBq ($\mu Sv\ y^{-1}\ MBq^{-1}$)	Scenario Radiological Capacity (MBq)	Dose per MBq ($\mu Sv\ y^{-1}\ MBq^{-1}$)	Scenario Radiological Capacity (MBq)	Dose per MBq ($\mu Sv\ y^{-1}\ MBq^{-1}$)	Scenario Radiological Capacity (MBq)
Th-232	$1.84\ 10^{-6}$	$1.63\ 10^{9}$	$4.15\ 10^{-6}$	$7.23\ 10^{8}$	$1.16\ 10^{-15}$	$1.73\ 10^{16}$
Pa-231	$1.10\ 10^{-5}$	$2.71\ 10^{8}$	$6.54\ 10^{-6}$	$4.58\ 10^{8}$	$5.85\ 10^{-26}$	$3.42\ 10^{26}$
U-232	$3.21\ 10^{-7}$	$9.33\ 10^{9}$	$4.40\ 10^{-7}$	$6.82\ 10^{9}$	$1.73\ 10^{-19}$	$1.16\ 10^{20}$
U-233	$4.64\ 10^{-8}$	$6.47\ 10^{10}$	$1.13\ 10^{-7}$	$2.66\ 10^{10}$	$6.63\ 10^{-32}$	$3.01\ 10^{32}$
U-234	$4.03\ 10^{-8}$	$7.44\ 10^{10}$	$9.34\ 10^{-8}$	$3.21\ 10^{10}$	$2.63\ 10^{-45}$	$7.61\ 10^{45}$
U-235	$1.51\ 10^{-7}$	$1.99\ 10^{10}$	$3.79\ 10^{-7}$	$7.93\ 10^{9}$	$1.83\ 10^{-29}$	$1.09\ 10^{30}$
U-236	$4.02\ 10^{-8}$	$7.46\ 10^{10}$	$8.62\ 10^{-8}$	$3.48\ 10^{10}$	$2.06\ 10^{-41}$	$9.70\ 10^{41}$
U-238	$4.47\ 10^{-8}$	$6.71\ 10^{10}$	$8.04\ 10^{-8}$	$3.73\ 10^{10}$	$9.52\ 10^{-24}$	$2.10\ 10^{24}$
Np-237	$2.15\ 10^{-7}$	$1.39\ 10^{10}$	$5.02\ 10^{-7}$	$5.98\ 10^{9}$	$1.41\ 10^{-26}$	$1.42\ 10^{27}$
Pu-238	$6.63\ 10^{-8}$	$4.52\ 10^{10}$	$6.42\ 10^{-7}$	$4.67\ 10^{9}$	$3.01\ 10^{-47}$	$6.64\ 10^{47}$
Pu-239	$1.16\ 10^{-7}$	$2.59\ 10^{10}$	$1.12\ 10^{-6}$	$2.67\ 10^{9}$	$1.86\ 10^{-31}$	$1.08\ 10^{32}$
Pu-240	$1.15\ 10^{-7}$	$2.60\ 10^{10}$	$1.12\ 10^{-6}$	$2.68\ 10^{9}$	$2.28\ 10^{-54}$	$8.77\ 10^{54}$
Pu-241	$3.85\ 10^{-9}$	$7.79\ 10^{11}$	$2.82\ 10^{-8}$	$1.06\ 10^{11}$	$6.35\ 10^{-41}$	$3.15\ 10^{41}$
Pu-242	$1.09\ 10^{-7}$	$2.74\ 10^{10}$	$1.03\ 10^{-6}$	$2.90\ 10^{9}$	$8.21\ 10^{-66}$	$2.44\ 10^{66}$
Pu-244	$1.10\ 10^{-7}$	$2.72\ 10^{10}$	$1.04\ 10^{-6}$	$2.88\ 10^{9}$	$2.28\ 10^{-24}$	$8.75\ 10^{24}$
Am-241	$1.15\ 10^{-7}$	$2.61\ 10^{10}$	$8.34\ 10^{-7}$	$3.60\ 10^{9}$	$4.23\ 10^{-61}$	$4.73\ 10^{61}$
Am-242m	$1.43\ 10^{-7}$	$2.10\ 10^{10}$	$1.14\ 10^{-6}$	$2.62\ 10^{9}$	$5.98\ 10^{-22}$	$3.35\ 10^{22}$
Am-243	$1.42\ 10^{-7}$	$2.12\ 10^{10}$	$9.55\ 10^{-7}$	$3.14\ 10^{9}$	$7.32\ 10^{-30}$	$2.73\ 10^{30}$
Cm-242	$3.39\ 10^{-10}$	$8.85\ 10^{12}$	$3.28\ 10^{-9}$	$9.14\ 10^{11}$	$1.78\ 10^{-41}$	$1.12\ 10^{42}$
Cm-243	$4.28\ 10^{-8}$	$7.01\ 10^{10}$	$2.13\ 10^{-7}$	$1.41\ 10^{10}$	$2.72\ 10^{-29}$	$7.35\ 10^{29}$
Cm-244	$7.35\ 10^{-9}$	$4.08\ 10^{11}$	$5.65\ 10^{-8}$	$5.31\ 10^{10}$	0	nd
Cm-245	$1.77\ 10^{-7}$	$1.70\ 10^{10}$	$1.08\ 10^{-6}$	$2.77\ 10^{9}$	$1.57\ 10^{-34}$	$1.27\ 10^{35}$
Cm-246	$1.21\ 10^{-7}$	$2.47\ 10^{10}$	$9.12\ 10^{-7}$	$3.29\ 10^{9}$	$1.35\ 10^{-138}$	$1.48\ 10^{139}$
Cm-248	$4.49\ 10^{-7}$	$6.69\ 10^{9}$	$3.38\ 10^{-6}$	$8.88\ 10^{8}$	0	nd

(1) Value is $5.16\ 10^{6}$ for the non-hazardous landfill.

Radionuclide	Intrusion - Smallholder (60y) All ages, Ra-226 at 5m depth		Intrusion - Borehole excavator (60y) - worker Ra-226 at 5m depth		Gas + Ext. (Recreational 0y) All ages Ra-226 at 5m depth	
	Dose per MBq ($\mu Sv\ y^{-1}\ MBq^{-1}$)	Scenario Radiological Capacity (MBq)	Dose per MBq ($\mu Sv\ y^{-1}\ MBq^{-1}$)	Scenario Radiological Capacity (MBq)	Dose per MBq ($\mu Sv\ y^{-1}\ MBq^{-1}$)	Scenario Radiological Capacity (MBq)

(2) Where dose is effectively zero the radiological capacity is infinite, marked here as nd (not determined).

Table 29 Scenario radiological capacity calculated for exposures after the period of authorisation

Radionuclide	Erosion to coast (2540y) All ages (PC-Cream)		Erosion - Dog walker (2540y) All ages		Leachate spillage (0y) All ages	
	Dose per MBq ($\mu Sv\ y^{-1}\ MBq^{-1}$)	Scenario Radiological Capacity (MBq)	Dose per MBq ($\mu Sv\ y^{-1}\ MBq^{-1}$)	Scenario Radiological Capacity (MBq)	Dose per MBq ($\mu Sv\ y^{-1}\ MBq^{-1}$)	Scenario Radiological Capacity (MBq)
H-3	0	nd	$1.21\ 10^{-74}$	$1.65\ 10^{75}$	$5.73\ 10^{-10}$	$5.24\ 10^{11}$
C-14	$8.46\ 10^{-9}$	$2.37\ 10^{9}$	$3.49\ 10^{-11}$	$5.73\ 10^{11}$	$6.79\ 10^{-9}$	$4.42\ 10^{10}$
Cl-36	$1.65\ 10^{-13}$	$1.21\ 10^{14}$	$1.04\ 10^{-9}$	$1.93\ 10^{10}$	$7.49\ 10^{-8}$	$4.01\ 10^{9}$
Ca-41	$1.56\ 10^{-12}$	$1.28\ 10^{13}$	$1.24\ 10^{-11}$	$1.62\ 10^{12}$	$1.06\ 10^{-9}$	$2.83\ 10^{11}$
Mn-54	0	nd	0	nd	$2.68\ 10^{-11}$	$1.12\ 10^{13}$
Fe-55	0	nd	$2.52\ 10^{-290}$	$7.93\ 10^{290}$	$1.62\ 10^{-11}$	$1.86\ 10^{13}$
Co-60	0	nd	$5.22\ 10^{-151}$	$3.83\ 10^{151}$	$8.38\ 10^{-10}$	$3.58\ 10^{11}$
Ni-59	$6.24\ 10^{-11}$	$3.20\ 10^{11}$	$8.36\ 10^{-12}$	$2.39\ 10^{12}$	$9.73\ 10^{-12}$	$3.08\ 10^{13}$
Ni-63	$3.17\ 10^{-19}$	$6.31\ 10^{19}$	$4.87\ 10^{-19}$	$4.11\ 10^{19}$	$2.39\ 10^{-11}$	$1.26\ 10^{13}$
Zn-65	0	nd	0	nd	$3.35\ 10^{-10}$	$8.95\ 10^{11}$
Se-79	$2.16\ 10^{-8}$	$9.27\ 10^{8}$	$6.77\ 10^{-10}$	$2.95\ 10^{10}$	$5.65\ 10^{-9}$	$5.31\ 10^{10}$
Sr-90	0	nd	$3.16\ 10^{-35}$	$6.33\ 10^{35}$	$1.16\ 10^{-8}$	$2.58\ 10^{10}$
Mo-93	$5.76\ 10^{-9}$	$3.47\ 10^{9}$	$2.48\ 10^{-10}$	$8.07\ 10^{10}$	$7.27\ 10^{-10}$	$4.13\ 10^{11}$

Radionuclide	Erosion to coast (2540y) All ages (PC-Cream)		Erosion - Dog walker (2540y) All ages		Leachate spillage (0y) All ages	
	Dose per MBq ($\mu Sv\ y^{-1}\ MBq^{-1}$)	Scenario Radiological Capacity (MBq)	Dose per MBq ($\mu Sv\ y^{-1}\ MBq^{-1}$)	Scenario Radiological Capacity (MBq)	Dose per MBq ($\mu Sv\ y^{-1}\ MBq^{-1}$)	Scenario Radiological Capacity (MBq)
Zr-93	$6.42\ 10^{-11}$	$3.12\ 10^{11}$	$3.13\ 10^{-11}$	$6.39\ 10^{11}$	$1.22\ 10^{-10}$	$2.45\ 10^{12}$
Nb-93m	0	nd	$2.45\ 10^{-58}$	$8.18\ 10^{58}$	$9.85\ 10^{-12}$	$3.05\ 10^{13}$
Nb-94	$3.58\ 10^{-8}$	$5.59\ 10^{8}$	$3.28\ 10^{-6}$	$6.09\ 10^{6}$	$1.10\ 10^{-10}$	$2.74\ 10^{12}$
Tc-99	$6.99\ 10^{-10}$	$2.86\ 10^{10}$	$1.69\ 10^{-10}$	$1.18\ 10^{11}$	$4.35\ 10^{-8}$	$6.90\ 10^{9}$
Ru-106	0	nd	0	nd	$3.28\ 10^{-10}$	$9.14\ 10^{11}$
Ag-108m	$3.30\ 10^{-10}$	$6.07\ 10^{10}$	$5.29\ 10^{-8}$	$3.78\ 10^{8}$	$9.04\ 10^{-11}$	$3.32\ 10^{12}$
Ag-110m	0	nd	0	nd	$4.68\ 10^{-11}$	$6.41\ 10^{12}$
Cd-109	0	nd	0	nd	$2.88\ 10^{-10}$	$1.04\ 10^{12}$
Sb-125	0	nd	$6.64\ 10^{-284}$	$3.01\ 10^{284}$	$7.19\ 10^{-10}$	$4.17\ 10^{11}$
Sn-119m	0	nd	0	nd	$3.56\ 10^{-11}$	$8.43\ 10^{12}$
Sn-123	0	nd	0	nd	$1.01\ 10^{-10}$	$2.97\ 10^{12}$
Sn-126	$2.76\ 10^{-7}$	$7.24\ 10^{7}$	$4.35\ 10^{-6}$	$4.60\ 10^{6}$	$1.00\ 10^{-9}$	$3.00\ 10^{11}$
Te-127m	0	nd	0	nd	$7.38\ 10^{-11}$	$4.07\ 10^{12}$
I-129	$1.53\ 10^{-9}$	$1.31\ 10^{10}$	$1.01\ 10^{-8}$	$1.99\ 10^{9}$	$2.08\ 10^{-7}$	$1.44\ 10^{9}$
Ba-133	0	nd	$1.52\ 10^{-79}$	$1.31\ 10^{80}$	$4.18\ 10^{-8}$	$7.18\ 10^{9}$
Cs-134	0	nd	0	nd	$2.97\ 10^{-9}$	$1.01\ 10^{11}$
Cs-135	$8.73\ 10^{-11}$	$2.29\ 10^{11}$	$7.52\ 10^{-11}$	$2.66\ 10^{11}$	$4.31\ 10^{-10}$	$6.96\ 10^{11}$
Cs-137	0	nd	$5.71\ 10^{-32}$	$3.50\ 10^{32}$	$2.74\ 10^{-9}$	$1.10\ 10^{11}$
Ce-144	0	nd	0	nd	$6.23\ 10^{-11}$	$4.81\ 10^{12}$
Pm-147	0	nd	0	nd	$1.40\ 10^{-11}$	$2.14\ 10^{13}$
Sm-147	$4.26\ 10^{-10}$	$4.69\ 10^{10}$	$1.11\ 10^{-8}$	$1.80\ 10^{9}$	$6.45\ 10^{-10}$	$4.65\ 10^{11}$
Sm-151	$3.61\ 10^{-21}$	$5.55\ 10^{21}$	$5.81\ 10^{-20}$	$3.44\ 10^{20}$	$2.93\ 10^{-12}$	$1.02\ 10^{14}$
Eu-152	0	nd	$8.77\ 10^{-63}$	$2.28\ 10^{63}$	$1.26\ 10^{-10}$	$2.38\ 10^{12}$
Eu-154	0	nd	$2.97\ 10^{-95}$	$6.74\ 10^{95}$	$1.98\ 10^{-10}$	$1.51\ 10^{12}$
Eu-155	0	nd	$1.69\ 10^{-168}$	$1.18\ 10^{169}$	$3.40\ 10^{-11}$	$8.81\ 10^{12}$

Radionuclide	Erosion to coast (2540y) All ages (PC-Cream)		Erosion - Dog walker (2540y) All ages		Leachate spillage (0y) All ages	
	Dose per MBq (µSv y^{-1} MBq^{-1})	Scenario Radiological Capacity (MBq)	Dose per MBq (µSv y^{-1} MBq^{-1})	Scenario Radiological Capacity (MBq)	Dose per MBq (µSv y^{-1} MBq^{-1})	Scenario Radiological Capacity (MBq)
Gd-153	0	nd	0	nd	$6.22\ 10^{-12}$	$4.83\ 10^{13}$
Pb-210	0	nd	$1.11\ 10^{-41}$	$1.80\ 10^{42}$	$1.02\ 10^{-7}$	$2.94\ 10^{9}$
Po-210	0	nd	0	nd	$4.86\ 10^{-8}$	$6.17\ 10^{9}$
Ra-226	$5.14\ 10^{-6}$	$3.89\ 10^{6}$	$1.49\ 10^{-6}$	$1.34\ 10^{7}$	$2.81\ 10^{-8}$	$1.07\ 10^{10}$
Ra-228	0	nd	$6.54\ 10^{-139}$	$3.06\ 10^{139}$	$1.33\ 10^{-8}$	$2.25\ 10^{10}$
Ac-227	$3.61\ 10^{-43}$	$5.54\ 10^{43}$	$9.53\ 10^{-42}$	$2.10\ 10^{42}$	$9.87\ 10^{-8}$	$3.04\ 10^{9}$
Th-228	0	nd	0	nd	$1.75\ 10^{-9}$	$1.72\ 10^{11}$
Th-229	$7.96\ 10^{-9}$	$2.51\ 10^{9}$	$6.95\ 10^{-7}$	$2.88\ 10^{7}$	$5.37\ 10^{-9}$	$5.58\ 10^{10}$
Th-230	$1.01\ 10^{-5}$	$1.98\ 10^{6}$	$2.93\ 10^{-6}$	$6.82\ 10^{6}$	$1.32\ 10^{-9}$	$2.28\ 10^{11}$
Th-232	$3.92\ 10^{-7}$	$5.10\ 10^{7}$	$2.52\ 10^{-6}$	$7.95\ 10^{6}$	$1.80\ 10^{-8}$	$1.67\ 10^{10}$
Pa-231	$3.01\ 10^{-8}$	$6.65\ 10^{8}$	$5.21\ 10^{-7}$	$3.84\ 10^{7}$	$3.34\ 10^{-9}$	$8.98\ 10^{10}$
U-232	$4.94\ 10^{-20}$	$4.05\ 10^{20}$	$8.87\ 10^{-19}$	$2.26\ 10^{19}$	$3.18\ 10^{-8}$	$9.43\ 10^{9}$
U-233	$1.96\ 10^{-9}$	$1.02\ 10^{10}$	$1.96\ 10^{-7}$	$1.02\ 10^{8}$	$2.40\ 10^{-9}$	$1.25\ 10^{11}$
U-234	$1.38\ 10^{-7}$	$1.45\ 10^{8}$	$1.35\ 10^{-8}$	$1.48\ 10^{9}$	$2.31\ 10^{-9}$	$1.30\ 10^{11}$
U-235	$2.98\ 10^{-9}$	$6.71\ 10^{9}$	$2.89\ 10^{-7}$	$6.93\ 10^{7}$	$2.23\ 10^{-9}$	$1.35\ 10^{11}$
U-236	$8.94\ 10^{-10}$	$2.24\ 10^{10}$	$1.02\ 10^{-8}$	$1.97\ 10^{9}$	$2.21\ 10^{-9}$	$1.36\ 10^{11}$
U-238	$1.44\ 10^{-9}$	$1.39\ 10^{10}$	$9.90\ 10^{-9}$	$2.02\ 10^{9}$	$2.43\ 10^{-9}$	$1.23\ 10^{11}$
Np-237	$2.67\ 10^{-8}$	$7.49\ 10^{8}$	$8.65\ 10^{-8}$	$2.31\ 10^{8}$	$2.97\ 10^{-8}$	$1.01\ 10^{10}$
Pu-238	$4.55\ 10^{-11}$	$4.39\ 10^{11}$	$3.95\ 10^{-12}$	$5.07\ 10^{12}$	$2.79\ 10^{-9}$	$1.08\ 10^{11}$
Pu-239	$2.00\ 10^{-8}$	$9.99\ 10^{8}$	$1.29\ 10^{-7}$	$1.55\ 10^{8}$	$3.06\ 10^{-9}$	$9.82\ 10^{10}$
Pu-240	$1.65\ 10^{-8}$	$1.21\ 10^{9}$	$1.06\ 10^{-7}$	$1.89\ 10^{8}$	$3.06\ 10^{-9}$	$9.82\ 10^{10}$
Pu-241	$3.82\ 10^{-12}$	$5.23\ 10^{12}$	$7.44\ 10^{-11}$	$2.69\ 10^{11}$	$5.59\ 10^{-11}$	$5.36\ 10^{12}$
Pu-242	$2.06\ 10^{-8}$	$9.70\ 10^{8}$	$1.26\ 10^{-7}$	$1.58\ 10^{8}$	$2.93\ 10^{-9}$	$1.02\ 10^{11}$
Pu-244	$3.47\ 10^{-8}$	$5.76\ 10^{8}$	$1.59\ 10^{-7}$	$1.26\ 10^{8}$	$2.95\ 10^{-9}$	$1.02\ 10^{11}$
Am-241	$1.11\ 10^{-10}$	$1.80\ 10^{11}$	$2.18\ 10^{-9}$	$9.19\ 10^{9}$	$9.15\ 10^{-10}$	$3.28\ 10^{11}$

Radionuclide	Erosion to coast (2540y) All ages (PC-Cream)		Erosion - Dog walker (2540y) All ages		Leachate spillage (0y) All ages	
	Dose per MBq ($\mu Sv\ y^{-1}\ MBq^{-1}$)	Scenario Radiological Capacity (MBq)	Dose per MBq ($\mu Sv\ y^{-1}\ MBq^{-1}$)	Scenario Radiological Capacity (MBq)	Dose per MBq ($\mu Sv\ y^{-1}\ MBq^{-1}$)	Scenario Radiological Capacity (MBq)
Am-242m	$5.62\ 10^{-11}$	$3.56\ 10^{11}$	$2.96\ 10^{-12}$	$6.76\ 10^{12}$	$1.10\ 10^{-9}$	$2.72\ 10^{11}$
Am-243	$1.05\ 10^{-8}$	$1.91\ 10^{9}$	$1.37\ 10^{-7}$	$1.46\ 10^{8}$	$9.20\ 10^{-10}$	$3.26\ 10^{11}$
Cm-242	0	nd	$1.24\ 10^{-18}$	$1.61\ 10^{19}$	$8.87\ 10^{-11}$	$3.38\ 10^{12}$
Cm-243	0	nd	$1.56\ 10^{-10}$	$1.29\ 10^{11}$	$1.71\ 10^{-9}$	$1.75\ 10^{11}$
Cm-244	0	nd	$2.94\ 10^{-10}$	$6.81\ 10^{10}$	$1.34\ 10^{-9}$	$2.23\ 10^{11}$
Cm-245	$1.48\ 10^{-8}$	$1.35\ 10^{9}$	$1.95\ 10^{-7}$	$1.02\ 10^{8}$	$2.44\ 10^{-9}$	$1.23\ 10^{11}$
Cm-246	$6.26\ 10^{-9}$	$3.19\ 10^{9}$	$7.86\ 10^{-8}$	$2.55\ 10^{8}$	$2.44\ 10^{-9}$	$1.23\ 10^{11}$
Cm-248	$3.25\ 10^{-8}$	$6.15\ 10^{8}$	$4.13\ 10^{-7}$	$4.84\ 10^{7}$	$8.95\ 10^{-9}$	$3.35\ 10^{10}$

* Where dose is effectively zero the radiological capacity is infinite, marked here as nd (not determined).

Table 30 Scenario radiological capacity calculated for landfill fire (non-hazardous landfill only) and for burrowing mammals

Radionuclide	Landfill fire		Burrowing mammals*	
	Dose per MBq ($\mu Sv\ y^{-1}\ MBq^{-1}$)	Scenario Radiological Capacity (MBq)	Dose to NHB per MBq ($\mu Gy\ h^{-1}\ MBq^{-1}$)	Scenario radiological capacity
H-3	$5.00\ 10^{-9}$	$6.00\ 10^{10}$	$1.13\ 10^{-10}$	$3.53\ 10^{11}$
C-14	$1.12\ 10^{-7}$	$2.69\ 10^{9}$	$5.59\ 10^{-9}$	$7.16\ 10^{9}$
Cl-36	$1.40\ 10^{-7}$	$2.14\ 10^{9}$	$2.12\ 10^{-7}$	$1.89\ 10^{8}$
Ca-41	$4.06\ 10^{-12}$	$7.38\ 10^{13}$	$6.93\ 10^{-9}$	$5.77\ 10^{9}$
Mn-54	$3.24\ 10^{-11}$	$9.26\ 10^{12}$	$2.13\ 10^{-18}$	$1.88\ 10^{19}$
Fe-55	$1.72\ 10^{-11}$	$1.74\ 10^{13}$	$1.23\ 10^{-16}$	$3.26\ 10^{17}$
Co-60	$6.05\ 10^{-10}$	$4.96\ 10^{11}$	$9.94\ 10^{-11}$	$4.02\ 10^{11}$
Ni-59	$8.46\ 10^{-12}$	$3.54\ 10^{13}$	$2.05\ 10^{-10}$	$1.95\ 10^{11}$

Radionuclide	Landfill fire		Burrowing mammals*	
	Dose per MBq ($\mu Sv\ y^{-1}\ MBq^{-1}$)	Scenario Radiological Capacity (MBq)	Dose to NHB per MBq ($\mu Gy\ h^{-1}\ MBq^{-1}$)	Scenario radiological capacity
Ni-63	$2.50\ 10^{-11}$	$1.20\ 10^{13}$	$1.65\ 10^{-10}$	$2.42\ 10^{11}$
Zn-65	$4.88\ 10^{-9}$	$6.15\ 10^{10}$	$1.15\ 10^{-18}$	$3.49\ 10^{19}$
Se-79	$1.31\ 10^{-7}$	$2.29\ 10^{9}$	$1.15\ 10^{-9}$	$3.47\ 10^{10}$
Sr-90	$3.11\ 10^{-9}$	$9.66\ 10^{10}$	$4.64\ 10^{-8}$	$8.62\ 10^{8}$
Mo-93	$4.42\ 10^{-11}$	$6.78\ 10^{12}$	$2.39\ 10^{-10}$	$1.67\ 10^{11}$
Zr-93	$4.81\ 10^{-10}$	$6.24\ 10^{11}$	$6.39\ 10^{-13}$	$6.26\ 10^{13}$
Nb-93m	$3.46\ 10^{-11}$	$8.66\ 10^{12}$	$1.41\ 10^{-11}$	$2.84\ 10^{12}$
Nb-94	$9.48\ 10^{-10}$	$3.16\ 10^{11}$	$1.51\ 10^{-7}$	$2.65\ 10^{8}$
Tc-99	$2.50\ 10^{-10}$	$1.20\ 10^{12}$	$4.31\ 10^{-9}$	$9.29\ 10^{9}$
Ru-106	$1.27\ 10^{-7}$	$2.36\ 10^{9}$	$2.59\ 10^{-19}$	$1.54\ 10^{20}$
Ag-108m	$7.17\ 10^{-9}$	$4.18\ 10^{10}$	$1.51\ 10^{-7}$	$2.65\ 10^{8}$
Ag-110m	$2.40\ 10^{-9}$	$1.25\ 10^{11}$	$2.97\ 10^{-18}$	$1.35\ 10^{19}$
Cd-109	$1.72\ 10^{-10}$	$1.74\ 10^{12}$	$1.47\ 10^{-19}$	$2.73\ 10^{20}$
Sb-125	$2.51\ 10^{-8}$	$1.20\ 10^{10}$	$1.79\ 10^{-14}$	$2.24\ 10^{15}$
Sn-119m	$4.23\ 10^{-11}$	$7.09\ 10^{12}$	$8.12\ 10^{-21}$	$4.92\ 10^{21}$
Sn-123	$1.56\ 10^{-10}$	$1.92\ 10^{12}$	$2.24\ 10^{-20}$	$1.78\ 10^{21}$
Sn-126	$5.54\ 10^{-10}$	$5.41\ 10^{11}$	$1.53\ 10^{-7}$	$2.62\ 10^{8}$
Te-127m	$1.89\ 10^{-8}$	$1.59\ 10^{10}$	$5.14\ 10^{-20}$	$7.78\ 10^{20}$
I-129	$8.25\ 10^{-7}$	$3.64\ 10^{8}$	$4.52\ 10^{-9}$	$8.85\ 10^{9}$
Ba-133	$1.94\ 10^{-10}$	$1.55\ 10^{12}$	$6.31\ 10^{-10}$	$6.34\ 10^{10}$
Cs-134	$3.90\ 10^{-8}$	$7.69\ 10^{9}$	$1.03\ 10^{-15}$	$3.88\ 10^{16}$
Cs-135	$1.65\ 10^{-8}$	$1.81\ 10^{10}$	$2.58\ 10^{-8}$	$1.55\ 10^{9}$
Cs-137	$7.52\ 10^{-8}$	$3.99\ 10^{9}$	$4.13\ 10^{-8}$	$9.69\ 10^{8}$
Ce-144	$1.14\ 10^{-9}$	$2.63\ 10^{11}$	$3.23\ 10^{-20}$	$1.24\ 10^{21}$
Pm-147	$9.62\ 10^{-11}$	$3.12\ 10^{12}$	$5.04\ 10^{-17}$	$7.94\ 10^{17}$
Sm-147	$1.85\ 10^{-7}$	$1.62\ 10^{9}$	$8.32\ 10^{-8}$	$4.81\ 10^{8}$

Radionuclide	Landfill fire		Burrowing mammals*	
	Dose per MBq ($\mu Sv\ y^{-1}\ MBq^{-1}$)	Scenario Radiological Capacity (MBq)	Dose to NHB per MBq ($\mu Gy\ h^{-1}\ MBq^{-1}$)	Scenario radiological capacity
Sm-151	$7.70\ 10^{-11}$	$3.90\ 10^{12}$	$5.53\ 10^{-11}$	$7.23\ 10^{11}$
Eu-152	$8.12\ 10^{-10}$	$3.70\ 10^{11}$	$4.97\ 10^{-9}$	$8.05\ 10^{9}$
Eu-154	$1.02\ 10^{-9}$	$2.93\ 10^{11}$	$9.57\ 10^{-10}$	$4.18\ 10^{10}$
Eu-155	$1.33\ 10^{-10}$	$2.26\ 10^{12}$	$5.87\ 10^{-13}$	$6.82\ 10^{13}$
Gd-153	$5.10\ 10^{-11}$	$5.88\ 10^{12}$	$5.89\ 10^{-20}$	$6.80\ 10^{20}$
Pb-210	$9.61\ 10^{-5}$	$3.12\ 10^{6}$	$8.25\ 10^{-8}$	$4.85\ 10^{8}$
Po-210	$8.27\ 10^{-8}$	$3.63\ 10^{9}$	$3.93\ 10^{-18}$	$1.02\ 10^{19}$
Ra-226	$3.76\ 10^{-7}$	$7.99\ 10^{8}$	$1.70\ 10^{-6}$	$2.36\ 10^{7}$
Ra-228	$1.15\ 10^{-6}$	$2.61\ 10^{8}$	$2.49\ 10^{-10}$	$1.61\ 10^{11}$
Ac-227	$1.09\ 10^{-5}$	$2.74\ 10^{7}$	$2.89\ 10^{-12}$	$1.38\ 10^{13}$
Th-228	$8.39\ 10^{-7}$	$3.57\ 10^{8}$	$1.33\ 10^{-16}$	$3.01\ 10^{17}$
Th-229	$4.93\ 10^{-6}$	$6.09\ 10^{7}$	$5.64\ 10^{-9}$	$7.09\ 10^{9}$
Th-230	$1.92\ 10^{-6}$	$1.56\ 10^{8}$	$4.13\ 10^{-8}$	$9.69\ 10^{8}$
Th-232	$3.26\ 10^{-6}$	$9.19\ 10^{7}$	$2.38\ 10^{-7}$	$1.68\ 10^{8}$
Pa-231	$2.69\ 10^{-6}$	$1.11\ 10^{8}$	$2.95\ 10^{-6}$	$1.36\ 10^{7}$
U-232	$1.55\ 10^{-6}$	$1.93\ 10^{8}$	$9.91\ 10^{-8}$	$4.04\ 10^{8}$
U-233	$1.85\ 10^{-7}$	$1.62\ 10^{9}$	$2.89\ 10^{-8}$	$1.38\ 10^{9}$
U-234	$1.81\ 10^{-7}$	$1.66\ 10^{9}$	$2.91\ 10^{-8}$	$1.37\ 10^{9}$
U-235	$1.64\ 10^{-7}$	$1.83\ 10^{9}$	$4.25\ 10^{-8}$	$9.42\ 10^{8}$
U-236	$1.67\ 10^{-7}$	$1.79\ 10^{9}$	$2.70\ 10^{-8}$	$1.48\ 10^{9}$
U-238	$1.54\ 10^{-7}$	$1.95\ 10^{9}$	$2.49\ 10^{-8}$	$1.60\ 10^{9}$
Np-237	$9.62\ 10^{-7}$	$3.12\ 10^{8}$	$2.82\ 10^{-6}$	$1.42\ 10^{7}$
Pu-238	$2.12\ 10^{-6}$	$1.42\ 10^{8}$	$5.29\ 10^{-8}$	$7.56\ 10^{8}$
Pu-239	$2.31\ 10^{-6}$	$1.30\ 10^{8}$	$7.96\ 10^{-8}$	$5.03\ 10^{8}$
Pu-240	$2.31\ 10^{-6}$	$1.30\ 10^{8}$	$7.92\ 10^{-8}$	$5.05\ 10^{8}$
Pu-241	$4.42\ 10^{-8}$	$6.78\ 10^{9}$	$4.26\ 10^{-9}$	$9.39\ 10^{9}$

Radionuclide	Landfill fire		Burrowing mammals*	
	Dose per MBq ($\mu Sv\ y^{-1}\ MBq^{-1}$)	Scenario Radiological Capacity (MBq)	Dose to NHB per MBq ($\mu Gy\ h^{-1}\ MBq^{-1}$)	Scenario radiological capacity
Pu-242	$2.12\ 10^{-6}$	$1.42\ 10^{8}$	$7.50\ 10^{-8}$	$5.34\ 10^{8}$
Pu-244	$2.12\ 10^{-6}$	$1.42\ 10^{8}$	$1.03\ 10^{-7}$	$3.88\ 10^{8}$
Am-241	$1.85\ 10^{-6}$	$1.62\ 10^{8}$	$1.32\ 10^{-7}$	$3.03\ 10^{8}$
Am-242m	$2.23\ 10^{-6}$	$1.35\ 10^{8}$	$2.29\ 10^{-6}$	$1.75\ 10^{7}$
Am-243	$1.85\ 10^{-6}$	$1.62\ 10^{8}$	$1.52\ 10^{-7}$	$2.62\ 10^{8}$
Cm-242	$1.14\ 10^{-7}$	$2.64\ 10^{9}$	$2.70\ 10^{-10}$	$1.48\ 10^{11}$
Cm-243	$1.33\ 10^{-6}$	$2.25\ 10^{8}$	$8.18\ 10^{-7}$	$4.89\ 10^{7}$
Cm-244	$1.10\ 10^{-6}$	$2.74\ 10^{8}$	$3.44\ 10^{-7}$	$1.16\ 10^{8}$
Cm-245	$1.90\ 10^{-6}$	$1.58\ 10^{8}$	$3.18\ 10^{-6}$	$1.26\ 10^{7}$
Cm-246	$1.89\ 10^{-6}$	$1.59\ 10^{8}$	$3.15\ 10^{-6}$	$1.27\ 10^{7}$
Cm-248	$6.93\ 10^{-6}$	$4.33\ 10^{7}$	$2.75\ 10^{-6}$	$1.45\ 10^{7}$

*Only applies to waste disposed of within the burrowing depth

Table 31 Port Clarence radiological capacities (MBq)

Radionuclide	Intrusion - Smallholder (60y) All ages, Ra-226 at 5m depth	Gas + Ext. (Recreational 0y) All ages Ra-226 at 5m depth	Erosion to coast (2540y) All ages (PC-Cream)	Erosion - Dog walker (2540y) All ages	Leachate spillage (0y) All ages	Fire in non-hazardous landfill - All ages
H-3	$4.34\ 10^{10}$	$6.43\ 10^{9}$	nd	$1.65\ 10^{75}$	$5.24\ 10^{11}$	$6.00\ 10^{10}$
C-14	$4.69\ 10^{7}$	$1.87\ 10^{8}$ (1)	$2.37\ 10^{9}$	$5.73\ 10^{11}$	$4.42\ 10^{10}$	$2.69\ 10^{9}$
Cl-36	$1.56\ 10^{8}$	$5.27\ 10^{29}$	$1.21\ 10^{14}$	$1.93\ 10^{10}$	$4.01\ 10^{9}$	$2.14\ 10^{9}$
Ca-41	$4.83\ 10^{10}$	nd	$1.28\ 10^{13}$	$1.62\ 10^{12}$	$2.83\ 10^{11}$	$7.38\ 10^{13}$
Mn-54	$4.36\ 10^{30}$	$3.74\ 10^{19}$	nd	nd	$1.12\ 10^{13}$	$9.26\ 10^{12}$
Fe-55	$1.16\ 10^{19}$	nd	nd	$7.93\ 10^{290}$	$1.86\ 10^{13}$	$1.74\ 10^{13}$

Radionuclide	Intrusion - Smallholder (60y) All ages, Ra-226 at 5m depth	Gas + Ext. (Recreational 0y) All ages Ra-226 at 5m depth	Erosion to coast (2540y) All ages (PC-Cream)	Erosion - Dog walker (2540y) All ages	Leachate spillage (0y) All ages	Fire in non-hazardous landfill - All ages
Co-60	$3.12\ 10^{12}$	$3.31\ 10^{17}$	nd	$3.83\ 10^{151}$	$3.58\ 10^{11}$	$4.96\ 10^{11}$
Ni-59	$5.06\ 10^{11}$	nd	$3.20\ 10^{11}$	$2.39\ 10^{12}$	$3.08\ 10^{13}$	$3.54\ 10^{13}$
Ni-63	$3.10\ 10^{11}$	nd	$6.31\ 10^{19}$	$4.11\ 10^{19}$	$1.26\ 10^{13}$	$1.20\ 10^{13}$
Zn-65	$1.35\ 10^{36}$	$5.24\ 10^{18}$	nd	nd	$8.95\ 10^{11}$	$6.15\ 10^{10}$
Se-79	$8.98\ 10^{8}$	$2.36\ 10^{65}$	$9.27\ 10^{8}$	$2.95\ 10^{10}$	$5.31\ 10^{10}$	$2.29\ 10^{9}$
Sr-90	$3.83\ 10^{8}$	$6.21\ 10^{26}$	nd	$6.33\ 10^{35}$	$2.58\ 10^{10}$	$9.66\ 10^{10}$
Mo-93	$1.44\ 10^{9}$	$8.92\ 10^{9}$	$3.47\ 10^{9}$	$8.07\ 10^{10}$	$4.13\ 10^{11}$	$6.78\ 10^{12}$
Zr-93	$1.48\ 10^{12}$	nd	$3.12\ 10^{11}$	$6.39\ 10^{11}$	$2.45\ 10^{12}$	$6.24\ 10^{11}$
Nb-93m	$3.94\ 10^{13}$	$5.06\ 10^{10}$	nd	$8.18\ 10^{58}$	$3.05\ 10^{13}$	$8.66\ 10^{12}$
Nb-94	$1.98\ 10^{9}$	$3.61\ 10^{19}$	$5.59\ 10^{8}$	$6.09\ 10^{6}$	$2.74\ 10^{12}$	$3.16\ 10^{11}$
Tc-99	$6.12\ 10^{8}$	$1.22\ 10^{49}$	$2.86\ 10^{10}$	$1.18\ 10^{11}$	$6.90\ 10^{9}$	$1.20\ 10^{12}$
Ru-106	$4.05\ 10^{27}$	$2.04\ 10^{21}$	nd	nd	$9.14\ 10^{11}$	$2.36\ 10^{9}$
Ag-108m	$2.20\ 10^{9}$	$4.42\ 10^{20}$	$6.07\ 10^{10}$	$3.78\ 10^{8}$	$3.32\ 10^{12}$	$4.18\ 10^{10}$
Ag-110m	$2.86\ 10^{35}$	$5.23\ 10^{18}$	nd	nd	$6.41\ 10^{12}$	$1.25\ 10^{11}$
Cd-109	$4.51\ 10^{23}$	$5.87\ 10^{49}$	nd	nd	$1.04\ 10^{12}$	$1.74\ 10^{12}$
Sb-125	$2.73\ 10^{16}$	$5.20\ 10^{21}$	nd	$3.01\ 10^{284}$	$4.17\ 10^{11}$	$1.20\ 10^{10}$
Sn-119m	$2.56\ 10^{33}$	nd	nd	nd	$8.43\ 10^{12}$	$7.09\ 10^{12}$
Sn-123	$1.41\ 10^{61}$	$1.89\ 10^{21}$	nd	nd	$2.97\ 10^{12}$	$1.92\ 10^{12}$
Sn-126	$1.47\ 10^{9}$	$1.58\ 10^{20}$	$7.24\ 10^{7}$	$4.60\ 10^{6}$	$3.00\ 10^{11}$	$5.41\ 10^{11}$
Te-127m	$1.43\ 10^{71}$	$2.96\ 10^{39}$	nd	nd	$4.07\ 10^{12}$	$1.59\ 10^{10}$
I-129	$3.01\ 10^{8}$	$1.92\ 10^{139}$	$1.31\ 10^{10}$	$1.99\ 10^{9}$	$1.44\ 10^{9}$	$3.64\ 10^{8}$
Ba-133	$5.02\ 10^{11}$	$2.16\ 10^{24}$	nd	$1.31\ 10^{80}$	$7.18\ 10^{9}$	$1.55\ 10^{12}$
Cs-134	$8.54\ 10^{17}$	$9.05\ 10^{19}$	nd	nd	$1.01\ 10^{11}$	$7.69\ 10^{9}$
Cs-135	$5.88\ 10^{10}$	$4.28\ 10^{57}$	$2.29\ 10^{11}$	$2.66\ 10^{11}$	$6.96\ 10^{11}$	$1.81\ 10^{10}$
Cs-137	$1.38\ 10^{10}$	$4.47\ 10^{20}$	nd	$3.50\ 10^{32}$	$1.10\ 10^{11}$	$3.99\ 10^{9}$
Ce-144	$3.32\ 10^{34}$	$3.63\ 10^{35}$	nd	nd	$4.81\ 10^{12}$	$2.63\ 10^{11}$

Radionuclide	Intrusion - Smallholder (60y) All ages, Ra-226 at 5m depth	Gas + Ext. (Recreational 0y) All ages Ra-226 at 5m depth	Erosion to coast (2540y) All ages (PC-Cream)	Erosion - Dog walker (2540y) All ages	Leachate spillage (0y) All ages	Fire in non-hazardous landfill - All ages
Pm-147	$2.89\ 10^{19}$	$1.79\ 10^{48}$	nd	nd	$2.14\ 10^{13}$	$3.12\ 10^{12}$
Sm-147	$7.17\ 10^{10}$	nd	$4.69\ 10^{10}$	$1.80\ 10^{9}$	$4.65\ 10^{11}$	$1.62\ 10^{9}$
Sm-151	$2.61\ 10^{13}$	nd	$5.55\ 10^{21}$	$3.44\ 10^{20}$	$1.02\ 10^{14}$	$3.90\ 10^{12}$
Eu-152	$5.92\ 10^{10}$	$8.04\ 10^{18}$	nd	$2.28\ 10^{63}$	$2.38\ 10^{12}$	$3.70\ 10^{11}$
Eu-154	$3.16\ 10^{11}$	$5.78\ 10^{18}$	nd	$6.74\ 10^{95}$	$1.51\ 10^{12}$	$2.93\ 10^{11}$
Eu-155	$6.49\ 10^{14}$	$1.26\ 10^{41}$	nd	$1.18\ 10^{169}$	$8.81\ 10^{12}$	$2.26\ 10^{12}$
Gd-153	$2.17\ 10^{38}$	$9.46\ 10^{42}$	nd	nd	$4.83\ 10^{13}$	$5.88\ 10^{12}$
Pb-210	$1.33\ 10^{9}$	$6.07\ 10^{22}$	nd	$1.80\ 10^{42}$	$2.94\ 10^{9}$	$3.12\ 10^{6}$
Po-210	$6.08\ 10^{56}$	$7.08\ 10^{24}$	nd	nd	$6.17\ 10^{9}$	$3.63\ 10^{9}$
Ra-226	$3.08\ 10^{13}$	$2.42\ 10^{14}$	$3.89\ 10^{6}$	$1.34\ 10^{7}$	$1.07\ 10^{10}$	$7.99\ 10^{8}$
Ra-228	$9.46\ 10^{10}$	$6.46\ 10^{15}$	nd	$3.06\ 10^{139}$	$2.25\ 10^{10}$	$2.61\ 10^{8}$
Ac-227	$2.10\ 10^{10}$	$1.66\ 10^{21}$	$5.54\ 10^{43}$	$2.10\ 10^{42}$	$3.04\ 10^{9}$	$2.74\ 10^{7}$
Th-228	$5.05\ 10^{18}$	$1.03\ 10^{16}$	nd	nd	$1.72\ 10^{11}$	$3.57\ 10^{8}$
Th-229	$5.17\ 10^{9}$	$3.87\ 10^{18}$	$2.51\ 10^{9}$	$2.88\ 10^{7}$	$5.58\ 10^{10}$	$6.09\ 10^{7}$
Th-230	$1.53\ 10^{9}$	$7.80\ 10^{38}$	$1.98\ 10^{6}$	$6.82\ 10^{6}$	$2.28\ 10^{11}$	$1.56\ 10^{8}$
Th-232	$1.63\ 10^{9}$	$1.73\ 10^{16}$	$5.10\ 10^{7}$	$7.95\ 10^{6}$	$1.67\ 10^{10}$	$9.19\ 10^{7}$
Pa-231	$2.71\ 10^{8}$	$3.42\ 10^{26}$	$6.65\ 10^{8}$	$3.84\ 10^{7}$	$8.98\ 10^{10}$	$1.11\ 10^{8}$
U-232	$9.33\ 10^{9}$	$1.16\ 10^{20}$	$4.05\ 10^{20}$	$2.26\ 10^{19}$	$9.43\ 10^{9}$	$1.93\ 10^{8}$
U-233	$6.47\ 10^{10}$	$3.01\ 10^{32}$	$1.02\ 10^{10}$	$1.02\ 10^{8}$	$1.25\ 10^{11}$	$1.62\ 10^{9}$
U-234	$7.44\ 10^{10}$	$7.61\ 10^{45}$	$1.45\ 10^{8}$	$1.48\ 10^{9}$	$1.30\ 10^{11}$	$1.66\ 10^{9}$
U-235	$1.99\ 10^{10}$	$1.09\ 10^{30}$	$6.71\ 10^{9}$	$6.93\ 10^{7}$	$1.35\ 10^{11}$	$1.83\ 10^{9}$
U-236	$7.46\ 10^{10}$	$9.70\ 10^{41}$	$2.24\ 10^{10}$	$1.97\ 10^{9}$	$1.36\ 10^{11}$	$1.79\ 10^{9}$
U-238	$6.71\ 10^{10}$	$2.10\ 10^{24}$	$1.39\ 10^{10}$	$2.02\ 10^{9}$	$1.23\ 10^{11}$	$1.95\ 10^{9}$
Np-237	$1.39\ 10^{10}$	$1.42\ 10^{27}$	$7.49\ 10^{8}$	$2.31\ 10^{8}$	$1.01\ 10^{10}$	$3.12\ 10^{8}$
Pu-238	$4.52\ 10^{10}$	$6.64\ 10^{47}$	$4.39\ 10^{11}$	$5.07\ 10^{12}$	$1.08\ 10^{11}$	$1.42\ 10^{8}$
Pu-239	$2.59\ 10^{10}$	$1.08\ 10^{32}$	$9.99\ 10^{8}$	$1.55\ 10^{8}$	$9.82\ 10^{10}$	$1.30\ 10^{8}$

Radionuclide	Intrusion - Smallholder (60y) All ages, Ra-226 at 5m depth	Gas + Ext. (Recreational 0y) All ages Ra-226 at 5m depth	Erosion to coast (2540y) All ages (PC-Cream)	Erosion - Dog walker (2540y) All ages	Leachate spillage (0y) All ages	Fire in non-hazardous landfill - All ages
Pu-240	$2.60\ 10^{10}$	$8.77\ 10^{54}$	$1.21\ 10^{9}$	$1.89\ 10^{8}$	$9.82\ 10^{10}$	$1.30\ 10^{8}$
Pu-241	$7.79\ 10^{11}$	$3.15\ 10^{41}$	$5.23\ 10^{12}$	$2.69\ 10^{11}$	$5.36\ 10^{12}$	$6.78\ 10^{9}$
Pu-242	$2.74\ 10^{10}$	$2.44\ 10^{66}$	$9.70\ 10^{8}$	$1.58\ 10^{8}$	$1.02\ 10^{11}$	$1.42\ 10^{8}$
Pu-244	$2.72\ 10^{10}$	$8.75\ 10^{24}$	$5.76\ 10^{8}$	$1.26\ 10^{8}$	$1.02\ 10^{11}$	$1.42\ 10^{8}$
Am-241	$2.61\ 10^{10}$	$4.73\ 10^{61}$	$1.80\ 10^{11}$	$9.19\ 10^{9}$	$3.28\ 10^{11}$	$1.62\ 10^{8}$
Am-242m	$2.10\ 10^{10}$	$3.35\ 10^{22}$	$3.56\ 10^{11}$	$6.76\ 10^{12}$	$2.72\ 10^{11}$	$1.35\ 10^{8}$
Am-243	$2.12\ 10^{10}$	$2.73\ 10^{30}$	$1.91\ 10^{9}$	$1.46\ 10^{8}$	$3.26\ 10^{11}$	$1.62\ 10^{8}$
Cm-242	$8.85\ 10^{12}$	$1.12\ 10^{42}$	nd	$1.61\ 10^{19}$	$3.38\ 10^{12}$	$2.64\ 10^{9}$
Cm-243	$7.01\ 10^{10}$	$7.35\ 10^{29}$	nd	$1.29\ 10^{11}$	$1.75\ 10^{11}$	$2.25\ 10^{8}$
Cm-244	$4.08\ 10^{11}$	nd	nd	$6.81\ 10^{10}$	$2.23\ 10^{11}$	$2.74\ 10^{8}$
Cm-245	$1.70\ 10^{10}$	$1.27\ 10^{35}$	$1.35\ 10^{9}$	$1.02\ 10^{8}$	$1.23\ 10^{11}$	$1.58\ 10^{8}$
Cm-246	$2.47\ 10^{10}$	$1.48\ 10^{139}$	$3.19\ 10^{9}$	$2.55\ 10^{8}$	$1.23\ 10^{11}$	$1.59\ 10^{8}$
Cm-248	$6.69\ 10^{9}$	nd	$6.15\ 10^{8}$	$4.84\ 10^{7}$	$3.35\ 10^{10}$	$4.33\ 10^{7}$

(1) Value is $5.16\ 10^{6}$ for the non-hazardous landfill.

(2) Where dose is effectively zero the radiological capacity is infinite, marked here as nd (not determined).

7.4.2.3 Sum of fraction for activity concentration

406. For the disposal of radioactive waste containing more than one radionuclide (n) the activity concentration of the different radionuclides (A_i) must also meet the following criterion:

$$\sum_{i=1 \text{ to } n} \frac{A_i}{A_{i\,Lim}} \le 1$$

where $A_{i\,Lim}$ is the activity concentration limit for radionuclide i.

407. This sum of fractions approach for activity concentration is the approach that is used to control disposals of the radionuclides shown in Table 4 under the Paris Convention on Third Party Liability (NEA, 2017).

408. Three scenarios have been used to calculate the limits to be applied to the activity concentrations of waste disposed at Port Clarence. These considered the exposure of a worker during emplacement, exposure of the public if a load is dropped and exposure of a trial pit excavator. The limiting concentrations have then been determined based on the dose criteria for the public and workers for these scenarios The values take into account the limits specified in the Paris convention (NEA, 2017).

409. Waste concentrations have then been banded as shown in Table 32. Six bands have been used to cover limits from 100 Bq g^{-1} to the upper limit of 10,000 Bq g^{-1}. A sum of fractions approach is used to limit the total activity concentration of consignments.

Table 32 Activity concentrations used to limit disposal of packaged LLW at Port Clarence

Activity concentration per consignment (Bq g^{-1})	Activity concentration per package that is part of a consignment (Bq g^{-1})	Radionuclides
100	500	Ra-228, Pu-239*, Am-241*
200	1,000	Co-60*, Sr-90*, Nb-94, Tc-99*, Ag-108m, Ag-110m, Sn-126, Cs-134, Cs-137*, Ra-226, Th-228, Th-232, Pa-231, U-232, U-238*
500	1,500	Mn-54, Zn-65, Eu-152, Eu-154, Th-229, Cm-248
1,000	3,000	Ba-133, Th-230, Pu-240, Pu-242, Pu-244, Am-242m, Am-243, Cm-245
2,000	4,000	Ru-106, Sb-125, Sm-147, Po-210, Ac-227, U-233, U-234, U-235, U-236, Np-237, Pu-238, Cm-242, Cm-243, Cm-244, Cm-246
10,000	12,000	H-3*, C-14*, Cl-36, Ca-41, Fe-55, Ni-59, Ni-63, Se-79, Mo-93, Zr-93, Nb-93m, Cd-109, Sn-119m, Sn-123,

Activity concentration per consignment (Bq g^{-1})	Activity concentration per package that is part of a consignment (Bq g^{-1})	Radionuclides
		Te-127m, I-129, Cs-135, Ce-144, Pm-147, Sm-151, Eu-155, Gd-153, Pb-210, Pu-241

Note: * radionuclides listed in the Paris convention

410. The activity limits for loose tipping wastes are calculated based on worker exposure and the risk to the public from a dropped load. The activity concentrations have been banded using four concentration limits from 5 Bq g^{-1} to 100 Bq g^{-1}. (see Table 33). A sum of fractions approach is used to limit the total activity concentration of loose tipped consignments.

Table 33 Activity concentrations used to limit disposal of LLW at Port Clarence by loose tipping

Activity concentration in the consignment (Bq g^{-1})	Radionuclides
5	Ac-227, Th-229, Th-232, Pa-231, Pu-239, Pu-240, Cm-248
10	Ra-228, Th-228, Th-230, U-232, Np-237, Pu-238, Pu-242, Pu-244, Am-241, Am-242m, Am-243, Cm-243, Cm-244, Cm-245, Cm-246
50	Ra-226
100	H-3, C-14, Cl-36, Ca-41, Mn-54, Fe-55, Co-60, Ni-59, Ni-63, Zn-65, Se-79, Sr-90, Mo-93, Zr-93, Nb-93m, Nb-94, Tc-99, Ru-106, Ag-108m, Ag-110m, Cd-109, Sb-125, Sn-119m, Sn-123, Sn-126, Te-127m, I-129, Ba-133, Cs-134, Cs-135, Cs-137, Ce-144, Pm-147, Sm-147, Sm-151, Eu-152, Eu-154, Eu-155, Gd-153, Pb-210, Po-210, U-233, U-234, U-235, U-236, U-238, Pu-241, Cm-242

7.4.2.4 Discussion

411. The sum of fractions approach is an internationally recognised approach (US NRC, 2014) and is considered to be best practice. The sum of fractions methodology described above takes account of the cumulative impact of disposal using the most restrictive scenario for each radionuclide. It is also proposed by the NEA (NEA, 2017) for the control of the activity concentration in the disposed waste. This sum of fractions approach is the approach proposed by Augean to control both the inventory disposed of at the site and the activity concentration of the waste that is accepted for disposal. Steps must be taken to ensure that the accumulated inventory at any time does not result in a sum of fractions exceeding one. Similarly, that the activity concentration in the waste proposed for disposal does not result in a sum of fraction exceeding one for the consignment or package. This is the approach proposed by Augean for the permit application for disposal of LLW.

412. An alternative approach for the control of the inventory at the site would be to attempt to forecast what the disposal inventory will be when the landfill closes and demonstrate that this assumed inventory is consistent with meeting regulatory guidance. For some disposal facilities, such estimates may be possible based on the National Waste Inventory and market projections. However, this approach is not desirable for Port Clarence landfills because the future inventory is very uncertain and subject to future commercial agreements.

413. Port Clarence also accepts Type 2 NORM under the provisions of the exemption from the requirement for a permit described in EPR. The radiological assessment that supported the Type 2 NORM exemption submission assumed that the Port Clarence site accepts about 100,000 t of Type 2 NORM per year. We propose to control the disposal of the Type 2 NORM according to this capacity, as is currently the case.

414. We also propose to control the disposal of LLW against the LLW capacity, using the sum of fractions approach described above. In addition, we will check that the dose constraint for a member of the public will also be met by calculating the combined dose from the LLW and from the NORM already disposed at the site. This check will be made before a LLW waste consignment is accepted for disposal and will apply to the receipts of LLW only.

7.4.3 Conditions for acceptance of LLW

415. Procedure LLW01 lists the conditions for acceptance (CFA) of LLW at the Port Clarence site that are part of the contract between the consignor and Augean. The conditions are in two parts: Part A being the "Specification" for the waste and Part B being the "Procedures" associated with the receipt and acceptance of the waste. Part A has four sections dealing with general requirements, radiological waste characteristics, hazardous waste and other conditions. Part B deals with the procedures that are applied. Those aspects that relate to the ESC are summarised below. The CFA is used in the contractual arrangements with consignors and is designed to provide information to Augean that will ensure that disposals at Port

Clarence meet permit conditions. The decision process leading to receipt of waste at the Port Clarence site is detailed in Section 7.3.1.

416. The working procedures that apply to radioactive waste accepted for disposal at the Port Clarence site include the following:

A procedure for the pre-acceptance of waste by the central technical team (LLW02).

A procedure for the receipt of waste, assay, quarantine, waste emplacement, coverage, record keeping and general LLW disposal operations (LLW03).

A procedure for the quarantine of non-compliant waste packages received at the Port Clarence site (LLW04).

A procedure for monitoring employee doses and instructions for measuring X-Ray and Gamma Radiation dose rates during acceptance of LLW waste at the Port Clarence site (LLW05).

A procedure for handling asbestos bearing packages.

Local rules in accordance with the Ionising Radiations Regulations

A procedure for routine and periodic health surveillance monitoring for contamination and exposure. An emergency plan including response arrangements to identified fault scenarios including:

i. Dropped load.

ii. Contamination discovery.

iii. Non-compliant load.

iv. Dose above threshold discovery.

v. Potentially contaminated person or wound.

Procedures for environmental monitoring incorporated into the Monitoring and Action Plans (MAPs).

A procedure outlining actions to be taken if consignments are unable to reach the site entrance in order to minimise risks to staff, the site and wider community (LLW06).

7.4.3.1 LLW01 Part A Conditions – Specification for Acceptance

General conditions

417. Consignors handling third party wastes to provide details of the organisation generating the waste and quality assurance to show the CFA have been applied at the point waste was produced.

418. Arrangements should be put in place by the consignor for the immediate return of non-compliant consignments delivered to the Port Clarence site.

Non-radiological characteristics

419. Non-radiological characteristics must be characterised for the waste to be assessed for acceptance.

420. Port Clarence landfill sites will not accept any of the following types of waste at the facility (definitions are from the Environmental Permitting Regulations):

any waste in liquid form;

waste which, in the conditions of landfill, is explosive, corrosive, oxidising, flammable or highly flammable;

hospital and other clinical wastes which arise from medical or veterinary establishments and which are infectious;

pressurised gas vessels; or,

chemical substances arising from research and development or teaching activities, such as laboratory residues, which are not identified or which are new, and whose effects on man or on the environment are not known.

421. In addition, the Port Clarence landfills will not accept waste with any of the following characteristics:

ion exchange materials (any material, whether synthetic or naturally occurring, that has the capability of interchanging ions from one substance to another by means of a reversible chemical or physical process);

complexing agents (either chelating agents or monodentate organic ligands);

waste which would otherwise present a danger to the facility operators during handling; or,

packages where the outer surface of the package is chemically contaminated.

422. All hazardous wastes deposited except asbestos must meet the specified leaching and other waste acceptance criteria in accordance with the Environmental Permitting Regulations.

423. All hazardous wastes disposed of at the site must meet the organic acceptance criteria; 10% Loss on ignition or 6% Total organic carbon.

Radiological acceptance criteria

424. The specific activity of radionuclides in any LLW consignment to Port Clarence is not greater than specified in Table 32 based on a sum of fractions.

425. The maximum mass of each waste/package/pallet combination to be received at the Port Clarence is normally limited to 2 t (arrangements can be made for heavier loads if necessary). The radioactive materials transport container used for transporting the waste to Port Clarence is the package that will be used for handling and final disposal. The container will be disposed directly to the final disposal position by careful offloading and will not be tipped. Packages should contain no void spaces and not be over-packed. Pallets will not be returned. Large surface contaminated objects or large items must be fully wrapped and sealed.

426. Port Clarence will accept unpackaged LLW waste for disposal by loose tipping if it is broadly homogeneous in physical form and activity concentration and meets the radiological acceptance criteria for unpackaged waste. Concentration limits for unpackaged waste are presented in Table 33.

427. The consignor needs to characterise the radionuclides in each package using good practice methods and provide details of quality assurance arrangements. The characterisation must be representative of the contents of the packages and not averaged over more than 10 t. Detection limits must be lower than Basic Safety Standards (BSS) exemption levels (European Commission, 2014). The activity of the radionuclides indicated in Table 6 where these are present at levels above the limit of detection must be reported. “Other radionuclides” need to be identified by name and activity, where reasonably practicable.

428. The total activity for the LLW in the package is the total activity of the radionuclides identified in column 1 of Table 6. Where the radionuclide is shown to have daughters in secular equilibrium (column 3), only the head of the chain should be reported. Where the activity of a daughter that is listed in column 1 (i.e. Pb-210 or Ra-228) exceeds the parent, the excess (i.e. the unsupported activity) of that daughter should also be reported. The risk assessments which underpin the ESC assume that the listed daughters always exist and appropriate dose conversion factors take this into account.

429. Radionuclides of less than a 3 month half-life are not normally included in the “Other radionuclides” category. However, if such nuclides are present in significant quantities (>5 MBq t^{-1} or a high percentage relative to the overall activity content) this must be reported.

430. The specific activity for radionuclides in the consignment, shall be such that the waste is defined as low level or very low level radioactive waste in accordance with current policy, except where wastes of less than a relevant exemption or exclusion order are mixed in with the LLW/VLLW as an inevitable result of the production such that separation is not reasonably practicable.

431. The sum of fractions of the radionuclides in the waste added to the sum of fractions of radionuclides already disposed of at Port Clarence is less than unity,

432. The consignor shall ensure that external non-fixed contamination levels on waste packages is as low as reasonably practicable throughout the process, complies with transport regulations and not more than 4 Bq cm^2 beta/gamma and 0.4 Bq cm^2 alpha

averaged over an area of 300 cm^2. The consignment is to be accompanied by monitoring certificates demonstrating compliance with this requirement.

433. External dose rates from packages are to be as low as reasonably practicable, in accordance with the transport regulations and will not exceed 0.01 mSv hr^{-1} at 1 m from the waste package on all sides. Monitoring certificates are required to demonstrate compliance.

434. It is not acceptable to purposely dilute waste or add shielding materials for the sole purpose of achieving compliance with these CFA.

435. Packages and unpackaged wastes should comply with the requirements of the current transport regulations, all the way through to the "as-disposed" condition. Additional shielding should not be used to ensure compliance. LLW waste for disposal by loose tipping should comply with the requirements for LSA 1 waste, be transported in such a manner that under routine conditions of transport there will be no escape of the radioactive contents from the conveyance, and each conveyance shall be under exclusive use of the consignor.

Other conditions

436. Waste characterisation shall be on a package by package basis unless a case can be made that characterisation of a waste stream of several packages can be justified for some or all determinants.

437. Waste to be received at the Port Clarence site will be provided with a full description including:

Source and origin of the waste;

The process producing the waste;

The composition of the waste and an assessment against relevant CFA values (including activity in consignment, mass of consignment and specific activity of consignment);

The appearance of the waste and a physical description;

A description of any non-radiological hazardous properties/classifications;

The mass of each package and the waste mass in each package, and for waste for loose tipping, the mass of waste in each vehicle;

Unique identification labelling of each waste package as required under the transport regulations;

An estimate of the void space in the package, where relevant;

Details of any pre-conditioning/treatment of the wastes that has been utilised; and,

Information relating to the safe transport of the waste as required under the transport regulations and details of the container/package to be used.

7.4.3.2 LLW01 Part B – Acceptance Procedures

438. All wastes must arise in the UK and the consigning site must have an appropriate transfer authorisation issued under EPR2016. As part of the pre-acceptance process applied by Augean, details of the methodology by which the waste was produced and characterised, the justification for the methodology and BAT reports, the quality assurance arrangements, container specifications including intermediate bulk containers (for waste exempt or excepted under radioactive materials transport regulations) and wrapping of large objects, the waste description and the results are required. Samples used in waste characterisation should be retained for one year after waste is received at the Port Clarence site and be available to Augean if requested. Pallet design is specified by Augean. Waste can only be shipped by the consignor once approval in writing is obtained from Augean, this will detail date for delivery and transport routing. Waste is to be transported by a carrier approved as competent by the consignor.

439. The pre-acceptance information supplied by the consignor is reviewed by the central technical assessment team (Procedure LLW02) and a decision taken in principle whether to approve or decline the consignment.

440. Wastes arriving at the landfill will be subject to the following on site verification:

The shipment will be checked while still on the vehicle against the pre-notified characterisation information for consistency and correctness.

The external dose rate at 1 m will be checked.

The packages will be visually checked for integrity.

The transport documentation will be checked for compliance with the transport regulations.

The characterisation documentation will be checked to ensure the waste has been pre-accepted and is compliant.

Receipt records will be generated.

The waste packages will not be opened or sampled at the landfill in order to minimise unnecessary exposure.

7.4.4 Radioactive waste disposal proposed permit conditions

441. Suggested Schedule 3 Tables are given below.

Table 34 Suggested Schedule 3 - Disposals of radioactive waste in hazardous landfill (Permit Table 3.1)

Table 3.1 Disposal by burial on the premises (hazardous landfill)							
Waste type	Disposal route	Sum of fractions limits					
		Radionuclide	Intrusion - Smallholder (60y) scenario - relevant value (TBq)	Gas + External (Recreational 0y) scenario - relevant value (TBq)	Erosion to coast (2540y) scenario - relevant value (TBq)	Erosion - Dog walker (2540y) scenario - relevant value (TBq)	Leachate spillage (0y) scenario - relevant value (TBq)
Solid waste with a maximum total activity concentration specified in Table 3.2	Burial on the premises in the hazardous waste landfill at Port Clarence.	H-3	$1.01\ 10^{5}$	$6.43\ 10^{3}$	nd	$1.65\ 10^{69}$	$5.24\ 10^{5}$
		C-14	$2.33\ 10^{2}$	$1.87\ 10^{2}$	$2.37\ 10^{3}$	$5.73\ 10^{5}$	$4.42\ 10^{4}$
		Cl-36	$1.56\ 10^{2}$	$5.27\ 10^{23}$	$1.21\ 10^{8}$	$1.93\ 10^{4}$	$4.01\ 10^{3}$
		Ca-41	$4.83\ 10^{4}$	nd	$1.28\ 10^{7}$	$1.62\ 10^{6}$	$2.83\ 10^{5}$
		Mn-54	$4.36\ 10^{24}$	$3.74\ 10^{13}$	nd	nd	$1.12\ 10^{7}$
		Fe-55	$1.16\ 10^{13}$	nd	nd	$7.93\ 10^{284}$	$1.86\ 10^{7}$
		Co-60	$3.12\ 10^{6}$	$3.31\ 10^{11}$	nd	$3.83\ 10^{145}$	$3.58\ 10^{5}$
		Ni-59	$5.06\ 10^{5}$	nd	$3.20\ 10^{5}$	$2.39\ 10^{6}$	$3.08\ 10^{7}$
		Ni-63	$3.10\ 10^{5}$	nd	$6.31\ 10^{13}$	$4.11\ 10^{13}$	$1.26\ 10^{7}$
		Zn-65	$1.35\ 10^{30}$	$5.24\ 10^{12}$	nd	nd	$8.95\ 10^{5}$
		Se-79	$8.98\ 10^{2}$	$2.36\ 10^{59}$	$9.27\ 10^{2}$	$2.95\ 10^{4}$	$5.31\ 10^{4}$
		Sr-90	$3.83\ 10^{2}$	$6.21\ 10^{20}$	nd	$6.33\ 10^{29}$	$2.58\ 10^{4}$
		Mo-93	$1.44\ 10^{3}$	$8.92\ 10^{3}$	$3.47\ 10^{3}$	$8.07\ 10^{4}$	$4.13\ 10^{5}$
		Zr-93	$1.48\ 10^{6}$	nd	$3.12\ 10^{5}$	$6.39\ 10^{5}$	$2.45\ 10^{6}$
		Nb-93m	$3.94\ 10^{7}$	$5.06\ 10^{4}$	nd	$8.18\ 10^{52}$	$3.05\ 10^{7}$
		Nb-94	$1.98\ 10^{3}$	$3.61\ 10^{13}$	$5.59\ 10^{2}$	$6.09\ 10^{0}$	$2.74\ 10^{6}$
		Tc-99	$6.12\ 10^{2}$	$1.22\ 10^{43}$	$2.86\ 10^{4}$	$1.18\ 10^{5}$	$6.90\ 10^{3}$
		Ru-106	$4.05\ 10^{21}$	$2.04\ 10^{15}$	nd	nd	$9.14\ 10^{5}$

Table 3.1 Disposal by burial on the premises (hazardous landfill)							
Waste type	Disposal route	Sum of fractions limits					
		Radionuclide	Intrusion - Smallholder (60y) scenario - relevant value (TBq)	Gas + External (Recreational 0y) scenario - relevant value (TBq)	Erosion to coast (2540y) scenario - relevant value (TBq)	Erosion - Dog walker (2540y) scenario - relevant value (TBq)	Leachate spillage (0y) scenario - relevant value (TBq)
		Ag-108m	$2.20\ 10^{3}$	$4.42\ 10^{14}$	$6.07\ 10^{4}$	$3.78\ 10^{2}$	$3.32\ 10^{6}$
		Ag-110m	$2.86\ 10^{29}$	$5.23\ 10^{12}$	nd	nd	$6.41\ 10^{6}$
		Cd-109	$4.51\ 10^{17}$	$5.87\ 10^{43}$	nd	nd	$1.04\ 10^{6}$
		Sb-125	$2.73\ 10^{10}$	$5.20\ 10^{15}$	nd	$3.01\ 10^{278}$	$4.17\ 10^{5}$
		Sn-119m	$2.56\ 10^{27}$	nd	nd	nd	$8.43\ 10^{6}$
		Sn-123	$1.41\ 10^{55}$	$1.89\ 10^{15}$	nd	nd	$2.97\ 10^{6}$
		Sn-126	$1.47\ 10^{3}$	$1.58\ 10^{14}$	$7.24\ 10^{1}$	$4.60\ 10^{0}$	$3.00\ 10^{5}$
		Te-127m	$1.43\ 10^{65}$	$2.96\ 10^{33}$	nd	nd	$4.07\ 10^{6}$
		I-129	$3.01\ 10^{2}$	$1.92\ 10^{133}$	$1.31\ 10^{4}$	$1.99\ 10^{3}$	$1.44\ 10^{3}$
		Ba-133	$5.02\ 10^{5}$	$2.16\ 10^{18}$	nd	$1.31\ 10^{74}$	$7.18\ 10^{3}$
		Cs-134	$8.54\ 10^{11}$	$9.05\ 10^{13}$	nd	nd	$1.01\ 10^{5}$
		Cs-135	$5.88\ 10^{4}$	$4.28\ 10^{51}$	$2.29\ 10^{5}$	$2.66\ 10^{5}$	$6.96\ 10^{5}$
		Cs-137	$1.38\ 10^{4}$	$4.47\ 10^{14}$	nd	$3.50\ 10^{26}$	$1.10\ 10^{5}$
		Ce-144	$3.32\ 10^{28}$	$3.63\ 10^{29}$	nd	nd	$4.81\ 10^{6}$
		Pm-147	$2.89\ 10^{13}$	$1.79\ 10^{42}$	nd	nd	$2.14\ 10^{7}$
		Sm-147	$7.17\ 10^{4}$	nd	$4.69\ 10^{4}$	$1.80\ 10^{3}$	$4.65\ 10^{5}$
		Sm-151	$2.61\ 10^{7}$	nd	$5.55\ 10^{15}$	$3.44\ 10^{14}$	$1.02\ 10^{8}$
		Eu-152	$5.92\ 10^{4}$	$8.04\ 10^{12}$	nd	$2.28\ 10^{57}$	$2.38\ 10^{6}$
		Eu-154	$3.16\ 10^{5}$	$5.78\ 10^{12}$	nd	$6.74\ 10^{89}$	$1.51\ 10^{6}$
		Eu-155	$6.49\ 10^{8}$	$1.26\ 10^{35}$	nd	$1.18\ 10^{163}$	$8.81\ 10^{6}$
		Gd-153	$2.17\ 10^{32}$	$9.46\ 10^{36}$	nd	nd	$4.83\ 10^{7}$
		Pb-210	$1.33\ 10^{3}$	$6.07\ 10^{16}$	nd	$1.80\ 10^{36}$	$2.94\ 10^{3}$
		Po-210	$6.08\ 10^{50}$	$7.08\ 10^{18}$	nd	nd	$6.17\ 10^{3}$

Table 3.1 Disposal by burial on the premises (hazardous landfill)								
Waste type	Disposal route	Sum of fractions limits						
		Radionuclide	Intrusion - Smallholder (60y) scenario - relevant value (TBq)	Gas + External (Recreational 0y) scenario - relevant value (TBq)	Erosion to coast (2540y) scenario - relevant value (TBq)	Erosion - Dog walker (2540y) scenario - relevant value (TBq)	Leachate spillage (0y) scenario - relevant value (TBq)
		Ra-226	$3.08\ 10^{7}$	$2.24\ 10^{11}$	$3.89\ 10^{0}$	$1.34\ 10^{1}$	$1.07\ 10^{4}$
		Ra-228	$9.46\ 10^{4}$	$6.46\ 10^{9}$	nd	$3.06\ 10^{133}$	$2.25\ 10^{4}$
		Ac-227	$2.10\ 10^{4}$	$1.66\ 10^{15}$	$5.54\ 10^{37}$	$2.10\ 10^{36}$	$3.04\ 10^{3}$
		Th-228	$5.05\ 10^{12}$	$1.03\ 10^{10}$	nd	nd	$1.72\ 10^{5}$
		Th-229	$5.17\ 10^{3}$	$3.87\ 10^{12}$	$2.51\ 10^{3}$	$2.88\ 10^{1}$	$5.58\ 10^{4}$
		Th-230	$1.53\ 10^{3}$	$7.80\ 10^{32}$	$1.98\ 10^{0}$	$6.82\ 10^{0}$	$2.28\ 10^{5}$
		Th-232	$1.63\ 10^{3}$	$1.73\ 10^{10}$	$5.10\ 10^{1}$	$7.95\ 10^{0}$	$1.67\ 10^{4}$
		Pa-231	$2.71\ 10^{2}$	$3.42\ 10^{20}$	$6.65\ 10^{2}$	$3.84\ 10^{1}$	$8.98\ 10^{4}$
		U-232	$9.33\ 10^{3}$	$1.16\ 10^{14}$	$4.05\ 10^{14}$	$2.26\ 10^{13}$	$9.43\ 10^{3}$
		U-233	$6.47\ 10^{4}$	$3.01\ 10^{26}$	$1.02\ 10^{4}$	$1.02\ 10^{2}$	$1.25\ 10^{5}$
		U-234	$7.44\ 10^{4}$	$7.61\ 10^{39}$	$1.45\ 10^{2}$	$1.48\ 10^{3}$	$1.30\ 10^{5}$
		U-235	$1.99\ 10^{4}$	$1.09\ 10^{24}$	$6.71\ 10^{3}$	$6.93\ 10^{1}$	$1.35\ 10^{5}$
		U-236	$7.46\ 10^{4}$	$9.70\ 10^{35}$	$2.24\ 10^{4}$	$1.97\ 10^{3}$	$1.36\ 10^{5}$
		U-238	$6.71\ 10^{4}$	$2.10\ 10^{18}$	$1.39\ 10^{4}$	$2.02\ 10^{3}$	$1.23\ 10^{5}$
		Np-237	$1.39\ 10^{4}$	$1.42\ 10^{21}$	$7.49\ 10^{2}$	$2.31\ 10^{2}$	$1.01\ 10^{4}$
		Pu-238	$4.52\ 10^{4}$	$6.64\ 10^{41}$	$4.39\ 10^{5}$	$5.07\ 10^{6}$	$1.08\ 10^{5}$
		Pu-239	$2.59\ 10^{4}$	$1.08\ 10^{26}$	$9.99\ 10^{2}$	$1.55\ 10^{2}$	$9.82\ 10^{4}$
		Pu-240	$2.60\ 10^{4}$	$8.77\ 10^{48}$	$1.21\ 10^{3}$	$1.89\ 10^{2}$	$9.82\ 10^{4}$
		Pu-241	$7.79\ 10^{5}$	$3.15\ 10^{35}$	$5.23\ 10^{6}$	$2.69\ 10^{5}$	$5.36\ 10^{6}$
		Pu-242	$2.74\ 10^{4}$	$2.44\ 10^{60}$	$9.70\ 10^{2}$	$1.58\ 10^{2}$	$1.02\ 10^{5}$
		Pu-244	$2.72\ 10^{4}$	$8.75\ 10^{18}$	$5.76\ 10^{2}$	$1.26\ 10^{2}$	$1.02\ 10^{5}$
		Am-241	$2.61\ 10^{4}$	$4.73\ 10^{55}$	$1.80\ 10^{5}$	$9.19\ 10^{3}$	$3.28\ 10^{5}$
		Am-242m	$2.10\ 10^{4}$	$3.35\ 10^{16}$	$3.56\ 10^{5}$	$6.76\ 10^{6}$	$2.72\ 10^{5}$

Table 3.1 Disposal by burial on the premises (hazardous landfill)								
Waste type	Disposal route	Sum of fractions limits						
		Radionuclide	Intrusion - Smallholder (60y) scenario - relevant value (TBq)	Gas + External (Recreational 0y) scenario - relevant value (TBq)	Erosion to coast (2540y) scenario - relevant value (TBq)	Erosion - Dog walker (2540y) scenario - relevant value (TBq)	Leachate spillage (0y) scenario - relevant value (TBq)
		Am-243	$2.12\ 10^{4}$	$2.73\ 10^{24}$	$1.91\ 10^{3}$	$1.46\ 10^{2}$	$3.26\ 10^{5}$
		Cm-242	$8.85\ 10^{6}$	$1.12\ 10^{36}$	nd	$1.61\ 10^{13}$	$3.38\ 10^{6}$
		Cm-243	$7.01\ 10^{4}$	$7.35\ 10^{23}$	nd	$1.29\ 10^{5}$	$1.75\ 10^{5}$
		Cm-244	$4.08\ 10^{5}$	nd	nd	$6.81\ 10^{4}$	$2.23\ 10^{5}$
		Cm-245	$1.70\ 10^{4}$	$1.27\ 10^{29}$	$1.35\ 10^{3}$	$1.02\ 10^{2}$	$1.23\ 10^{5}$
		Cm-246	$2.47\ 10^{4}$	$1.48\ 10^{133}$	$3.19\ 10^{3}$	$2.55\ 10^{2}$	$1.23\ 10^{5}$
		Cm-248	$6.69\ 10^{3}$	nd	$6.15\ 10^{2}$	$4.84\ 10^{1}$	$3.35\ 10^{4}$

Table 35 Suggested Schedule 3 - Disposals of radioactive waste in hazardous landfill (Permit Table 3.1)

Table 3.1 Disposal by burial on the premises (non-hazardous landfill)								
Waste type	Disposal route	Sum of fractions limits						
		Radionuclide	Intrusion - Smallholder (60y) scenario - relevant value (TBq)	Gas + External (Recreational 0y) scenario - relevant value (TBq)	Erosion to coast (2540y) scenario - relevant value (TBq)	Erosion - Dog walker (2540y) scenario - relevant value (TBq)	Leachate spillage (0y) scenario - relevant value (TBq)	Fire in non-hazardous landfill - relevant value (TBq)
Solid waste with a maximum total activity concentration	Burial on the premises in the non-hazardous	H-3	$1.01\ 10^{5}$	$6.43\ 10^{3}$	nd	$1.65\ 10^{69}$	$5.24\ 10^{5}$	$6.00\ 10^{4}$
		C-14	$2.33\ 10^{2}$	$5.16\ 10^{0}$	$2.37\ 10^{3}$	$5.73\ 10^{5}$	$4.42\ 10^{4}$	$2.69\ 10^{3}$
		Cl-36	$1.56\ 10^{2}$	$5.27\ 10^{23}$	$1.21\ 10^{8}$	$1.93\ 10^{4}$	$4.01\ 10^{3}$	$2.14\ 10^{3}$
		Ca-41	$4.83\ 10^{4}$	nd	$1.28\ 10^{7}$	$1.62\ 10^{6}$	$2.83\ 10^{5}$	$7.38\ 10^{7}$
		Mn-54	$4.36\ 10^{24}$	$3.74\ 10^{13}$	nd	nd	$1.12\ 10^{7}$	$9.26\ 10^{6}$

Table 3.1 Disposal by burial on the premises (non-hazardous landfill)								
Waste type	Disposal route	Sum of fractions limits						
		Radionuclide	Intrusion - Smallholder (60y) scenario - relevant value (TBq)	Gas + External (Recreational 0y) scenario - relevant value (TBq)	Erosion to coast (2540y) scenario - relevant value (TBq)	Erosion - Dog walker (2540y) scenario - relevant value (TBq)	Leachate spillage (0y) scenario - relevant value (TBq)	Fire in non-hazardous landfill - relevant value (TBq)
specified in Table 3.2	waste landfill at Port Clarence.	Fe-55	$1.16\ 10^{13}$	nd	nd	$7.93\ 10^{284}$	$1.86\ 10^{7}$	$1.74\ 10^{7}$
		Co-60	$3.12\ 10^{6}$	$3.31\ 10^{11}$	nd	$3.83\ 10^{145}$	$3.58\ 10^{5}$	$4.96\ 10^{5}$
		Ni-59	$5.06\ 10^{5}$	nd	$3.20\ 10^{5}$	$2.39\ 10^{6}$	$3.08\ 10^{7}$	$3.54\ 10^{7}$
		Ni-63	$3.10\ 10^{5}$	nd	$6.31\ 10^{13}$	$4.11\ 10^{13}$	$1.26\ 10^{7}$	$1.20\ 10^{7}$
		Zn-65	$1.35\ 10^{30}$	$5.24\ 10^{12}$	nd	nd	$8.95\ 10^{5}$	$6.15\ 10^{4}$
		Se-79	$8.98\ 10^{2}$	$2.36\ 10^{59}$	$9.27\ 10^{2}$	$2.95\ 10^{4}$	$5.31\ 10^{4}$	$2.29\ 10^{3}$
		Sr-90	$3.83\ 10^{2}$	$6.21\ 10^{20}$	nd	$6.33\ 10^{29}$	$2.58\ 10^{4}$	$9.66\ 10^{4}$
		Mo-93	$1.44\ 10^{3}$	$8.92\ 10^{3}$	$3.47\ 10^{3}$	$8.07\ 10^{4}$	$4.13\ 10^{5}$	$6.78\ 10^{6}$
		Zr-93	$1.48\ 10^{6}$	nd	$3.12\ 10^{5}$	$6.39\ 10^{5}$	$2.45\ 10^{6}$	$6.24\ 10^{5}$
		Nb-93m	$3.94\ 10^{7}$	$5.06\ 10^{4}$	nd	$8.18\ 10^{52}$	$3.05\ 10^{7}$	$8.66\ 10^{6}$
		Nb-94	$1.98\ 10^{3}$	$3.61\ 10^{13}$	$5.59\ 10^{2}$	$6.09\ 10^{0}$	$2.74\ 10^{6}$	$3.16\ 10^{5}$
		Tc-99	$6.12\ 10^{2}$	$1.22\ 10^{43}$	$2.86\ 10^{4}$	$1.18\ 10^{5}$	$6.90\ 10^{3}$	$1.20\ 10^{6}$
		Ru-106	$4.05\ 10^{21}$	$2.04\ 10^{15}$	nd	nd	$9.14\ 10^{5}$	$2.36\ 10^{3}$
		Ag-108m	$2.20\ 10^{3}$	$4.42\ 10^{14}$	$6.07\ 10^{4}$	$3.78\ 10^{2}$	$3.32\ 10^{6}$	$4.18\ 10^{4}$
		Ag-110m	$2.86\ 10^{29}$	$5.23\ 10^{12}$	nd	nd	$6.41\ 10^{6}$	$1.25\ 10^{5}$
		Cd-109	$4.51\ 10^{17}$	$5.87\ 10^{43}$	nd	nd	$1.04\ 10^{6}$	$1.74\ 10^{6}$
		Sb-125	$2.73\ 10^{10}$	$5.20\ 10^{15}$	nd	$3.01\ 10^{278}$	$4.17\ 10^{5}$	$1.20\ 10^{4}$
		Sn-119m	$2.56\ 10^{27}$	nd	nd	nd	$8.43\ 10^{6}$	$7.09\ 10^{6}$
		Sn-123	$1.41\ 10^{55}$	$1.89\ 10^{15}$	nd	nd	$2.97\ 10^{6}$	$1.92\ 10^{6}$
		Sn-126	$1.47\ 10^{3}$	$1.58\ 10^{14}$	$7.24\ 10^{1}$	$4.60\ 10^{0}$	$3.00\ 10^{5}$	$5.41\ 10^{5}$
		Te-127m	$1.43\ 10^{65}$	$2.96\ 10^{33}$	nd	nd	$4.07\ 10^{6}$	$1.59\ 10^{4}$
		I-129	$3.01\ 10^{2}$	$1.92\ 10^{133}$	$1.31\ 10^{4}$	$1.99\ 10^{3}$	$1.44\ 10^{3}$	$3.64\ 10^{2}$
		Ba-133	$5.02\ 10^{5}$	$2.16\ 10^{18}$	nd	$1.31\ 10^{74}$	$7.18\ 10^{3}$	$1.55\ 10^{6}$

Table 3.1 Disposal by burial on the premises (non-hazardous landfill)								
Waste type	Disposal route	Sum of fractions limits						
		Radionuclide	Intrusion - Smallholder (60y) scenario - relevant value (TBq)	Gas + External (Recreational 0y) scenario - relevant value (TBq)	Erosion to coast (2540y) scenario - relevant value (TBq)	Erosion - Dog walker (2540y) scenario - relevant value (TBq)	Leachate spillage (0y) scenario - relevant value (TBq)	Fire in non-hazardous landfill - relevant value (TBq)
		Cs-134	$8.54\ 10^{11}$	$9.05\ 10^{13}$	nd	nd	$1.01\ 10^{5}$	$7.69\ 10^{3}$
		Cs-135	$5.88\ 10^{4}$	$4.28\ 10^{51}$	$2.29\ 10^{5}$	$2.66\ 10^{5}$	$6.96\ 10^{5}$	$1.81\ 10^{4}$
		Cs-137	$1.38\ 10^{4}$	$4.47\ 10^{14}$	nd	$3.50\ 10^{26}$	$1.10\ 10^{5}$	$3.99\ 10^{3}$
		Ce-144	$3.32\ 10^{28}$	$3.63\ 10^{29}$	nd	nd	$4.81\ 10^{6}$	$2.63\ 10^{5}$
		Pm-147	$2.89\ 10^{13}$	$1.79\ 10^{42}$	nd	nd	$2.14\ 10^{7}$	$3.12\ 10^{6}$
		Sm-147	$7.17\ 10^{4}$	nd	$4.69\ 10^{4}$	$1.80\ 10^{3}$	$4.65\ 10^{5}$	$1.62\ 10^{3}$
		Sm-151	$2.61\ 10^{7}$	nd	$5.55\ 10^{15}$	$3.44\ 10^{14}$	$1.02\ 10^{8}$	$3.90\ 10^{6}$
		Eu-152	$5.92\ 10^{4}$	$8.04\ 10^{12}$	nd	$2.28\ 10^{57}$	$2.38\ 10^{6}$	$3.70\ 10^{5}$
		Eu-154	$3.16\ 10^{5}$	$5.78\ 10^{12}$	nd	$6.74\ 10^{89}$	$1.51\ 10^{6}$	$2.93\ 10^{5}$
		Eu-155	$6.49\ 10^{8}$	$1.26\ 10^{35}$	nd	$1.18\ 10^{163}$	$8.81\ 10^{6}$	$2.26\ 10^{6}$
		Gd-153	$2.17\ 10^{32}$	$9.46\ 10^{36}$	nd	nd	$4.83\ 10^{7}$	$5.88\ 10^{6}$
		Pb-210	$1.33\ 10^{3}$	$6.07\ 10^{16}$	nd	$1.80\ 10^{36}$	$2.94\ 10^{3}$	$3.12\ 10^{0}$
		Po-210	$6.08\ 10^{50}$	$7.08\ 10^{18}$	nd	nd	$6.17\ 10^{3}$	$3.63\ 10^{3}$
		Ra-226	$3.08\ 10^{7}$	$2.24\ 10^{11}$	$3.89\ 10^{0}$	$1.34\ 10^{1}$	$1.07\ 10^{4}$	$7.99\ 10^{2}$
		Ra-228	$9.46\ 10^{4}$	$6.46\ 10^{9}$	nd	$3.06\ 10^{133}$	$2.25\ 10^{4}$	$2.61\ 10^{2}$
		Ac-227	$2.10\ 10^{4}$	$1.66\ 10^{15}$	$5.54\ 10^{37}$	$2.10\ 10^{36}$	$3.04\ 10^{3}$	$2.74\ 10^{1}$
		Th-228	$5.05\ 10^{12}$	$1.03\ 10^{10}$	nd	nd	$1.72\ 10^{5}$	$3.57\ 10^{2}$
		Th-229	$5.17\ 10^{3}$	$3.87\ 10^{12}$	$2.51\ 10^{3}$	$2.88\ 10^{1}$	$5.58\ 10^{4}$	$6.09\ 10^{1}$
		Th-230	$1.53\ 10^{3}$	$7.80\ 10^{32}$	$1.98\ 10^{0}$	$6.82\ 10^{0}$	$2.28\ 10^{5}$	$1.56\ 10^{2}$
		Th-232	$1.63\ 10^{3}$	$1.73\ 10^{10}$	$5.10\ 10^{1}$	$7.95\ 10^{0}$	$1.67\ 10^{4}$	$9.19\ 10^{1}$
		Pa-231	$2.71\ 10^{2}$	$3.42\ 10^{20}$	$6.65\ 10^{2}$	$3.84\ 10^{1}$	$8.98\ 10^{4}$	$1.11\ 10^{2}$
		U-232	$9.33\ 10^{3}$	$1.16\ 10^{14}$	$4.05\ 10^{14}$	$2.26\ 10^{13}$	$9.43\ 10^{3}$	$1.93\ 10^{2}$
		U-233	$6.47\ 10^{4}$	$3.01\ 10^{26}$	$1.02\ 10^{4}$	$1.02\ 10^{2}$	$1.25\ 10^{5}$	$1.62\ 10^{3}$

Table 3.1 Disposal by burial on the premises (non-hazardous landfill)								
Waste type	Disposal route	Sum of fractions limits						
		Radionuclide	Intrusion - Smallholder (60y) scenario - relevant value (TBq)	Gas + External (Recreational 0y) scenario - relevant value (TBq)	Erosion to coast (2540y) scenario - relevant value (TBq)	Erosion - Dog walker (2540y) scenario - relevant value (TBq)	Leachate spillage (0y) scenario - relevant value (TBq)	Fire in non-hazardous landfill - relevant value (TBq)
		U-234	$7.44\ 10^{4}$	$7.61\ 10^{39}$	$1.45\ 10^{2}$	$1.48\ 10^{3}$	$1.30\ 10^{5}$	$1.66\ 10^{3}$
		U-235	$1.99\ 10^{4}$	$1.09\ 10^{24}$	$6.71\ 10^{3}$	$6.93\ 10^{1}$	$1.35\ 10^{5}$	$1.83\ 10^{3}$
		U-236	$7.46\ 10^{4}$	$9.70\ 10^{35}$	$2.24\ 10^{4}$	$1.97\ 10^{3}$	$1.36\ 10^{5}$	$1.79\ 10^{3}$
		U-238	$6.71\ 10^{4}$	$2.10\ 10^{18}$	$1.39\ 10^{4}$	$2.02\ 10^{3}$	$1.23\ 10^{5}$	$1.95\ 10^{3}$
		Np-237	$1.39\ 10^{4}$	$1.42\ 10^{21}$	$7.49\ 10^{2}$	$2.31\ 10^{2}$	$1.01\ 10^{4}$	$3.12\ 10^{2}$
		Pu-238	$4.52\ 10^{4}$	$6.64\ 10^{41}$	$4.39\ 10^{5}$	$5.07\ 10^{6}$	$1.08\ 10^{5}$	$1.42\ 10^{2}$
		Pu-239	$2.59\ 10^{4}$	$1.08\ 10^{26}$	$9.99\ 10^{2}$	$1.55\ 10^{2}$	$9.82\ 10^{4}$	$1.30\ 10^{2}$
		Pu-240	$2.60\ 10^{4}$	$8.77\ 10^{48}$	$1.21\ 10^{3}$	$1.89\ 10^{2}$	$9.82\ 10^{4}$	$1.30\ 10^{2}$
		Pu-241	$7.79\ 10^{5}$	$3.15\ 10^{35}$	$5.23\ 10^{6}$	$2.69\ 10^{5}$	$5.36\ 10^{6}$	$6.78\ 10^{3}$
		Pu-242	$2.74\ 10^{4}$	$2.44\ 10^{60}$	$9.70\ 10^{2}$	$1.58\ 10^{2}$	$1.02\ 10^{5}$	$1.42\ 10^{2}$
		Pu-244	$2.72\ 10^{4}$	$8.75\ 10^{18}$	$5.76\ 10^{2}$	$1.26\ 10^{2}$	$1.02\ 10^{5}$	$1.42\ 10^{2}$
		Am-241	$2.61\ 10^{4}$	$4.73\ 10^{55}$	$1.80\ 10^{5}$	$9.19\ 10^{3}$	$3.28\ 10^{5}$	$1.62\ 10^{2}$
		Am-242m	$2.10\ 10^{4}$	$3.35\ 10^{16}$	$3.56\ 10^{5}$	$6.76\ 10^{6}$	$2.72\ 10^{5}$	$1.35\ 10^{2}$
		Am-243	$2.12\ 10^{4}$	$2.73\ 10^{24}$	$1.91\ 10^{3}$	$1.46\ 10^{2}$	$3.26\ 10^{5}$	$1.62\ 10^{2}$
		Cm-242	$8.85\ 10^{6}$	$1.12\ 10^{36}$	nd	$1.61\ 10^{13}$	$3.38\ 10^{6}$	$2.64\ 10^{3}$
		Cm-243	$7.01\ 10^{4}$	$7.35\ 10^{23}$	nd	$1.29\ 10^{5}$	$1.75\ 10^{5}$	$2.25\ 10^{2}$
		Cm-244	$4.08\ 10^{5}$	nd	nd	$6.81\ 10^{4}$	$2.23\ 10^{5}$	$2.74\ 10^{2}$
		Cm-245	$1.70\ 10^{4}$	$1.27\ 10^{29}$	$1.35\ 10^{3}$	$1.02\ 10^{2}$	$1.23\ 10^{5}$	$1.58\ 10^{2}$
		Cm-246	$2.47\ 10^{4}$	$1.48\ 10^{133}$	$3.19\ 10^{3}$	$2.55\ 10^{2}$	$1.23\ 10^{5}$	$1.59\ 10^{2}$
		Cm-248	$6.69\ 10^{3}$	nd	$6.15\ 10^{2}$	$4.84\ 10^{1}$	$3.35\ 10^{4}$	$4.33\ 10^{1}$

7.5 Monitoring {R14}

442. The NS-GRA outlines the requirement for the operator to undertake a monitoring programme to support the environmental safety case (Requirement 14):

> "In support of the environmental safety case, the developer/operator of a disposal facility for solid radioactive waste should carry out a programme to monitor for changes caused by construction, operation and closure of the facility.
>
> The developer/operator should establish a reasoned and proportionate approach to a programme for monitoring the site and facility. This monitoring will provide data during the period of authorisation to ensure that the facility is operating within the parameters set out in the environmental safety case. However, the monitoring must not itself compromise the environmental safety of the facility.
>
> (UK Environment Agencies, 2009), para 6.4.31 and 6.4.32."

443. There are two main reasons for a monitoring programme at the site:

- Demonstration of compliance with stated regulatory requirements; and,
- Reassurance of stakeholders that disposal at Port Clarence is safe and being managed appropriately.

7.5.1 Existing monitoring programme

444. Augean currently operates a monitoring programme at Port Clarence in connection with the hazardous waste and non-hazardous waste disposal permits.

7.5.2 Proposed monitoring programme in relation to the LLW permit

445. Augean currently operates a LLW permit monitoring programme at the ENRMF. Augean propose using a similar LLW permit monitoring programme and reporting arrangements at Port Clarence with minor modifications. The key aspects are:

- bi-annual radiochemical analysis of groundwater for several existing boreholes close to the site, analysis would be for gamma spectrometry, gross alpha / beta in waters and H-3 in aqueous samples;
- annual radiochemical analysis of bulked leachate, analysis would be for gamma spectrometry, gross alpha / beta in waters and H-3 in aqueous samples;
- quarterly radiochemical analysis of leachate treated off-site, analysis would be for gamma spectrometry, gross alpha / beta in waters and H-3 in aqueous samples;

- bi-annual radiochemical analysis of surface water, analysis would be for gamma spectrometry, gross alpha/beta in waters and H-3 in aqueous samples;
- bi-annual radiochemical analysis of the landfill gas generator input for the radioactive gases identified in the risk assessment;
- quarterly radiochemical analysis for dust deposited on a powered static air sampler paper at one predominantly downwind location on the site boundary to include gamma spectrometry and gross alpha/beta;
- quarterly site perimeter dose rate at four locations; and,
- annual analysis of randomly selected surface soils from four points around the site boundary to include gamma spectrometry and gross alpha/beta.

7.5.3 Reassurance

446. The monitoring results will be made available for public scrutiny and published through the company website (http://www.augeanplc.com/enrmf). This will include a commentary to provide a context for the monitoring results and help with their interpretation.

447. It is expected that independent analysis of samples from the site will be undertaken by the Environment Agency to provide a check on the validity of the monitoring work undertaken by Augean.

448. Additional monitoring will also be undertaken prior to work starting on new waste cells to ensure the development has no impact on system performance. This will be repeated once work on each cell is completed.

7.5.4 Groundwater monitoring programme

449. The monitoring programme for groundwater has considered the predicted groundwater concentrations, the detection limits and the expected doses from the predicted concentrations.

450. The projected peak groundwater concentrations at the boundary of the site are shown in Table 36 for the radionuclides listed above. The peak concentration during the period of authorisation (PoA) and that observed over the whole period modelled are presented.

Table 36 Peak groundwater concentrations at the site boundary, analytical detection limits and water concentrations producing a dose of 20 µSv

Radionuclide	Typical detection limit	Projected groundwater concentration after disposal of the radiological capacity - Max during PoA (Bq l^{-1})	Drinking water concentration giving a dose of 20 µSv (Bq l^{-1})
H-3	4 Bq l^{-1}	1.35 10^{-2}	2000
Cl-36[1]	0.29 Bq l^{-1}	6.84 10^{-4}	20.8
Sr-90[1]	0.11 Bq l^{-1}	2.11 10^{-14}	0.8
I-129[1]	0.02 Bq l^{-1}	2.02 10^{-9}	0.20
Pb-210	0.002 Bq g^{-1}	4.26 10^{-23}	0.012

1. Detection limit reported for Sellafield groundwater assessments.

451. Typical detection limits are also listed. This shows that even if the radiological capacity is disposed of at the site, no radionuclides would be detected in groundwater during the PoA.

452. The last column of the table provides an estimate of activity concentrations in water that result in a dose of 20 µSv y^{-1}, based on HPA assessments (Ewers & Mobbs, 2010). Their value is greater than the projected groundwater concentration for H-3 and Sr-90, indicating that doses from groundwater will be lower than 20 µSv y^{-1} even if these radionuclides are disposed of at the radiological capacity.

453. This review shows that, based on the radiological capacity that can be disposed of at the site and the radionuclide mix of the wastes, these radionuclides are very unlikely to be detected in groundwater using current techniques. Routine analysis of radionuclides that are expected to be at levels below the detection limits, and are found to be below the detection limits, does not provide any useful information.

454. There is uncertainty associated with the groundwater model predictions and for this reason the list of radionuclides routinely analysed in groundwater should be reviewed as the inventory accumulates. Thus, additional radionuclides would be analysed as the inventory of the radionuclides increases and passes certain trigger levels.

455. Routine groundwater monitoring will include analysis for H-3 and Pb-210. If the levels are found to be above those expected, then following confirmation of the unexpected results, the analytical approach will be changed to look for all of the radionuclides identified above.

8 Summary of the Environmental Safety Case

456. This document is a new ESC for the disposal of LLW at the Port Clarence site. A permit is sought to allow receipt and disposal of radioactive waste to the hazardous and non-hazardous landfills. A submission to the European Commission under Article 37 of the Euratom treaty is based on this ESC.

457. The overall safety strategy for the disposal of LLW at Port Clarence involves both active (operational) management and the construction of passive barriers ensuring that disposed wastes will give rise to low impacts, within the dose and risk guidance levels laid down in the regulatory guidance, the NS-GRA (UK Environment Agencies, 2009). The ESC has considered all of the requirements in the NS-GRA and put forward calculations and arguments to demonstrate compliance. The sections of this document follow the structure of the NS-GRA (section titles indicate how document sections relate to the NS-GRA requirements). This final section draws together the main arguments that demonstrate the environmental safety of the Port Clarence landfills now and in the future.

458. Other applications are being submitted to the Environment Agency in parallel concerning the disposal of non-hazardous and hazardous waste to the landfills. Refer to permits EPR/BV/1399IT for the disposal of hazardous waste and EPR/BV/1402IC for the disposal of non-hazardous waste.

459. The Port Clarence landfills have been operating since 2000 and by Augean North Limited since 2004. The site has two landfills, one accepting hazardous waste and one accepting non-hazardous waste. Very low activity NORM waste has been disposed at the site since 2016. Typically this NORM waste has concentrations between 1 and 2 Bq g^{-1} and is disposed at Port Clarence without an Environmental Permit through compliance with Paragraphs 18 and 19 in Section 6 of Part 6 to Schedule 23 of the Environmental Permitting Regulations.

460. The strategic need for disposal of LLW at a site in the northeast is discussed in Section 1.1 in terms of national policy and location. There have been no fundamental changes to the strategic need or legislation since the planning inspectors report for the ENRMF (The Planning Inspectorate, 2013).

8.1 Protection against radiological hazards

461. The inventory requiring disposal at Port Clarence is uncertain at this stage. Our approach is therefore to define the inventory that can be safely accepted and to put in place controls to ensure that this inventory is not exceeded. The ESC considers scenarios involving exposure to waste during normal operations, scenarios involving the expected site evolution and a full range of scenarios involving unexpected exposure resulting from the disposal of LLW. This range of scenarios ensures that for all reasonably foreseeable circumstances doses or risks remain below the relevant dose and risk guidance levels. The level of complexity that we have used in our assessments is proportionate and consistent with the level of detail in other safety cases.

462. The ESC takes a similar approach to the application document prepared for the ENRMF (Eden NE, 2015a; Eden NE, 2015b) using many of the same models that supported the radiological assessments underpinning the proposed disposal limits for LLW. The parameters used in the models have been updated as necessary to reflect the Port Clarence environment and any intervening changes in recommendations.

463. The assessment methodology that we have used draws heavily on methodologies developed under the sponsorship of the Environment Agency. We have used approaches developed by the Health Protection Agency (now PHE), the environment agencies (SNIFFER) and a screening methodology developed by the Environment Agency for operational releases. Where relevant we have also adopted approaches used in the LLWR ESC that have already been subject to detailed review by the Environment Agency.

464. The SNIFFER methodology and data have been used for several scenarios (SNIFFER, 2006). Model parameters have been adjusted to account for site specific inputs and have been adapted to take into account National Dose Assessment Working Group (NDAWG) recommendations concerning critical groups (NDAWG, 2013). The scenarios that use the SNIFFER approaches are shown in Table 37.

465. The assessment of worker exposures has been carried out using the occupancy times used for the ENRMF assessment. The assessment of dropped loads adopts the UKAEA methodology as used for the ENRMF assessment. Assessment of the impact of radioactive particles and discrete items was based on the models used by LLWR.

466. The assessment of the impact on non-human biota has been undertaken using the assessment tool developed as part of the ERICA project (Environmental Risk from Ionising Contaminants: Assessment and Management) (ERICA, 2008) and has used the version released in June 2019. The ERICA toolkit allows for consideration of three ecosystems: terrestrial, freshwater and marine. Each of these has been considered for the Port Clarence site. Within these ecosystems, the ERICA Tool considers a range of wildlife groups. The assessment undertaken for non-human biota shows that the controls on the waste inventory, which are aimed at protecting the public, do not represent a risk to local biota. The assessment also includes the impact on burrowing mammals that dig into the waste post closure and show that they are protected if LLW waste is buried below the burrowing depth, or restrictions are placed on wastes within the burrowing depth.

467. The groundwater pathways have been assessed using a model implemented specifically for the Port Clarence site and environs. The model was developed using the GoldSim software, which was used because it provides a flexible modelling framework and the effects of decay and ingrowth can easily be accounted for. Where appropriate, input data have been used that are consistent with the HRA (MJCA, 2019b). Data have been used from other sources where appropriate.

Table 37 Summary of modelling approaches

Scenario	Exposed group	Modelling approach
Period of Authorisation – likely to occur		
Direct exposure	Worker	HPA/IAEA SR44
Loose tipping	Worker	IAEA SR44
	Member of public	IAEA SR44
Leachate processing off- site at treatment works	Treatment worker	Initial radiological assessment methodology (Environment Agency)
	Farming family	
	Angler	
Leachate processing using Reed Bed	Treatment worker	Initial radiological assessment methodology
	Angler	
Release to atmosphere	Member of public	SNIFFER/PC Cream
Period of Authorisation – unlikely to occur		
Leachate spillage	Farming family	SNIFFER
Dropped load	Worker	UKAEA methodology
Wound exposure	Worker	NCRP biokinetic model and IAEA injection dose
Landfill fire	Member of public	SNIFFER
After the Period of Authorisation – likely to occur		
Recreational user	Member of public	SNIFFER
Site erosion	Member of public	PC Cream/LLWR ESC
Groundwater to estuary	Member of public	Goldsim/PC CREAM
Wildlife exposure	Critical species	ERICA assessment tool
After the Period of Authorisation – unlikely to occur		
Water abstraction	Farming family	GoldSim
Bathtubbing	Farming family	
Gas release and external	Site resident	SNIFFER
Borehole drilling	Worker	
Trial pit excavation	Worker	
Excavation for housing	Worker/Resident	SNIFFER
Excavation for smallholder	Farming family	
Heterogeneous wastes		
Exposure to discrete items	Worker	LLWR ESC
	Member of public	
Exposure to heterogeneously contaminated large objects during or following excavation	Worker	LLWR ESC
	Member of public	
Exposure to particles	Worker	LLWR ESC
	Member of public	

468. The radiological assessments described in the ESC have been used to derive a limit for each radionuclide that will ensure the dose constraints and risk guidance levels are not exceeded in any of the assessed scenarios. The use of a sum of fractions approach based on these limits ensures that the disposed inventory will not result in impacts in excess of regulatory requirements. The following criteria have been used based on the NS-GRA (Environment Agency, 2012).

469. During the Period of Authorisation:

Dose constraint for the public from a single source 0.3 mSv yr^{-1}; and,

Site dose criterion for workers – 1 mSv yr^{-1}

After the end of management:

0.02 mSv yr^{-1} for events that are certain to occur; and,

3 mSv yr^{-1} for human intrusion.

470. The radiological assessments of dose to the public from disposals of LLW to Port Clarence landfills look at the behaviour of radionuclides in the landfill, consider ways that material can enter the local environment and have looked at the timescale over which this may occur. Particular attention has been given to groundwater and leachate. Assessments also consider the future of the site once it has been closed, examining different site uses and potential intrusion scenarios. The assessment approaches are cautious in nature and overestimate the doses that may occur, this leads to a set of radiological capacities that are also cautious. The scenario radiological capacities that are proposed for use with the sum of fractions are given in Table 31 and shown as the proposed relevant values for Schedule 3 of a revised permit (Table 34 and Table 35).

471. The sum of fractions is calculated for each landfill and each scenario separately using the relevant values in Table 34 or Table 35 . The results from the two landfills are then combined to produce a total sum of fractions for each scenario. This combined value must be less than or equal to one for each of the scenarios listed in Table 35 for waste disposal to occur.

472. Port Clarence also accepts Type 2 NORM under the provisions of the exemption from the requirement for a permit described in EPR. The radiological assessment that supported the Type 2 NORM exemption submission assumed that the Port Clarence site accepts about 100,000 t of Type 2 NORM per year. We propose to control the disposal of the Type 2 NORM according to this capacity, as is currently the case.

473. We also propose to control the disposal of LLW against the LLW capacity, using the sum of fractions approach described above. In addition, we will check that the dose constraint for a member of the public will also be met by calculating the combined dose from the LLW and from the NORM already disposed at the site. This check will be made before a LLW waste consignment is accepted for disposal and will apply to the receipts of LLW only.

474. We propose to use a sum of fractions approach to control the activity concentration in waste that is accepted at Port Clarence. Activity concentration limits for a consignment and for a package within a consignment have been determined from a set of exposure scenarios. We propose 5 bands of activity concentration for packaged waste. We also propose lower activity concentration limits for loose tipped waste.

475. Discrete items are defined as “a distinct item of waste that, by its characteristics, is recognisable as unusual or not of natural origin and could be a focus of interest, out of curiosity or potential for recovery and recycling/re-use of materials should the waste item be exposed after repository closure.” We have derived Discrete item Limits for the

discrete items that can be accepted at Port Clarence. These limits are the same or more restrictive than those applied at LLWR.

476. We have assessed the impact of particles and propose limits for the maximum activity on a particle that can be accepted in waste disposed at Port Clarence.

477. The LLW that is expected to come to Port Clarence is similar to the LLW that has been accepted at ENRMF. Therefore the inventory that has been disposed of at ENRMF (July 2019) has been used to illustrate the expected doses and use of the radiological capacity. Port Clarence does not have a tonnage limit but Augean wish to keep the quantity of LLW at or below 20% of the mass of the waste accepted at the site.

478. The impact of uncertainty in estimated doses and risks has been considered and demonstrates that the ESC is robust in meeting all relevant dose and risk guidance levels.

479. Environmental monitoring during the period of authorisation will check the integrity of barriers and safety plans. A site monitoring plan will be prepared and put in place to check the levels of radioactivity in groundwater, surface water, landfill gas, dust, surface soils and leachate. Samples will be taken on a regular basis and an interpretative report will be prepared for the Environment Agency, who will also undertake an independent sampling programme. All these samples will provide additional assurance that the site is performing as expected and can be used as the basis for dose assessments to confirm that impacts are low. Site perimeter dose rate measurements will also be undertaken.

480. Monitoring will continue to the end of the period of authorisation (the period of management control). If any undue adverse impacts were to arise appropriate action will be agreed with the Environment Agency.

481. The Augean management culture and safety procedures ensure that wastes are transported and handled safely reducing the potential for dose impact to the workforce and the risk of accidents leading to unplanned impacts on the environment. The site management controls will ensure that the inventory is not exceeded. There are working procedures in place controlling LLW activities at Port Clarence (Section 5.2.5). The procedures cover prior agreement between the consignor and Augean for disposal, detail appropriate receipt procedures and keeping records of disposals, procedures for waste emplacement, monitoring worker exposure, environmental monitoring and emergency plans to deal with events such as dropped loads. These are all part of Augean's Integrated Management System.

8.2 Optimisation

482. The requirement for optimisation in relation to radiological risk may be considered at three levels.

The design of the Port Clarence landfills is consistent with best practice and regulatory requirements for the disposal of hazardous wastes and non-hazardous wastes and may therefore be considered to be optimised;

We have considered a number of specific ways in which the management and the design of the site may be enhanced to achieve an optimised solution for the disposal of radioactive wastes; and,

Waste consignors are required to manage wastes in a manner consistent with BAT and must demonstrate that disposal to Port Clarence is an optimal solution and hence consistent with BAT. We note that this aspect is a matter for consignors.

483. The design features and arrangements provide an appropriate strategy to limit the environmental impacts arising from non-radioactive contaminants. The design satisfies the requirements set out in the Landfill Directive. In the context of the assumed timescales and approach to landfill risk assessment, these measures will also be effective in limiting the environmental impacts arising from radioactive contaminants. In this sense, the design of the facility may already be considered to have been optimised. As the design of the facility is already recognised as consistent with good practice for landfills and the hazards associated with the proposed disposals of radioactive waste are low, a detailed and systematic analysis of alternative design and management strategies for the facility has not been undertaken.

484. A number of specific considerations have led to enhancements to the operational or emplacement approach to ensure that performance for radioactive waste is optimised. These include:

The use of waste packages, which reduce the probability of doses during operations, will also reduce leaching post-closure and increase the prospect of the waste being recognised as hazardous during future intrusion. Lower limits to the activity concentrations of any loose tipped waste and site procedures to cover these operations which will minimise dispersion of the waste material during tipping.

The implementation of a limit on putrescible materials accepted at the hazardous waste landfill ensures that microbial activity is minimised and gaseous release from microbial action or the potential for fire is minimised.

Augean places a constraint on the level of dust on the surface of LLW packages to ensure this does not represent a hazard. LLW placed in the landfill are also covered daily to prevent dust suspension and hence the risk of impacts via the inhalation pathway during the operational period. A check is also undertaken on dose measurements at 1 m above the surface of the covered LLW, to ensure exposure of less than 2 μSv hr^{-1}. The depth of cover will be increased if necessary to ensure that this limit is not exceeded. These precautions will provide additional confidence that no specific protective measures are needed for workers at the site who are closest to the LLW and will provide additional confidence that anyone off site is also suitably protected.

Operational constraints have been put in place to restrict the placement of LLW in a landfill cell, placing non-radioactive waste to a specified depth at the base (2 m), distance from sides (2 m) and top (1 m) of a cell. This creates a barrier between the LLW and the side liner of a waste cell which will need to be located when the cell is capped. An additional limitation is proposed for wastes with significant radium contamination. Such wastes will be disposed at least 5 m below the restored surface of the site. This places radium below a reasonable intrusion depth and reduces the potential dose due to radon gas release from the landfill.

The inventory of LLW disposed of at the site is controlled so that the dose constraint to members of the public during the period of authorisation is not exceeded, even when taking into account the Type 2 NORM disposals at the site.

485. The profiling of the restored surface will encourage surface runoff, preventing the development of puddles and reducing infiltration.

8.3 Protection against non-radiological hazards

486. The Port Clarence landfills are designed to take either hazardous wastes or non-hazardous wastes and the HRA (MJCA, 2019b) for the site demonstrates that no unacceptable environmental impacts will arise. The existing landfills at Port Clarence are permitted under the Environmental Permitting Regulations and satisfy the requirements of the Landfill Directive in terms of the management, engineering and monitoring of the site.

487. Those defined as hazardous under the European Waste Catalogue are subject to the hazardous waste acceptance criteria under the Landfill Directive (European Commission, 1999). The hazardous wastes accepted at the site are largely hazardous due to harmful, toxic, carcinogenic, irritant or eco-toxic properties. No explosive, flammable, corrosive, oxidising or infectious wastes are accepted at the site. The IMS includes established procedures for safe handling and disposal of the hazardous wastes accepted at the site. These processes are similar to those for the handling of LLW and do not conflict with them.

488. The arrangements for construction design, waste acceptance, groundwater protection, landfill gas management, leachate management, landfill stability, pollution prevention, nuisance prevention and quality assurance, construction quality assurance, maintenance, landfill capping, site restoration, operations, waste handling/placement, security, use of raw materials, secondary wastes, accident arrangements, monitoring, closure, aftercare and surrender are described in existing documentation for the landfill site.

8.4 Reliance on human action

489. The disposal facility is designed to minimise any reliance on human action to maintain the safety case during the period of operation. During the post-closure period of authorisation (i.e. the period after which no further disposals are received and the disposal cells are capped, but during which the site Permit issued under EPR2016 remains in force), leachate management will continue alongside monitoring to

demonstrate that the overall system is continuing to limit entry of radionuclides to the accessible environment, consistent with the arguments in this ESC.

490. Following surrender of the site Permit (i.e. at the end of the period of authorisation), there is no continuing reliance on monitoring or any other active management or intervention measure to ensure the continuing safety of the overall system.

8.5 Openness and inclusivity

491. Augean's approach is based on openness and inclusivity and draws on experience from preparations for disposals of LLW at the ENRMF. Consultations will cover all aspects of the proposed development including the disposal of LLW. Augean has existing engagement activities with local community in relation to the hazardous and non-hazardous landfills. Augean will prepare a register of stakeholders. Consultation activities will include briefings for the local Member of Parliament, District Councillors and the Tees Valley Combined Authority. Augean will also host community consultation meetings and site tours. Throughout the consultation programme a careful record will be kept of all the activities and responses and collated into a Statement of Community Involvement, which will accompany the planning application.

492. Consultation activities will include briefings for the local Member of Parliament, District Councillors and the Tees Valley Combined Authority. Augean will also host community consultation events, site tours and will establish a register of stakeholders. Throughout the consultation programme a careful record will be kept of all the activities and responses and collated into a Statement of Community Involvement, which will accompany the planning application.

493. Augean will report back to the local community via the register of stakeholders about the planning application and the environmental permit. Augean uses the register of stakeholders to contact those interested in the proposals via an electronic newsletter. This provides a good and responsive medium for offering further opportunities to visit the site, and explaining in a detailed way aspects of the scheme by giving further information about specific topics that may be of particular interest or concern raised during the consultation process.

494. On submission of the permit application Augean will inform the local community representatives of the submission. Augean will also prepare a non-technical summary of the application proposals for circulation in the community. A site open day will be organised in October 2019 at which the community can discuss the application with Augean and the company's expert advisors. The Environment Agency will be invited to take part in this event.

8.6 Conclusion

495. Overall, we consider that the measures set out in this ESC provide assurance that the proposed disposal of LLW will be managed appropriately and will give rise to radiological impacts well within relevant regulatory criteria.

496. The ESC will be subject to periodic review. It is suggested that this is undertaken every 10 years. However, should any new information arise that affects the assumptions supporting the ESC, or monitoring results indicate that the assessments could be challenged, a review would be initiated.

497. Disposal of LLW at Port Clarence would secure a cost-effective, regional LLW disposal solution for nuclear sites located in the north east of the United Kingdom, which exceeds the required environmental standards. In accordance with national objectives for LLW management, it would help to ensure that disposal capacity at the LLWR is only used for wastes requiring a more highly engineered disposal solution.

9 References

Environment Agency, 2016. Northumbria River Basin District Flood Risk Management Plan 2015-2021. PART B – Sub Areas in the Northumbria River Basin District, Horizon House, Bristol: Environment Agency.

Allen, D. J. et al., 1997. The Physical Properties of Major Aquifers in England and Wales, Keyworth, Nottingham: BGS Technical Report, WD/97/34; Environment Agency R & D Publication 8.

Augean, 2006. Hydrogeological risk assessment for Port Clarence Landfill Site near Middlesbrough, Atherstone, Warwickshire: MJCA Report reference AU/PC/PDH/2603/01/HRA.

Augean, 2009. Application for Disposal of LLW including HV-VLLW under the Radioactive Substances Act 1993, for the East Northants Resource Management Facility, Walton, Nr Wetherby: Augean plc.

Augean, 2010. Information to satisfy the requirements Article 37 of the Euraton Treaty, Walton, Nr Wetherby: Augean plc.

Augean, 2011b. Preliminary Hydrogeological Risk Assessment for the Proposed Extension to the existing Hazardous Waste Landfill at East Northants Resource Management Facility. Walton, Nr Wetherby: Augean plc.

Augean, 2014. Planning Application to Remove Condition 2 of Planning Permission Reference TDC/94/065 to Extend the Operational Life of the Non-Hazardous and Hazardous Waste Landfill Site at Port Clarence, Stockton-On-Tees. Part 2 Environmental Statement, Atherstone, Warwickshire: MJCA, AU/PC/ABW/1636/01/ES November 2014.

Augean, 2019. Conditions for Acceptance of Solid Low Level Radioactive, Walton, Nr Wetherby: Augean South Ltd.

Bailey BR, E. K. T. L., 2003. Rad. Prot. Dosimetry, 105(1-4):509 -12 "An analysis of a puncture wounds case with medical intervention", s.l.: s.n.

Baker, M. V., Tapper, B., Johns, C. & Herring, P., 2007. England’s Historic Seascapes: Scarborough to Hartlepool and Adjacent Marine Zone, Historic Seascape Characterisation, Truro: Cornwall County Council, Report No. 2007R021.

BEIS and NDA, 2017. Radioactive Wastes in the UK: UK Radioactive Waste Inventory Report, Herdus House, Mor Row, Cumbria: Nuclear Decommissioning Authority.

BGS, 2012. UK Geohazard Note: Coastal Erosion, Keyworth: British Geological Society.

Bishop, G. P., 1989. Review of biosphere information: biotic transport of radionuclides as a result of mass movement of soil by burrowing animals, Oxford: Nires Safety Studies.

Blott, S. et al., 2013. Great Britain. In: E. Pranzini & A. Williams, eds. Coastal erosion and protection in Europe. Abingdon, Oxon: Routledge, pp. pp. 173-208.

Bristol Post, 2009. A look inside a Bristol sewage works. s.l.:s.n.

British Geological Survey and the Environment Agency, 2006. Baseline Report Series: 23. The Lincolnshire Limestone. s.l.:s.n.

Brown, J. E. et al., 2004. Radiation doses to aquatic organisms from natural radionuclides. Journal of Radiological Protection, Volume 24, pp. A63-A77.

Clarke, R. H., 1979. The first report of a Working Group on Atmospheric Dispersion: a model for short and medium range dispersion of radionuclides released to atmosphere, Harwell, Didcot: National Radiological Protection Board.

Copplestone, D., Brown, J. E. & Beresford, N. A., 2010. Considerations for the integration of human and wildlife radiological assessments. Journal of Radiological Protection, Volume 30, pp. 283-297.

Copplestone, D., Hingston, J. & Real, A., 2008. The development and purpose of the FREDERICA radiation effects database. Journal of Environmental Radioactivity, Volume 99, pp. 1456-1463.
DECC, 2012. Strategy for the management of solid low level radioactive waste from the non-nuclear industry in the United Kingdom: Part 1 – Anthropogenic radionuclides, London: Department of Energy & Climate Change.
DECC, 2014. Strategy for the management of Naturally Occurring Radioactive Material (NORM) waste in the United Kingdom, London: Department of Energy & Climate Change.
DECC, 2016. UK Strategy for the Management of Solid Low Level Waste from the Nuclear Industry, London: Department of Energy & Climate Change.
Defra, DTI and the Devolved Administrations, 2007. Policy for the Long Term Management of Solid Low Level Radioactive Waste in the United Kingdom, London: Department for Environment and Rural Affairs, PB12522.
Defra, 2009. Protecting our Water, Soil and Air. A Code of Good Agricultural Practice for farmers, growers and land managers.. s.l.:s.n.
Dewar, A., S, J. & C, S., 2011. Parameter values used in coastal dispersion modelling for radiological assessments, s.l.: s.n.
Eden NE, 2015a. Environmental Safety Case: Disposal of Low Activity Low Level Radioactive Waste at East Northants Resource Management Facility, Penrith, Cumbria: Eden Nuclear and Environment Ltd.
Eden NE, 2015b. Addendum to Environmental Safety Case: Disposal of Low Activity Low Level Radioactive Waste at East Northants Resource Management Facility, Penrith, Cumbria: Eden NE, ENE-154/002.
Eden, L., 2010. Environmental Safety Case for the disposal of very low and low level radioactive waste at the Clifton Marsh Landfill Site, Risley, Warrington: Nuvia, Issue 2.
Environment Agencies, 2018. Management of radioactive waste from decommissioning of nuclear sites: Guidance on Requirements for Release from Radioactvie Substances Regulation, Bristol: Environment Agency.
Environment Agency, 1999. State of the Tees Estuary environment, and strategy into the millenium, Newcastle Upon Tyne: Environment Agency.
Environment Agency, 2003. The Development of LandSim 2.5. s.l.:s.n.
Environment Agency, 2006a. Initial radiological assessment methodology - part 1 user report. s.l.:s.n.
Environment Agency, 2006b. Initial radiological assessment methodology - part 2 methods and input data. s.l.:s.n.
Environment Agency, 2009. Habitats Assessments for Radioactive Substances, s.l.: Science report: SC060083/SR1.
Environment Agency, 2011. Greatham Managed Realignment: Environmental Statement, Bristol: Environment Agency.
Environment Agency, 2012. Guidance Note for Developers and Operators of Radioactive Waste Disposal Facilities in England and Wales. Near-Surface Disposal Facilities on Land for Solid Radioactive Wastes: Guidance on Requirements for Authorisation. Supplementary. s.l.:s.n.
Environment Agency, 2015. Adapting to Climate Change: Advice for Flood and Coastal Erosion Risk Management Authorities, Bristol: Environment Agency.
Environment Agency, 2016. How to apply for an environmental permit. Party RSR-B5 - New bespoke radioactivity substances activity permit (burial of radioactive waste), Bristol: Environment Agency.

Environment Agency, 2018. Flood map for planning. [Online]
Available at: https://flood-map-for-planning.service.gov.uk
[Accessed 20 11 2018].
ERICA, 2008. ERICA Assessment Tool., s.l.: s.n.
ESL, 2014a. A Planning Application to Amend Condition 2 of Planning Permission Reference TDC/94/065 for the Continuation of Waste Disposal Activities at Port Clarence Landfill Site, Stockton on Tees: Updated Baseline Ecology Survey and Assessment of Impacts, Lincoln: ESL (Ecological Services) Ltd.
ESL, 2014b. Ornithological Studies of Port Clarence Landfill Site, Stockton on Tees, Lincoln: ESL (Ecological Services) Ltd.
European Commission, 1993. Principles and Methods for Establishing Concentrations and Quantities (Exemption Values) below which Reporting is not Required in the European Directive, Luxembourg: Commission of the European Communities, Radiological Protection - RP65.
European Commission, 1995. Propositions de niveaux d'activité pour l'enfouissement de déchets en décharges contrôlées en France et en Belgique. J.-M. Asselineau, P. Guétat, P. Renaud, L. Baekelandt and B. Ska. Luxembourg: Commission of the European Communities, Rapport EUR 15483 FR.
European Commission, 1999. Council Directive of 26 April 1999 on the landfill of waste. Official Journal of the European Communities, L182/1: Luxembourg.
European Commission, 2014. Council Directive 2013/59/Euratom of 5 December 2013 laying down basic safety standards for protection against the dangers arising from exposure to ionising radiation., s.l.: s.n.
Ewers, L. W. & Mobbs, S. M., 2010. Derivation of liquid exclusion or exemption levels to support the RSA93 Exemption Order, s.l.: Health Protection Agency.
Finch, H. J., Samuel, A. M. & Lane, G. p., 2002. Lockhart and Wiseman's Crop husbandary including grassland. s.l.:s.n.
Fouracre, L., 2005. A Cultural Heritage Desk-Based Assessment of Northern Gateway, Teesside, Midlothian: AOC Archaeology Group.
Galson Science Ltd, 2011. Assessment Calculations for Human Intrusion for the LLWR 2011 ESC. s.l.:Galson Science Ltd.
Gane, R., 2014. Pers. Comm to Andy Baker, Eden NE Ltd, Landfill cap details - 5 February. s.l.:s.n.
GoldSim Technology Group, 2013. Goldsim User's Guide (Volume 1, Volume 2 and Appendices, Version 11). s.l.:s.n.
GoldSim Technology Group, 2013. User's Guide: GoldSim Contaminant Transport Module. s.l.:s.n.
Good Stuff Ltd, 2019. River Tees at Tees Dock. [Online]
Available at: https://riverlevels.uk/north-yorkshire-tees-dock-tidal#.XKd-baR7mCg
[Accessed 2 May 2019].
Grinsted, A., Jevrejeva, S., Riva, R. E. M. & Dahl-Jensen, D., 2015. Sea level rise projections for northern Europe under RCP8.5. CLIMATE RESEARCH, Volume 64, p. 15–23.
Guthrie, G. & Lane, N., 2007. Shoreline Management Plan 2: River Tyne to Flamborough Head, Peterborough: HASKONING UK LTD for North East Coastal Authorities Group Reference 9P0184/R/nl/PBor.
Hicks, T. W. & Baldwin, T. D., 2011. Assessment Calculations for Human Intrusion for the LLWR 2011 ESC. s.l.:Gaslon Sciences Ltd 977-3: Issue 2.

HPA, 2005. Health Implications of Dounreay Fuel Fragments: Estimates of Doses and Risks. Didcot, Oxon: Health Protection Agency.
HPA, 2007. Radiological Assessment of Disposals of Large Quantities of Very Low Level Waste in Landfill Sites. s.l.:Health Protection Agency.
HPA, 2008. Guidance on the Application of Dose Coefficients for the Embryo, Fetus and Breastfed Infant in Dose Assessments for Members of the Public. s.l.:Health Protection Agency.
HPA, 2009. Radiological Protection Objectives for the Land-based Disposal of Solid Radioactive Wastes: Advice from the Health Protection Agency, Radiation, Chemical and Environmental Hazards. s.l.:Health Protection Agency.
HPA, 2011. Health risks from radioactive objects on beaches in the vicinity of the Sellafield site., Didcot, Oxon: HPA-CRCE-018.
HSE, 2001. Reducing Risks, Protecting People. HSE's decision-making process. s.l.:Health and Safety Executive.
Hung, C. Y., 2000. User's Guide for PRESTO-EPA-CPG/POP Operation System – Version 4.2. Washington, DC 20460: U.S. Environmental Protection Agency, Office of Radiation and Indoor Air.
IAEA, 1992. Effects of ionising radiation on plants and animals at levels implied by current radiation protection standards, Technical Report Series 332.. Vienna: International Atomic Energy Agency.
IAEA, 2002. External human induced events in site evaluation for nuclear power plants. Vienna: International Atomic Energy Agency.
IAEA, 2003. Derivation of activity limits for the disposal of radioactive waste in near surface disposal facilities. Vienna: International Atomic Energy Agency, IAEA TecDoc 1380.
IAEA, 2004. Improvement of Safety Assessment Methodologies for Near-Surface Disposal Facilities (2 volumes). Vienna: International Atomic Energy Agency.
IAEA, 2004. Safety Reports Series No. 37 Methods for assessing occupational radiation doses due to intakes of radionuclides, Vienna: IAEA.
IAEA, 2005. Derivation of activity concentration values for exclusion, exemptiom and clearance, Vienna: International Atomic Energy Agency, IAEA SR44.
IAEA, 2010. Handbook of parameter values for the prediction of radionuclide transfer in terrestrial and freshwater environments. Vienna: International Atomic Energy Agency TRS 472.
ICRP, 1996. ICRP Publication 72: Age-dependent Doses to Members of the Public from Intake of Radionuclides: Part 5: Compilation of Ingestion and Inhalation Dose Coefficients, Oxford: International Commission on Radiological Protection.
ICRP, 2007. ICRP Publication 103. The 2007 recommendations of the International Commission on Radiological Protection. Annals ICRP, Volume 37 (2-4).
ICRP, 2008. Environmental Protection: the Concept and Use of Reference Animals and Plants. s.l.:ICRP Publication 108.
ICRP, 2012. ICRP Publication 119, Compendium of Dose Coefficients based on ICRP 60. Elsevier, Amsterdam: ICRP Volume 41 Supplement 1.
Ilyn LA, 2001. Skin wounds and burns contamianted by radioactive substances (metabloism, decontamination, tactics and techniques of medical care). In: Medical Management of Radiation Accidents. s.l.:CRC Press.
Inst. of Geological Sciences, 1981. Tyne-Tees Sheet 54N-02W 1:250,000 Series. s.l.:Institute of Geological Sciences.

Jackson, D., Smith, K. & Wood, M., 2014. Demonstrating Compliance with Protection Objectives for Non-Human Biota within Post-closure Safety Cases for Radioactive Waste Repositories. J Environ Radioact, Volume 133, pp. 60-68.

Jakes, S., 2017. East Northants Resource Management Facility. Ionising Radiations Regulations 1999. Radiation Risk Assessment for LLW with a Specific Activity up to 200Bq/g, s.l.: Public Health England.

Jones, K. A., Anderson, T. & Harvey, M. P., 2014. Assessment of the radioalogical capacity of the Port Clarence landfill site for the disposal of NORM waste, Didcot, Oxfordshire: Public Health England, Contract Report CRCE-EA-7-2014.

Lambeck, K. et al., 2014. Sea level and global ice volumes from the Last Glacial Maximum to the Holocene. PNAS October 28, 111(43), pp. 15296-15303.

Le Guillou, M., 1978. A History of the River Tees. Middlesborough: Cleveland County Libraries.

Leuven, J., Kleinhans, M., Weisscher, S. & van der Vegt, M., 2016. Tidal sand bar dimensions and shapes in estuaries. Earth-Science Reviews, Volume 161, pp. 204-223.

Lindborg, T., 2018. BIOMASS 2020: Interim report. BIOPROTA report, produced in association with IAEA MODARIA II working group 6, Solna: Svensk Kärnbränslehantering AB, SKB R-18-02.

LLWR Ltd, 2011a. Radiological Handbook. Pelham House, Seascale, Cumbria: Low Level Waste Repository Ltd.

LLWR Ltd, 2011b. The 2011 Environmental Safety Case: Assessment of Long Term Radiological Impacts, LLWR/ESC/R(11)10028. Pelham House, Seascale, Cumbria: LLW Repository Ltd.

LLWR Ltd, 2011. The 2011 Environmental Safety Case, Pelham House, Seascale, Cumbria: LLWR/ESC/R(11)10016.

LLWR Ltd, 2013. Assessment of Discrete Items and Basis for WAC, Pelham House, Seascale, Cumbria: LLW Repository Ltd.

LLWR Ltd, 2013. The LLWR Environmental Safety Case: Assessment of Carbon-14 Bearing Gas, Pelham House, Seascale, Cumbria: LLWR/ESC/R(13)10059.

LLWR Ltd, 2019. Discrete Item Decision Summaries. [Online]
Available at: https://tools.llwrsite.com/introduction-to-discrete-items/discrete-item-decision-summaries/
[Accessed 14 June 2019].

Lowe, J. A. & et al., 2009. UK Climate Projections science report: Marine and coastal projections, Exeter, UK: Met Office Hadley Centre.

MJCA, 2007. Waste Recovery Park Planning Application. Appendix C: Copies of the Historical Maps for the Site and Surrounding Area, Atherstone, Warwickshire: Augean plc.

MJCA, 2018. Personal communication Heasman, L, Atherstone: MJCA.

MJCA, 2018. The results of the topographical survey carried out by MJCA on 26 and 27 June 2018, Atherstone: MJCA.

MJCA, 2019a. DRAFT - An Application to Vary Environmental Permit Numbers EPR/BV1399IT And EPR/BV1402IC for the Port Clarence Hazardous and Non Hazardous Waste Landfill Sites Operated by Augean North Limited. Environmental Setting and Installation Design (ESID) Report., Atherstone: Report reference: AU/PC/AW/5606/01/ESID.

MJCA, 2019b. Draft: Review of the Hydrogeological Risk Assessment for Port Clarence Non-hazardous Waste and Hazardous Waste Landfill Sites, Atherstone, Warwickshire: MJCA Report reference: AU/PC/JRC/2949/01 March 2019.

Natural England, 2014. National Character Area profile: 23. Tees Lowlands, Worcester: Crown Copyright.
NCRP, 2007. Development of a biokinetic Model for Radionuclide contaminated Wounds and Procedures for their Assessment, Dosimetry and Treatment, s.l.: s.n.
NDA, 2010. UK Strategy for the Management of Solid Low Level Radioactive Waste from the Nuclear Industry, Moor Row, Cumbria: Nuclear Decommissioning Authority.
NDA, 2013. UK Radioactive Waste Inventory: Radioactivity Content of Wastes. Moor Row, Cumbria: Nuclear Decommissioning Authority.
NDA, 2016. Radioactive Wastes in the UK: UK Radioactive Waste Inventory Report, Moor Row, Cumbria: Nuclear Decommissioning Authority.
NDA, 2016. Strategy Effective from April 2016, Moor Row, Cumbria: Nuclear Decommissioning Authority.
NDAWG, 2013. NDAWG Guidance Note 7. Use of habits data in prospective dose assessments.. s.l.:s.n.
NEA, 1987. Shallow land burial of radioactive waste: reference levelsfor the acceptanceof long-lived radionuclides, Paris: Nuclear Energy Agency.
NEA, 2017. Decision and Recommendation Concerning the Application of the Paris Convention on Third Party Liability in the Field of Nuclear Energy to Nuclear Installations for the Disposal of Certain Types of Low-level Radioactive Waste. Paris: OECD, NUCLEAR ENERGY AGENCY STEERING COMMITTEE FOR NUCLEAR ENERGY.
Nelson, T. J., 2003. Identifying sediment sources in the tees catchment, Durham: Durham theses, Durham University. Available at Durham E-Theses Online: http://etheses.dur.ac.uk/3684/.
Nix, J., 2010. Farm management pocketbook. s.l.:The Andersons Centre.
NRPB, 2003b. Generalised Habit Data for Radiological Assessments. s.l.:National Radiological Protection Board.
Oatway, W. B. & Mobbs, S. F., 2003. Methodology for Estimating the Doses to Members of the Public from the Future Use of Land Previously Contaminated with Radioactivity. s.l.:National Radiological Protection Board.
ONR, 2018. Analysis of Coastal Flood Hazards for Nuclear Sites: NS-TAST-GD-013 Annex 3 Reference Paper, Bootle: Office for Nuclear Regulation.
Palmer, M. et al., 2018. UKCP18 Marine report, Exeter: Met Office Hadley Centre Climate Programme.
Passive House Institute, 2012. Criteria for residential passive house buildings. s.l.:s.n.
Penfold, J. & Paulley, A., 2011. Assessment of Environmental Safety during the Period of Authorisation for the LLWR 2011 ESC, Pelham House, Seascale, Cumbria: LLWR: Quintessa Report QRS-1433ZB-1 Version 1.4.
Quintessa Ltd, 2011. Assessment Calculations for Radon for the LLWR 2011 ESC. s.l.:s.n.
Rabbitmatters, n.d. http://www.rabbitmatters.com/wildrabbtis.html, s.l.: s.n.
Real, A., Sundell-Bergman, S., Knowles, J. F. & Woodhead, D. S., 2004. Effects of ionising radiation exposure on plants, fish and mammals: relevant data for environmental radiation protection. Journal of Radiological Protection, Volume 24, pp. A123-A137.
RIFE-23, 2018. Radioactivity in Food and the Environment, 2017, Cefas, Lowestoft, Sufflok: Environment Agency, Food Standards Agency, Food Standards Scotland, Natural Resource Wales, Northern Ireland Environment Agency and the Scottish Environment Protection Agency.

Robinson, C., Smith, K., Jackson, D. & Towler, P., 2010. Application of Radiation Screening Levels for Biota in Geological Disposal Facility Assessments: Issues to Consider. SKM Enviros report to NDA JL30168.. s.l.:s.n.
Schadilov AE, B. M. a. L. E., 2010. Health Physics, 99(4):560-7 "A Case of wound intake of Pu isotopes and 241Am in a human: application and improvement of the NCRP wound model, s.l.: s.n.
Schadilov AE, B. M. a. L. E., 2010. Health Physics, 99(4):560-7 "A Case of wound intake of Pu isotopes and 241Am in a human: application and improvement of the NCRP wound model, s.l.: s.n.
Shaw, G., Wadey, P. & Bell, J. N. B., 2004. Radionuclide transport above a near surface water table: IV. Soil migration and crop uptake of Chlorine-36 and Technetium-99, 1990 to 1993. Journal of Environmental Quality, Volume 33, pp. 2272-2280.
Smith, G. M. et al., 1988. Assessment of the Radiological Impact of Disposal of Solid Radioactive Waste at Drigg. s.l.:NRPB M148.
Smith, J. G. & Simmonds, J. R., 2015. The Methodology for Assessing the Radiological Consequences of Routine Releases of Radionuclides to the Environment Used in PC-CREAM 08, version1.1, Didcot, Oxon: Health Protection Agency.
Smith, K. R. & Jones, A. L., 2003. Generalised Habit Data for Radiological Assessments. s.l.:National Radiological Protection Board.
Smith, K. et al., 2010. Non-human Biota Dose Assessment: Sensitivity Analysis and Knowledge Quality Assessment. s.l.:s.n.
SNIFFER, 2006. Development of a Framework for Assessing the Suitability of Controlled Landfills to Accept Disposals of Solid Low-Level Radioactive Waste: Technical Reference Manual. s.l.:s.n.
Stocker, T. F. et al., 2013. Climate change 2013: the physical science basis. Working Group I Contribution to the fifth assessment report of the Intergovernmental Panel on Climate Change, Cambridge: Cambridge University Press.
Stockton on Tees Borough Council, 2013. Lead Local Flood Authority: Flood Investigation Report - Tees Tidal Flooding, Stockton on Tees: Stockton on Tees Borough Council.
Sumerling, T. J., 2013. Assessment of individual radioactive particles and WAC for active particles, Pelham House, Seascale, Cumbria: LLW Repository Ltd.
The Planning Inspectorate, 2013. Examining Authority's Report of Findings, Conclusions and Recommendations to the Secretary of State., s.l.: s.n.
Thorne, M., 2010. External Memorandum: Comparison of Sphere and Slab Dose Factors, s.l.: s.n.
Thorne, M. C., 2006. Distinctions in Annual Effective Dose between Different Age Groups, Report to United Kingdom Nirex Limited. Durham: Mike Thorne and Associates Limited.
Toohey RE, B. L. S. S. W. A. a. C. D., n.d. Dose Coefficients for intakes of Radionuclides via Conmtaminated Wounds https://orise.orau.gov/files/reacts/Retention-Intake.pd, s.l.: s.n.
Towler, G. et al., 2010. Development and Testing of a Capability for Radiological Assessment of Coastal Erosion, Henley, Oxon: QRS-1443U-R1 Version 1.1.
TVCCRG, 2012. An assessment of the impact of climate change on the natural environment of the Tees Valley, s.l.: Tees Valley Climate Change Resilience Group.
Tyler, A. N. et al., 2013. The radium legacy: Contaminated land and the committed effective dose from the ingestion of radium contaminated materials. Environment International, Volume 59, p. 449–455.
UK Environment Agencies, 2009. Near-surface Disposal Facilities on Land for Solid Radioactive Wastes Guidance on Requirements (Environment Agency, Northern Ireland

Environment Agency, and Scottish Environment Protection Agency), Bristol: Environment Agency.
UK Government SI, 2016. The Environmental Permitting (England and Wales) Regulations 2016, SI2016/675, London: The Stationery Office.
UK Government SI, 2018. The Environmental Permitting (England and Wales) (Amendment) (No. 2) Regulations 2018, SI2018/428, London: The Stationary Office.
UNSCEAR, 1996. Sources and effects of ionising radiation, Report of the general assembly with scientific annex A/AC.82/R.54. New York: United Nations.
UNSCEAR, 2011. Sources and Effects of Ionizing Radiation. Report to the General Assembly with Scientific Annexe (2008). New York: United Nations.
US EPA, 1993. External Exposure to Radioniuclides in air, water and soil (KF Eckerman & JC Ryman). Federal Guidance Report 12, Washington DC, USA: US Environmental Protection Agency, EPA-402-R-93-081.
US EPA, 2014. Memorandum dated 6/2/2014; US EPA OSWER Directive 9200.1-120. s.l.:s.n.
US EPA, 2018. External Exposure to Radionculides in Air, Water and Soil. External Dose Rate Coefficients for General Application, Washington: FEDERAL GUIDANCE REPORT NO. 15, EPA 402-R-18-001.
US NRC, 2014. NRC Regulations Title 10, Code of Federal Regulations (61.55 Waste classification), s.l.: s.n.
Villars, M. T. & Delvigne, G., 2001. Estuarine Processes, The Netherlands: WL Delft hydraulics.
Wilson, G., 2013. Pers. Comm to Andy Baker, Eden NE Ltd, Landfill cap details - 18 December. s.l.:s.n.

Appendix A. Glossary

In the context of this Glossary, the term ‘waste’ refers, in general, to radioactive waste unless otherwise specified.

absorbed dose. See dose, absorbed.

activation. The process of inducing radioactivity. Most commonly used to refer to the induction of radioactivity in moderators, coolants, and structural and shielding materials, caused by irradiation with neutrons.

activation product. A radionuclide produced by activation. Often used in distinction from fission products. For example, in decommissioning waste comprising structural materials from a nuclear facility, activation products might typically be found primarily within the matrix of the material, whereas fission products are more likely to be present in the form of contamination on surfaces.

activity. The quantity A for an amount of radionuclide in a given energy state at a given time. The SI unit of activity is the reciprocal second (s^{-1}), termed the Becquerel (Bq). Formerly expressed in curie (Ci), which is still sometimes used.

activity concentration. Of a material, the activity per unit mass or volume of the material in which the radionuclides are essentially uniformly distributed.

activity, specific. Of a Waste Consignment means the Activity in the consignment divided by the weight of the consignment. In the context of conditioned wastes, the weight of the consignment is the weight of the waste and immobilising material or grout. In accounting for Activity against these limits, the Activity of Decay Products shall be accounted for as listed in Column 1 of 0.

ALARP & ALARA. As low as reasonably practicable. As low as reasonably achievable. ALARP & ALARA describe approaches to optimisation. The optimisation principle states “in relation to any particular source within a practice, the magnitude of individual doses, the number of people exposed, and the likelihood of incurring exposures where these are not certain to be received should all be kept as low as reasonably achievable (ALARA), economic and social factors being taken into account…” ALARA is incorporated in UK law via RSA 1993 (BSS) Direction 2000. ALARA & ALARP focus on impacts to people.

aquifer. A water bearing formation below the surface of the earth that can furnish an appreciable supply of water for a well or spring.

area, controlled. A defined area in which specific protection measures and safety provisions are or could be required for controlling normal exposures or preventing the spread of contamination during normal working conditions, and preventing or limiting the extent of potential exposures.

assessment. The process, and the result, of analysing systematically the hazards associated with sources and practices, and associated protection and safety measures, aimed at quantifying performance measures for comparison with criteria.

assessment, environmental (impact). An evaluation of radiological and nonradiological impacts of a proposed activity, where the performance measure is overall environmental impact, including radiological and other global measures of impact on safety and environment.

assessment, performance. An assessment of the performance of a system or subsystem and its implications for protection and safety at a planned or an authorized facility. This differs from safety assessment in that it can be applied to parts of a facility, and does not necessarily require assessment of radiological impacts.

assessment, risk. An assessment of the radiological risks associated with normal operation and potential accidents involving a source or practice. This will normally include consequence assessment and associated probabilities.

assessment, safety. An analysis to evaluate the performance of an overall system and its impact, where the performance measure is radiological impact or some other global measure of impact on safety. See also assessment, performance.

audit. A documented activity performed to determine by investigation, examination and evaluation of objective evidence the adequacy of, and adherence to, established procedures, instructions, specifications, codes, standards, administrative or operational programmes and other applicable documents, and the effectiveness of implementation.

authorization. The granting by a regulatory body or other governmental body of written permission for an operator to perform specified activities. Authorization could include, for example, a permit, licensing, certification and registration. See also licence.

background (radiation). The dose, dose rate or an observed measure related to the dose or dose rate, attributable to all sources other than the one(s) specified.

barrier. A physical obstruction that prevents or delays the movement of radionuclides or other material between components in a system, for example a waste repository. In general, a barrier can be an engineered barrier which is constructed or a natural (or geological) barrier.

barrier, intrusion. The components of a repository designed to prevent inadvertent access to the waste by humans, animals and plants.

barriers, multiple. Two or more natural or engineered barriers used to isolate radioactive waste in, and prevent radionuclide migration from, a repository. See also barrier.

borehole. A cylindrical excavation, made by a drilling device. Boreholes are drilled during site investigation and testing and are also used for waste emplacement in repositories and monitoring.

Bq/g A Becquerel (abbreviated as Bq) is the International System (SI) unit for the activity of radioactive material. One Bq of radioactive material is that amount of material in which one atom is transformed or undergoes one disintegration every second. A Gram (abbreviated as g) is a unit of mass. A Becquerel per Gram (abbreviated Bq/g) is therefore a measure of the concentration of radioactivity in a material.

characterization, site. Detailed surface and subsurface investigations and activities at candidate disposal sites to obtain information to determine the suitability of the site for a repository and to evaluate the long term performance of a repository at the site.

characterization, waste. Determination of the physical, chemical and radiological properties of the waste to establish the need for further adjustment, treatment, conditioning, or its suitability for further handling, processing, storage or disposal.

clay. Minerals that are essentially hydrated aluminium silicates or occasionally hydrated magnesium silicates, with sodium, calcium, potassium and magnesium cations. Also denotes a natural material with plastic properties which is essentially a composition of fine to very fine clay particles. Clays differ greatly mineralogically and chemically and consequently in their physical properties. Because of their large surface areas, most of them have good sorption characteristics.

clearance. Removal of radioactive materials or radioactive objects within authorised practices from any further regulatory control by the regulatory body.

closure. Administrative and technical actions directed at a repository at the end of its operating lifetime — for example covering the disposed waste (for a near surface repository) or backfilling and/or sealing (for a geological repository and the passages leading to it) — and termination and completion of activities in any associated structures.

conductivity, hydraulic, K. Ratio of groundwater flow rate n to driving force dh/dl (the change of hydraulic head with distance) for viscous flow of a fluid in a porous medium. This is the so-called constant of proportionality K in Darcy's Law and depends on both the porous medium and the fluid properties. See also permeability.

consignment, a set of one or more waste packages not exceeding 10 tonnes.

container, waste. The vessel into which the waste form is placed for handling, transport, storage and/or eventual disposal; also the outer barrier protecting the waste from external intrusions. The waste container is a component of the waste package. See also barrier; waste package.

containment. Methods or physical structures designed to prevent the release of radioactive substances.

contamination. (1) Radioactive substances on surfaces, or within solids, liquids or gases (including the human body), where their presence is unintended or undesirable, (2) the presence of such substances in such places or (3) the process giving rise to their presence in such places.

control, institutional. Control of a waste site by an authority or institution designated under the laws of a country. This control may be active (monitoring, surveillance and remedial work) or passive (land use control) and may be a factor in the design of a nuclear facility (e.g. a near surface repository).

control, regulatory. Any form of control applied to facilities or activities by a regulatory body for reasons related to protection or safety.

criteria. Conditions on which a decision or judgement can be based. They may be qualitative or quantitative and should result from established principles and standards. See also requirement; specifications.

critical group. A group of members of the public which is reasonably homogeneous with respect to its exposure for a given radiation source and given exposure pathway and is typical of individuals receiving the highest effective dose or equivalent dose (as applicable) by the given exposure pathway from the given source. The same as a representative person.

decommissioning. Administrative and technical actions taken to allow the removal of some or all of the regulatory controls from a facility. This does not apply to a repository or to certain nuclear facilities used for mining and milling of radioactive materials, for which closure is used.

decontamination. The complete or partial removal of contamination by a deliberate physical, chemical or biological process.

diffusion. The movement of atoms or molecules from a region of higher concentration of the diffusing species to regions of lower concentration, due to a concentration gradient.

discharge. A planned and controlled release of (usually gaseous or liquid) radioactive material to the environment.

disintegration per second. See also Bq/g. A disintegration is any nuclear transformation

disposal. Emplacement of waste in an appropriate facility without the intention of retrieval. Some countries use the term disposal to include discharges of effluents to the environment.

distribution coefficient, K_d. The ratio of the amount of substance sorbed on a unit mass of dry solid to the concentration of the substance in a solution in contact with the solid, assuming equilibrium conditions. The SI units are: $m^3\ kg^{-1}$.

dose. A measure of the energy deposited by radiation in a target. Absorbed dose, committed equivalent dose, committed effective dose, effective dose, equivalent dose or organ dose, depending on the context. All these quantities have the dimensions of energy divided by mass.

dose, absorbed, D. The fundamental dosimetric quantity D. The unit is $J\ kg^{-1}$, termed the gray (Gy).

dose constraint. A prospective and source related restriction on the individual dose from a source, which provides a basic level of protection for the most highly exposed individuals from a source and serves as an upper bound on the dose in optimization of protection for that source. The UK government has set a maximum dose constraint value of 0.3 mSv y^{-1} when determining applications for discharge authorization from a single new source.

dose, effective, E. A summation of the tissue equivalent doses, each multiplied by the appropriate tissue weighting factor: The unit of effective dose is J kg^{-1}, with the special name Sievert (Sv). The committed effective dose is the effective dose that will be received by the person over their lifetime as a result of radionuclides taken into the body e.g. by ingestion or inhalation.

dose, equivalent, H_T. The radiation-weighted dose in a tissue or organ. This takes account of the different amounts of damage caused by different types of radiation eg alpha particles, gamma radiation. The unit of equivalent dose is J/kg, termed Sievert (Sv).

dose limit. See limit, dose. The value of the effective dose or the equivalent dose to individuals from planned exposure situations that shall not be exceeded. For the purposes of discharge authorizations, the UK has (since 1986) applied a dose limit of 1 mSv y^{-1} to members of the public from all man-made sources of radioactivity (other than from medical applications).

effluent. Gaseous or liquid radioactive materials which are discharged to the environment. See also discharge, authorized.

emanation. Generation of radioactive gas by the decay of a radioactive solid.

environmental impact statement. A set of documents recording the results of an evaluation of the physical, ecological, cultural and socioeconomic effects of a planned facility (e.g. a repository) or of a new technology.

exemption. The determination by a regulatory body that a source or practice need not be subject to some or all aspects of regulatory control on the basis that the exposure (including potential exposure) due to the source or practice is too small to warrant the application of those aspects. See also level, clearance.

exposure. The act or condition of being subject to irradiation. Exposure can either be external exposure due to sources outside the body or internal exposure due to sources inside the body.

exposure, normal. Exposure which is expected to occur under the normal operating conditions of a facility or activity, including possible minor mishaps that can be kept under control, i.e. during normal operation and anticipated operational occurrences.

exposure, potential. Exposure that is not expected to occur with certainty but that may result from an accident at a source or owing to an event or sequence of events of a probabilistic nature, including equipment failures and operating errors.

exposure pathway. A route by which radiation or radionuclides can reach humans and cause exposure. An exposure pathway may be very simple, for example external exposure from airborne radionuclides, or involve a more complex chain, for example internal exposure from drinking milk from cows that ate grass contaminated with deposited radionuclides.

fissile material. Uranium-233, uranium-235, plutonium-239, plutonium-241, or any combination of these radionuclides. Excepted from this definition is: (a) natural uranium or depleted uranium which is unirradiated, (b) natural uranium or depleted uranium which has been irradiated in thermal reactors only.

fission product. A radionuclide produced by nuclear fission.

flow, unsaturated. The flow of water in unsaturated soil by capillary action and gravity.

fracture. A general term for any breaks in rock whether or not it causes displacement.

gradient, hydraulic. The change in total hydraulic head per unit distance of flow in a given direction.

groundwater. Water that is held in rocks and soil beneath the surface of the earth.

half-life, T1/2. The time taken for the quantity of a specified material (e.g. a radionuclide) in a specified place to decrease by half as a result of any specified process or processes that follow similar exponential patterns to radioactive decay.

half-life, effective, Teff. The time taken for the activity of a radionuclide in a specified place to halve as a result of all relevant processes.

half-life, radioactive. For a radionuclide, the time required for the activity to decrease, by a radioactive decay process, by half.

Harwell. The UKAEA Harwell site in Oxfordshire is an ex-RAF WWII airbase that has been used since 1946 for nuclear research, mainly in support of civilian power generation. The site is now well advanced with decommissioning. The aim is to return the site to a delicensed status by 2025.

HV-VLLW. High volume very low level waste. A sub-category of LLW as defined in "Policy for the Long Term Management of Solid Low Level Radioactive Waste in the United Kingdom" (DEFRA, 2007).

HPA. The Health Protection Agency (HPA) was an independent body, now Public Health England (PHE) that protects the health and well-being of the population. The HPA includes the ex-National Radiological Protection Board (NRPB).

HSE. Britain's Health and Safety Commission (HSC) and the Health and Safety Executive (HSE) are responsible for the regulation of almost all the risks to health and safety arising from work activity in Britain.

inadvertent human intrusion. Accidental intrusion into a disposal facility without prior knowledge of the presence of the facility or accidental intrusion, without prior knowledge, into an area adjacent to the facility in such a way that it degrades the environmental safety performance of the facility.

immobilization. Conversion of waste into a waste form by solidification, embedding or encapsulation. The aim is to reduce the potential for migration or dispersion of radionuclides during handling, transport, storage and/or disposal. See also conditioning.

inert waste. Material which does not undergo any significant physical, chemical or biological transformations; does not dissolve, burn or otherwise physically or chemically react, biodegrade or adversely affect other matter with which it comes into contact in a way likely to give rise to environmental pollution or harm to human health; and whose total leachability and pollutant content and the ecotoxicity of its leachate are insignificant and in particular do not endanger the quality of any surface water or groundwater. This is defined by UK waste legislation for non-radioactive wastes.

infiltration. The downward entry of water through the ground surface into soil or rock.

intervention. Any action intended to reduce or avert exposure or the likelihood of exposure to sources which are not part of a controlled practice or which are out of control as a consequence of an accident.

leach rate. The rate of dissolution or erosion of material or the release by diffusion from a solid, this is hence a measure of how rapidly radionuclides may be released from that material. The term usually refers to the durability of a solid waste form but also describes the removal of sorbed material from the surface of a solid or porous bed.

leach test. A test conducted to determine the leach rate of a waste form. The test results may be used for judging and comparing different types of waste forms, or may serve as input data for a long term safety assessment of a repository. Many different test parameters have to be taken into account, for example water composition and temperature.

leachate. A solution that has been in contact with waste form and, as a result, may contain radionuclides.

level, clearance. A value, established by a regulatory body and expressed in terms of activity concentration and/or total activity, at or below which a source of radiation may be released from regulatory control. See also clearance.

level, exemption. A value, established by a regulatory body and expressed in terms of activity concentration and/or total activity, at or below which a source of radiation may be granted exemption from regulatory control without further consideration.

licence. A legal document issued by the regulatory body granting authorization to perform specified activities related to a facility or activity. The holder of a current licence is termed a licensee**.** A licence is a product of the authorization process, although the term licensing process is sometimes used.

limit, dose. The value of the effective dose or the equivalent dose to individuals from controlled practices that shall not be exceeded.

liner. (1) A layer of material placed between a waste form and a container to resist corrosion or any other degradation of a waste package. (2) A layer of clay, plastic, asphalt or other low permeability material placed around or beneath a landfill site, repository or tailings impoundment to minimise leakage and/or erosion. (3) A structural component (made, for example, of concrete or steel) on the surface of a tunnel or shaft in a repository.

LLW. See waste, low and intermediate level. Low Level Radioactive Waste. With certain specific exceptions, LLW is defined as waste which has an activity concentration greater than the out of scope levels and up to 4,000 Bq g^{-1} for alpha emitters and 12,000 Bq g^{-1} for beta-gamma emitters. Where Bq g^{-1} is Becquerel per gram, a measure of activity within the SI system equivalent to 1 disintegration per second. Where an alpha emitter is a form of radioactive decay involving emission of alpha particles (a helium nucleus). Where beta decay is a type of radioactive decay involving the emission of electrons or positrons.

Low Level Waste Repository (LLWR). The LLWR is located 6 km southeast of Sellafield near the village of Drigg, and has operated safely for over 40 years disposing of Low Level Radioactive Wastes (LLW) from the nuclear and general industries, universities and hospitals.

long term. In radioactive waste disposal, refers to periods of time that exceed the time during which active institutional control can be expected to last.

long term stewardship. Conducting, supervising, or managing something entrusted to one's care. In the context of nuclear waste sites the phrase encompasses the activities undertaken after closure of the site to maintain and monitor the wastes in the long term.

LSG. Local Stakeholder Group. A group of stakeholders that meet regularly in relation to a nuclear licensed site.

Isotope. Different forms of atoms of the same element that have different numbers of neutrons in their nuclei. An element may have a number of isotopes. For example, the three isotopes of hydrogen are protium, deuterium, and tritium. All three have one proton in their nuclei, but deuterium also has one neutron, and tritium has two neutrons. Different isotopes can have different radioactive properties and present different risks.

migration. The movement of contaminants in the environment as a result of natural processes.

minimization, waste. The process of reducing the amount and activity of radioactive waste to a level as low as reasonably achievable, at all stages from the design of a facility or activity to decommissioning, by reducing waste generation and by means such as recycling and reuse, and treatment, with due consideration for secondary as well as primary waste. See also pretreatment; treatment; volume reduction.

model. A representation of a system and the ways in which phenomena occur within that system, used to simulate or assess the behaviour of the system for a defined purpose.

model, computational. A calculation tool that implements a mathematical model.

model, conceptual. A set of qualitative assumptions used to describe a system.

model, mathematical. A set of mathematical equations designed to represent a conceptual model.

model, pathways. A mathematical representation used to simulate the transport of radionuclides from a source to a receptor.

model, transport. A mathematical representation of mechanisms controlling the movement of finely dispersed or dissolved substances in fluids.

monitoring. Continuous or periodic measurement of radiological and other parameters or determination of the status of a system.

naturally occurring radioactive material (NORM). Material containing no significant amounts of radionuclides other than naturally occurring radionuclides. The exact definition of 'significant amounts' would be a regulatory decision. Materials in which the activity concentrations of the naturally occurring radionuclides have been changed by human made processes are included. These are sometimes referred to as technically enhanced NORM or TENORM.

naturally occurring radionuclides. Radionuclides that occur naturally in significant quantities on earth. The term is usually used to refer to the primordial radionuclides potassium-40, uranium- 235, uranium-238 and thorium-232 (the decay product of primordial uranium-236), their radioactive decay products, and tritium and carbon-14 generated by natural activation processes.

NDA. Nuclear Decommissioning Authority. A public body that oversees nuclear decommissioning in the UK on designated sites such as Harwell.

nuclear facility. A facility and its associated land, buildings and equipment in which radioactive materials are produced, processed, used, handled, stored or disposed of on such a scale that consideration of safety is required.

nuclear material. Plutonium except that with isotopic concentration exceeding 80% in plutonium- 238; uranium-233; uranium enriched in the isotope 235 or 233; uranium containing the mixture of isotopes occurring in nature other than in the form of ore or ore residue; any material containing one or more of the foregoing.

nuclear site licence. A licence issued under the Nuclear Installations Act.

off-site. Outside the physical boundary of a site.

ONR. Office for Nuclear Regulation. Under UK law (the Health and Safety at Work etc. Act 1974) employers are responsible for ensuring the safety of their workers and the public, and this is just as true for a nuclear site as for any other. This responsibility is reinforced for nuclear installations by the Nuclear Installations Act 1965 (NIA), as amended. Under the relevant statutory provisions of the NIA, a site cannot have nuclear plant on it unless the user has been granted a site licence by the Health and Safety Executive (HSE). This licensing function is administered by HSE's Office for Nuclear Regulation (ONR).

on-site. Within the physical boundary of a site.

operation. All the activities performed to achieve the purpose for which a facility was constructed.

operational period. The period during which a nuclear facility (e.g. a repository) is being used for its intended purpose until it is decommissioned or is submitted for permanent closure.

optimization. The process of determining what level of protection and safety makes exposures, and the probability and magnitude of potential exposures, 'as low as reasonably achievable, economic and social factors being taken into account' (ALARA).

out of scope level (OoSL). The activity concentration of a radionuclide that is out of the scope of the radioactive substances regulations. Material and waste containing levels of radioactivity below the OoSL are not considered to be radioactive material or radioactive waste. Often the same as clearance levels.

overpack. A secondary (or additional) outer container for one or more waste packages, used for handling, transport, storage or disposal.

package, waste. The product of conditioning that includes the waste form and any container(s) and internal barriers (e.g. absorbing materials and liners), prepared in accordance with the requirements for handling, transport, storage and/or disposal.

permeability, k. The ability of a porous medium to transmit fluid.

Permit. A document issued by the Environment Agency to allow the accumulation, disposal or discharge of waste.

plume. The spatial distribution of a release of airborne or waterborne material as it disperses in the environment.

PHE. Public Health England (PHE) is an independent body, formerly The Health Protection Agency (HPA), that protects the health and well-being of the population. The HPA includes the ex-National Radiological Protection Board (NRPB).

porosity. The ratio of the aggregate volume of interstices in rock, soil or other porous media to its total volume.

post-closure period. The period of time following the closure of a repository and decommissioning of related surface facilities. Some type of surveillance or control will probably be maintained in this period, particularly for near surface repositories. See also closure; preclosure period.

practice. Any human activity that introduces additional sources of exposure or exposure pathways or extends exposure to additional people or modifies the network of exposure pathways from existing sources, so as to increase the exposure or the likelihood of exposure of people or the number of people exposed.

preclosure period. The period of time spanning the construction and operation of a repository up to and including the closure and decommissioning of related surface facilities. See also closure; post-closure period.

predisposal. Any radioactive waste management steps carried out prior to disposal, such as pretreatment, treatment, conditioning, storage and transport activities. Decommissioning is considered to be a part of predisposal management of radioactive waste.

pretreatment. Any or all of the operations prior to waste treatment, such as collection, segregation, chemical adjustment and decontamination.

quality assurance (QA). Planned and systematic actions necessary to provide adequate confidence that an item, process or service will satisfy given requirements for quality, for example those specified in the licence.

quality control (QC). The part of quality assurance intended to verify that systems and components correspond to predetermined requirements.

radioactive material. Material designated in national law or by a regulatory body as being subject to regulatory control because of its radioactivity.

radioactivity. The phenomenon whereby atoms undergo spontaneous random disintegration, usually accompanied by the emission of radiation.

radionuclide. A nucleus (of an atom) that possesses properties of spontaneous disintegration (radioactivity). Nuclei are distinguished by their mass and atomic number.

records. A set of documents, such as instrument charts, certificates, log books, computer printouts and magnetic tapes for each nuclear facility, organized in such a way that it provides past and present representations of facility operations and activities including all phases from design through closure and decommissioning (if the facility has been decommissioned). Records are an essential part of quality assurance.

regulatory body. An authority or a system of authorities designated by the government of a State as having legal authority for conducting the regulatory process, including issuing authorizations, and thereby for regulating the siting, design, construction, commissioning, operation, closure, decommissioning and, if required, subsequent institutional control of the nuclear facilities (e.g. near surface repositories) or specific aspects thereof.

remedial action. Action taken when a specified action level is exceeded, to reduce a radiation dose that might otherwise be received, in an intervention situation involving chronic exposure. Examples are: (a) actions which include decontamination, waste removal and environmental restoration of a site during decommissioning and/or closure efforts; (b) actions taken beyond stabilization of tailings impoundments to allow for other uses of the area or to restore the area to near pristine conditions.

repository. A nuclear facility where waste is emplaced for disposal.

repository, near surface. A facility for disposal of radioactive waste located at or within a few tens of metres from the earth's surface.

representative person. See critical group.

retardation. A reduction in the rate of radionuclide movement through the soil due to the interaction (e.g. by sorption) with an immobile matrix.

retardation coefficient, Rd. A measure of capability of porous media to impede the movement of a particular radionuclide being carried by fluid.

retrievability. The ability to remove waste from where it has been emplaced.

risk. A multiattribute quantity expressing hazard, danger or chance of harmful or injurious consequences associated with actual or potential exposures. It relates to quantities such as the probability that specific deleterious consequences may arise and the magnitude and character of such consequences. (2) The combination of the frequency, or probability, of occurrence and the consequence of a specified hazardous event. The concept of risk always has two elements: the frequency or probability with which a hazardous event occurs and the consequences of the hazardous event. Risk = Probability x Consequence.

safety case. An integrated collection of arguments and evidence to demonstrate the safety of a facility. This will normally include a safety assessment, but could also typically include information (including supporting evidence and reasoning) on the robustness and reliability of the safety assessment and the assumptions made therein.

safety culture. The assembly of characteristics and attitudes in organizations and individuals which establishes that, as an overriding priority, protection and safety issues receive the attention warranted by their significance.

safety report. A document required from the operating organization by the regulatory body containing information concerning a nuclear facility (e.g. a repository), the site characteristics, design, operational procedures, etc., together with a safety analysis and details of any provisions needed to restrict risk to personnel and the public.

scenario. A postulated or assumed set of conditions and/or events. They are most commonly used in analysis or assessment to represent possible future conditions and/or events to be modelled, such as possible accidents at a nuclear facility, or the possible future evolution of a repository and its surroundings.

screening. A type of analysis aimed at eliminating from further consideration factors that are less significant for the purpose of the analysis, in order to concentrate on the more significant factors. Screening is usually conducted at an early stage in order to narrow the range of factors needing detailed consideration in an analysis or assessment.

segregation. An activity where waste or materials (radioactive and exempt) are separated or are kept separate according to radiological, chemical and/or physical properties which will facilitate waste handling and/or processing. For example, it may be possible to segregate radioactive waste from exempt waste and thus reduce the waste volume.

Semi infinite plane. A semi-infinite plane is bounded in one direction, i.e. it is a surface, and unbounded in another (stretches infinitely in all directions).

shielding. A material interposed between a source of radiation and persons, or equipment or other objects, in order to absorb radiation and thereby reduce radiation exposure.

site. The area containing, or under investigation for its suitability for, a nuclear facility (e.g. a repository). It is defined by a boundary and is under effective control of the operating organization.

solidification. Immobilization of gaseous, liquid or liquid-like materials by conversion into a solid waste form, usually with the intent of producing a physically stable material that is easier to handle and less dispersible. Calcination, drying, cementation, bituminization and vitrification are some of the typical ways of solidifying liquid waste. See also conditioning; immobilization.

solubility. The amount of a substance that will dissolve in a given amount of another substance.

sorption. The interaction of an atom, molecule or particle with the surface of a solid. A general term including absorption (sorption taking place largely within the pores of a solid) and adsorption (surface sorption with a non-porous solid). The processes involved may also be divided into chemisorption (chemical bonding with the substrate) and physisorption (physical attraction, for example by weak electrostatic forces).

source. (1) Anything that may cause radiation exposure, such as by emitting ionizing radiation or by releasing radioactive substances or materials. (2) More specifically, radioactive material used as a source of radiation.

source, natural. A naturally occurring source of radiation, such as the sun and stars (sources of cosmic radiation) and rocks and soil (terrestrial sources of radiation).

source term. A mathematical expression used to denote information about the actual or potential release of radiation or radioactive material from a given source, which may include further specifications, for example the composition, the initial amount, the rate and the mode of release of the material.

storage. (1). The holding of spent fuel or of radioactive waste in a facility that provides for its containment, with the intention of retrieval. (2). Storage is by definition an interim measure, and the term interim storage would therefore be appropriate only to refer to short term temporary storage when contrasting this with the longer term fate of the waste. Storage as defined above should not be described as interim storage.

surface water. Water which fails to penetrate into the soil and flows along the surface of the ground, eventually entering a lake, a river or the sea.

survey, radiological. An evaluation of the radiological conditions and potential hazards associated with the production, use, transfer, release, disposal, or presence of radioactive material or other sources of radiation.

transport, radionuclide. The movement (migration) of radionuclides in the environment, for example radionuclide transport by groundwater. This could include processes such as advection, diffusion, sorption and uptake. This usage does not include intentional transport of radioactive materials by humans (transport of radioactive wastes in casks, etc). See also migration.

treatment. Operations intended to benefit safety and/or economy by changing the characteristics of the waste. Three basic treatment objectives are: volume reduction, removal of radionuclides from the waste and change of composition. Treatment may result in an appropriate waste form.

UKAEA The United Kingdom Atomic Energy Authority (UKAEA) was incorporated as a statutory corporation in 1954 and pioneered the development of nuclear energy in the UK. Today UKAEA are responsible for managing the decommissioning of the nuclear reactors and other radioactive facilities used for the UK's nuclear research and development programme in a safe and environmentally sensitive manner. UKAEA is a non-departmental public body, funded mainly by its lead department the Department of Trade and Industry under contract to the NDA.

uptake. A general term for the processes by which radionuclides enter one part of a biological system from another. Used in a range of situations, particularly in describing the overall effect when there are a number of contributing processes, for example root uptake, the transfer of radionuclides from soil to plants through the plant roots.

very low level waste (VLLW). See waste, very low level.

volume reduction. A treatment method that decreases the physical volume of a waste. Volume reduction is employed because it is economical and facilitates subsequent handling, storage, transport and disposal of the waste. Typical volume reduction methods are mechanical compaction, incineration and evaporation. Volume reduction of a given waste results in a corresponding increase in radionuclide concentration. The total volume of waste may also be reduced through decontamination (with subsequent exemption) or through the avoidance of waste generation. See also minimization, waste.

waste. Material in gaseous, liquid or solid form for which no further use is foreseen.

waste, alpha bearing. Radioactive waste containing one or more alpha emitting radionuclides. Alpha bearing waste can be short lived or long lived.

waste, exempt. Waste released from regulatory control in accordance with exemption principles. See also clearance levels; exemption.

waste, mixed. Radioactive waste that also contains non-radioactive toxic or hazardous substances.

waste, radioactive. For legal and regulatory purposes, waste that contains or is contaminated with radionuclides at concentrations or activities greater than clearance levels or out of scope levels as established by the regulatory body. It should be recognized that this definition is purely for regulatory purposes and that material with activity concentrations equal to or less than clearance levels is radioactive from a physical viewpoint — although the associated radiological hazards are considered negligible.

waste, secondary. A form and quality of waste that results as a by-product from processing of waste.

waste, very low level (VLLW). Radioactive waste considered suitable by the regulatory body for authorized disposal, subject to specified conditions, with ordinary waste in facilities not specifically designed for radioactive waste disposal.

waste acceptance criteria. Quantitative or qualitative criteria for radioactive waste to be accepted by the operator of a repository for disposal, or by the operator of a storage facility for storage. Waste acceptance criteria might include, for example, restrictions on the activity concentration or the total activity of particular radionuclides (or types of radionuclide) in the waste or requirements concerning the waste form or waste package.

waste form. Waste in its physical and chemical form after treatment and/or conditioning (resulting in a solid product) prior to packaging. The waste form is a component of the waste package.

waste generator. The operating organization of a facility or activity that generates waste. See also operator.

waste inventory. Quantity, radionuclides, activity and waste form characteristics of wastes for which an operator is responsible.

waste management, radioactive. All activities, administrative and operational, that are involved in the handling, pretreatment, treatment, conditioning, transport, storage and disposal of radioactive waste.

water table. The upper surface of a zone of groundwater saturation.

zone, saturated. A subsurface zone in which all the interstices are filled with water. This zone is separated from the unsaturated zone, i.e. the zone of aeration, by the water table. See also zone, unsaturated.

zone, unsaturated. A subsurface zone in which at least some interstices contain air or water vapour, rather than liquid water. Also referred to as the 'zone of aeration'. See also zone, saturated.

Appendix B. Baseline Monitoring

498. Samples of water, dust and surface soil were taken to establish the background level of radioactivity at the site prior to receipt of any radioactive waste in accordance with a radioactive substances permit. The dose rate at the site perimeter was also monitored.

B.1. Water samples

499. Groundwater samples were collected from the existing boreholes at/around the site. The samples were collected after an appropriate volume of water had been purged using the waterra tubing installed in the boreholes or a clean sampling bailer. A sample was then collected and placed straight into a 1 litre sampling bottle. This was then placed in a coolbox until it was transferred into packaging to be sent off to Public Health England (PHE, formally HPA) within sample stability times.

500. Surface water samples were collected using a jug connected to an extendable rod. To avoid stagnant water being collected, a purge was conducted in the area of water that a sample will be collected (two litres of surface water). A sample was then collected and placed straight into a 1 litre sampling bottle. This was then placed in a coolbox until it was transferred into packaging to be sent off to PHE within sample stability times.

501. All leachate samples were collected using a clean 1 metre sampling bailer. Once the 1 litre sampling bottle had been filled, it was transferred to a coolbox where it was kept until the sample was packaged for collection to be delivered to PHE within the specified stability times.

502. In the following tables, “<” indicates a result is less than or equal to a test methods Limit of Detection (LOD) for that parameter at the time of analysis.

Table 38 Analysis of radioactivity in groundwater samples from various locations on 03/06/2019

Component	Units	Location Id							
		PCGW01	PCGW03	PCGW09	PCGW10B	PCGW11	PCGW12	PCGW17	PCGW18
Total alpha	Bq/g	<0.00085	<0.00085	<0.00082	<0.00084	<0.00084	<0.00083	<0.00084	<0.00083
Total beta	Bq/g	<0.00535	0.00581	0.00595	0.01153	<0.00529	0.00711	<0.00525	0.00543
Total Gamma	Bq/L	3.43	7.39	10.1	8.74	15.46	9.1	3.72	0.662
Tritium Liquids	Bq/L	<6.69	<6.69	<6.53	<6.68	<6.6	<6.69	<6.67	<6.66
Total Actinium-228	Bq/g	<0.00125	0.00173	<0.00121	0.000556	0.00117	<0.00124	<0.00083	0.000662
Total Americium-241	Bq/g	<0.00131	<0.00104	<0.00135	<0.00021	<0.00124	<0.00136	<0.0002	<0.00021
Total Cobalt-60	Bq/g	<0.00029	<0.0003	<0.0003	<0.00025	<0.00032	<0.00031	<0.00024	<0.00025
Total Caesium-137	Bq/g	<0.0003	<0.00028	<0.0003	<0.00021	<0.00032	<0.0003	<0.00022	<0.00022
Total Potassium-40	Bq/g	0.00237	0.00521	<0.00483	0.00799	<0.00397	0.00782	0.00339	<0.00298
Total Lead-210	Bq/g	<0.0273	<0.0254	<0.0279	<0.00207	<0.0287	0.0281	<0.00196	<0.00195
Total Lead-212	Bq/g	<0.00062	0.000445	<0.00061	0.000194	<0.0006	0.00063	0.000326	<0.00029
Total Lead-214	Bq/g	0.00106	<0.00073	<0.00074	<0.00044	0.00843	0.00128	<0.00042	<0.00046
Total Radium-224	Bq/g	<0.00652	<0.00601	<0.00645	<0.00316	0.00586	<0.00671	<0.00322	<0.00306
Total Radium-226	Bq/g	<0.00674	<0.00691	<0.00692	<0.00298	<0.00686	<0.00692	<0.00305	<0.0031
Total Thorium-234	Bq/g	<0.0116	<0.0099	0.0101	<0.00199	<0.0116	<0.0118	<0.00193	<0.00198
Total Uranium-235	Bq/g	<0.00042	<0.00043	<0.00043	<0.00018	<0.00043	<0.00043	<0.00019	<0.00019

Table 39 Analysis of radioactivity in surface water samples from various locations on 03/06/2019

Component	Units	Location Id			
		PCSWGate	PCSWTees	PCSWBlag	PCSWWheelwash
Total alpha	Bq/g	<0.00085	<0.00085	<0.00085	<0.00085
Total beta	Bq/g	<0.00534	0.01204	<0.00533	0.00618
Total Gamma	Bq/L	2.71	10.3	<0.28	<0.31
Tritium Liquids	Bq/L	<6.66	<6.68	<6.65	<6.68
Total Actinium-228	Bq/g	<0.0012	<0.00079	<0.00108	<0.00118
Total Americium-241	Bq/g	<0.00131	<0.00017	<0.00104	<0.00131
Total Cobalt-60	Bq/g	<0.0003	<0.00024	<0.0003	<0.00451
Total Caesium-137	Bq/g	<0.00031	<0.0002	<0.00028	<0.00031
Total Potassium-40	Bq/g	0.00271	0.0103	<0.00361	<0.00451
Total Lead-210	Bq/g	<0.0276	<0.00195	<0.025	<0.0273
Total Lead-212	Bq/g	<0.00061	<0.00028	<0.00052	<0.00059
Total Lead-214	Bq/g	<0.00071	<0.00043	<0.00068	<0.0007
Total Radium-224	Bq/g	<0.00645	<0.00298	<0.00568	<0.00629
Total Radium-226	Bq/g	<0.00673	<0.00308	<0.00613	<0.00682
Total Thorium-234	Bq/g	<0.0113	<0.00202	<0.00961	<0.0115
Total Uranium-235	Bq/g	<0.00042	<0.00019	<0.00038	<0.00042

Table 40 Analysis of radioactivity in leachate samples from various locations on 05/06/2019

Component	Units	Location Id								
		PCLW1A1	PCLW1BC1	PCLW1BM1	PCLWDC1	PCLW2A1	PCLW2B1	PCLW3A1	PCLW4A1	PCLW5A1
Total Actinium-228	Bq/g	<0.00112	<0.00112	<0.00112	<0.00128	<0.00113	0.00101	<0.00118	<0.00103	<0.00127
Total alpha	Bq/g	<0.00085	<0.00085	<0.00084	<0.00084	<0.00084	<0.00083	<0.00085	<0.00085	<0.00085
Total Americium-241	Bq/g	<0.00066	<0.00067	<0.00106	<0.00135	<0.00066	<0.00023	<0.00068	<0.00026	<0.00118
Total beta	Bq/g	0.0233	0.0392	0.0333	0.0421	0.0467	0.0317	0.0994	0.136	0.154
Total Cobalt-60	Bq/g	<0.00028	<0.00028	<0.00031	<0.00034	<0.00029	<0.00025	<0.00032	<0.00031	<0.00037
Total Caesium-137	Bq/g	<0.00028	<0.00028	<0.0003	<0.00021	<0.00029	<0.00021	<0.0003	<0.00025	<0.00032
Total gamma in liquid	Bq/L	25	34.8	35.3	38.7	51.2	33.1	104	132	163
Tritium Liquids	Bq/L	45.2	45.7	23.9	28.1	29	59	<6.67	55.9	33.7
Total Potassium-40	Bq/g	0.025	0.0348	0.0353	0.0387	0.0478	0.0321	0.0996	0.132	0.163
Total Lead-210	Bq/g	<0.00674	<0.000674	<0.0258	<0.0283	0.00337	<0.00209	0.00446	<0.00253	<0.0268
Total Lead-212	Bq/g	<0.00058	<0.00059	<0.00052	<0.00061	<0.00059	<0.00027	<0.00093	<0.00031	<0.00057
Total Lead-214	Bq/g	<0.00067	<0.00069	<0.0007	<0.00073	<0.00069	<0.00044	<0.0007	<0.00046	<0.00073
Total Radium-224	Bq/g	<0.00626	<0.00509	<0.00572	<0.00648	<0.00646	<0.00197	<0.00631	<0.00337	<0.00619
Total Radium-226	Bq/g	<0.00774	<0.00777	<0.00612	<0.0068	<0.00769	<0.00315	<0.00788	<0.00328	<0.00656
Total Thorium-234	Bq/g	<0.00647	<0.00653	<0.00975	<0.012	<0.00648	<0.0021	<0.00658	<0.00249	<0.0106
Total Uranium-235	Bq/g	<0.00048	<0.00048	<0.00038	<0.00042	<0.00048	<0.0002	<0.00049	<0.0002	<0.00041

Table 41 Analysis of radioactivity in leachate collection tanks on 05/06/2019

Component	Units	Location ID	
		PCLWTankNon-Haz	PCLWTankHaz
Total Actinium-228	Bq/g	<0.00133	<0.001
Total alpha	Bq/g	<0.00083	<0.00085
Total Americium-241	Bq/g	<0.00133	<0.00027
Total beta	Bq/g	0.0412	0.129
Total Cobalt-60	Bq/g	<0.00033	<0.00031
Total Caesium-137	Bq/g	<0.00033	<0.00025
Total gamma in liquid	Bq/L	46.5	132
Tritium Liquids	Bq/L	46.2	41.8
Total Potassium-40	Bq/g	0.0465	0.132
Total Lead-210	Bq/g	<0.0282	<0.00254
Total Lead-212	Bq/g	<0.00061	<0.00031
Total Lead-214	Bq/g	<0.00074	<0.00046
Total Radium-224	Bq/g	<0.00645	<0.0033
Total Radium-226	Bq/g	<0.00687	<0.00338
Total Thorium-234	Bq/g	<0.0117	<0.00243
Total Uranium-235	Bq/g	<0.00042	<0.00021

B.2. Dust sampling

503. All dust samples were collected during the monthly routine monitoring. De-ionised water was used to rinse the deposited dust from the top of the dust gauge (collection Frisbee) through 227mm pipework into a 5 litre HDPE collection bottle. The entire sample is filtered at the on-site laboratory and the dried filter sent off for analysis at PHE.

Table 42 Analysis of radioactivity in dust samples (Bq/filter) from two locations on 30/04/2019

Component in dust	Location PCDD04	Location PCDD05
Total Actinium-228 in dust	<0.135	0.142
Total alpha in dust	0.09	0.02
Total Americium-241 in dust	<0.073	<0.114
Total beta in dust	0.39	0.19
Total Cobalt-60 in dust	<0.044	<0.04
Total Caesium-137 in dust	<0.034	<0.034
Total gamma in deposited dust	0.331	1.33
Total Potassium-40 in dust	0.331	1.19
Total Lead-210 in dust	<1.36	<2.68
Total Lead-212 in dust	<0.049	<0.06
Total Lead-214 in dust	<0.071	<0.077
Total Radium-224 in dust	<0.54	<0.656
Total Radium-226 in dust	<0.554	<0.142
Total Thorium-234 in dust	<0.699	<0.041
Total Uranium-235 in dust	<0.035	<0.114

B.3. Surface soil samples

504. All soil samples were collected using a Soil Sampler Pro (a cross-sectional soil sampler) to a maximum depth of 10 centimetres at four locations. The samples were stored in labelled plastic tubs which were then securely sealed and boxed to be collected and delivered to PHE within the specified stability times.

Table 43 Analysis of radioactivity in soil samples from four locations on 04/06/2019

Component in soil	Units	Location PCSoil01	Location PCSoil02	Location PCSoil03	Location PCSoil04
Total alpha	Bq/g	0.1416	0.1215	0.0672	0.123

Component in soil	Units	Location PCSoil01	Location PCSoil02	Location PCSoil03	Location PCSoil04
Total beta	Bq/g	0.2813	0.1741	0.0967	0.3008
Total Gamma	Bq/kg	399	371	228	776
Total Actinium-228	Bq/g	0.037	0.0364	0.0275	0.0586
Total Americium-241	Bq/g	<0.0005	<0.00071	<0.00059	<0.00084
Total Cobalt-60	Bq/g	<0.00065	<0.00056	<0.00052	<0.00091
Total Caesium-137	Bq/g	0.00191	0.00178	0.00267	0.0246
Total Potassium-40	Bq/g	0.178	0.165	0.0799	0.414
Total Lead-210	Bq/g	0.0469	0.0289	0.0243	0.0661
Total Lead-212	Bq/g	0.0344	0.0363	0.0275	0.0555
Total Lead-214	Bq/g	0.035	0.0192	0.0186	0.0387
Total Radium-224	Bq/g	<0.021	0.0106	0.0289	0.0233
Total Radium-226	Bq/g	0.0298	0.0463	<0.0105	0.0431
Total Thorium-234	Bq/g	0.033	0.0235	0.00245	0.0487
Total Uranium-235	Bq/g	0.00331	0.00287	0.00245	0.00267

B.4. Site perimeter dose rate

505. The site perimeter dose rate check is carried out by Augean's Environmental Monitoring Technician. In accordance with the Monitoring Action Plan for perimeter dose rate monitoring, the perimeter dose rate analysis was carried out using a fully calibrated AT1121 X Ray and Gamma Radiation Dosimeter. An average reading over a 10 minute period at a height of 1 metre is recorded at each location. Weather conditions including barometric pressure, temperature, wind speed and direction and ground conditions are also recorded.

Table 44 Site perimeter total gamma dose rate (mSv h^{-1}) measurements at the site boundary location

Location Id	02/07/2019
Office	0.139
Office Car Park	0.152
PC22	0.129
PCDD07	0.194
PCDD05	0.120
PC16AB	0.140
PC10AB	0.128

Appendix C. Policy Statement and Integrated Management System

Health, Safety, Quality and Environment Policy statement

This policy sets out our core commitments to be a responsible and sustainable business which are reported annually in our Corporate Social Responsibility Report. the Policy provides a framework of objectives to reduce our effects on the environment, to ensure the health, safety and welfare of our personnel, stakeholders, contractors, visitors and the public as well as maintaining client satisfaction through service excellence, across the Group. The policy is driven from top level in the Group through Directors and Managers to every employee and is reviewed at regular intervals. The policy is made available to all interested parties including contractors and is published on our web site.

We strive to achieve our sustainability commitments by satisfying all legal and other compliance obligations as a minimum; by continually improving the management system; and through following these key principles:

Health and Safety

- Recognising that our employees are our greatest asset and their health and safety is a top priority for the Group
- Ensuring the health and safety risks arising from our activities are well controlled and injuries and ill health are prevented
- Sustaining a safe and healthy working environment by providing and maintaining appropriate plant and equipment; providing safe systems of work; and ensuring safe storage, use, handling and transport of substances
- Providing all required instruction, information, training, supervision and other relevant health and safety information to employees, visitors and contractors to ensure health and safety risks arising from our activities are controlled and injuries and ill health are prevented
- Making available, as necessary, safety and protective equipment at no cost to employees
- Complying with all applicable legal and other requirements as a minimum.
- Preventing injury and ill health to employees and others who may be affected by our activities.
- Engaging and consulting with employees on day-to-day health and safety conditions and providing advice and supervision on occupational health.
- Maintaining effective emergency response procedures for potential incidents including, but not limited to, fire, major spillages or uncontrolled emissions.

Quality

- Applying a consistent management focus on quality including monitoring performance
- Motivating our employees to take ownership of their work and communicating the importance of customer satisfaction
- Understanding our customers' goals, embracing them and delivering to their expectations
- Providing ongoing training to advance the skills of our employees
- Identifying and solving problems to avoid compromising the quality of our services.

Environmental

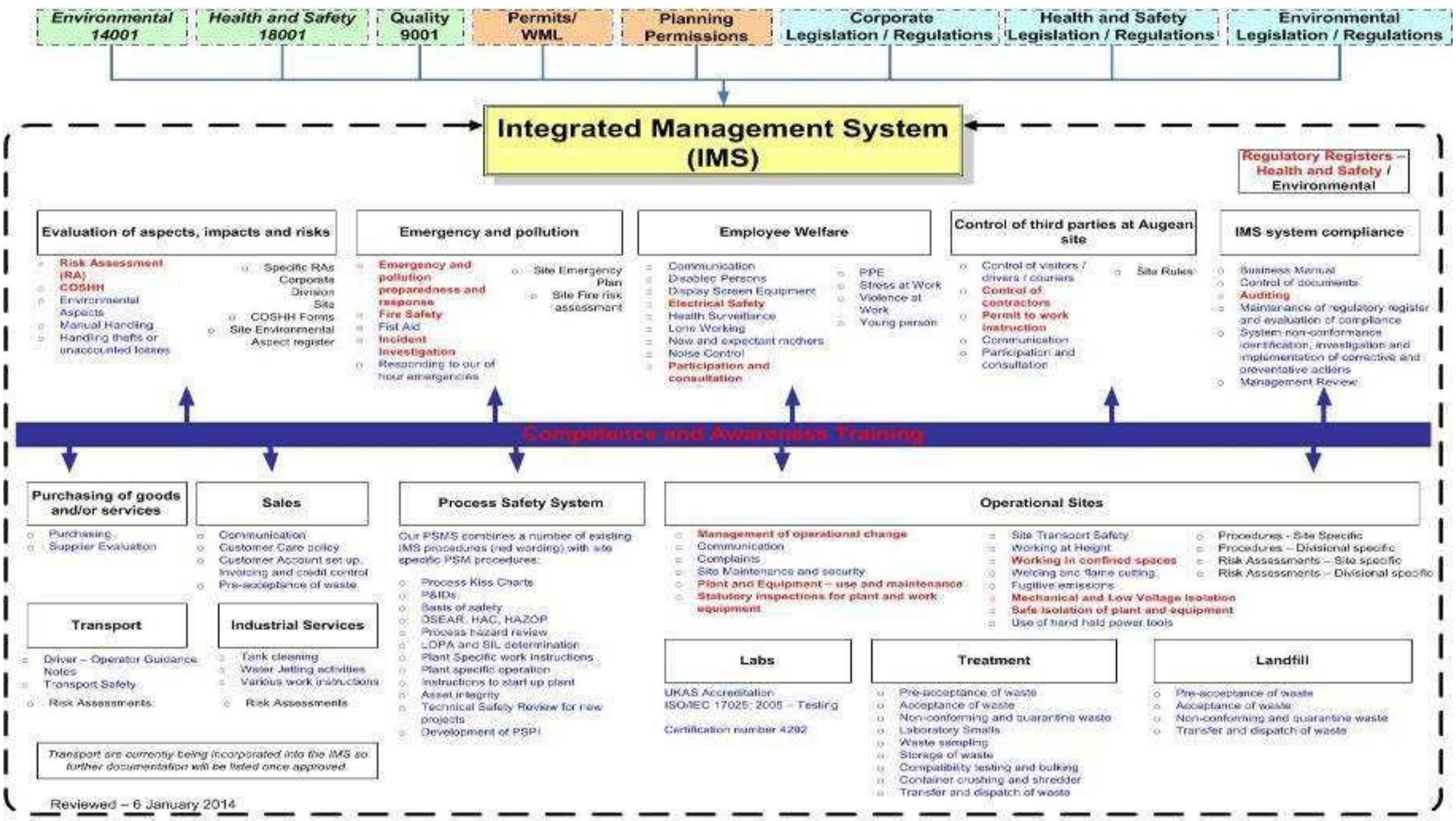
- Setting clear objectives and regularly monitoring progress against them
- Recognising that the minimum acceptable level of environmental performance is that stipulated in environmental legislation
- Protecting the environment by seeking to avoid and reduce the pollution of air, water and land that may result as a consequence of our activities
- Promotion of sustainable transport alternatives to, from and between Augean sites
- Ensuring that activities and building developments are sensitive to visual amenity and the local community, and the impact on ecology and wildlife habitats is benign, if not beneficial
- Providing suitable environmental training for appropriate personnel and promoting the general environmental awareness to all staff

Operational improvement and corporate objectives shall be set on an annual basis and our performance is monitored through audits and inspections. We pursue a programme of continual improvement in all aspects of our business to achieve this high level of regulatory compliance and client satisfaction.

Our Directors are committed to protecting and improving the working environment and employee health and safety by seeking continuous improvements and periodic review of our management policies and objectives.

Each employee has a responsibility for their own safety and that of fellow employees and visitors, along with the obligation to meet health & safety and environmental regulations, and provide a quality service to our customers

Delivery of this policy is a business priority. Consistent with our whistleblowing policy, we encourage employees who have any concerns regarding compliance with this policy to report this directly, and if necessary anonymously, to Gene Wilson (the Management Board champion for this policy), who will investigate the matter confidentially.


Environmental 14001
Health and Safety 18001
Quality 9001
Permits/ WML
Planning Permissions
Corporate Legislation / Regulations
Health and Safety Legislation / Regulations
Environmental Legislation / Regulations
Integrated Management System (IMS)
Regulatory Registers – Health and Safety / Environmental
Evaluation of aspects, impacts and risks
Risk Assessment (RA)
COSHH
Environmental Aspects
Manual Handling
Handling thefts or unaccounted losses
Specific RAs Corporate Division Site
COSHH Forms
Site Environmental Aspect register
Emergency and pollution
Emergency and pollution preparedness and response
Fire Safety
First Aid
Incident Investigation
Responding to our of hour emergencies
Site Emergency Plan
Site Fire risk assessment
Employee Welfare
Communication
Disabled Persons
Display Screen Equipment
Electrical Safety
Health Surveillance
Lone Working
New and expectant mothers
Noise Control
Participation and consultation
PPE
Stress at Work
Violence at Work
Young person
Control of third parties at Augean site
Control of visitors / drivers / couriers
Control of contractors
Permit to work instruction
Communication
Participation and consultation
Site Rules
IMS system compliance
Business Manual
Control of documents
Auditing
Maintenance of regulatory register and evaluation of compliance
System non-conformance identification, investigation and implementation of corrective and preventative actions
Management Review
Competence and Awareness Training
Purchasing of goods and/or services
Purchasing
Supplier Evaluation
Sales
Communication
Customer Care policy
Customer Account set up, Invoicing and credit control
Pre-acceptance of waste
Transport
Driver – Operator Guidance Notes
Transport Safety
Risk Assessments
Industrial Services
Tank cleaning
Water Jetting activities
Various work instructions
Risk Assessments
Transport are currently being incorporated into the IMS so further documentation will be listed once approved.
Process Safety System
Our PSMS combines a number of existing IMS procedures (red wording) with site specific PSM procedures:
Process Kiss Charts
P&IDs
Basis of safety
DSEAR, HAC, HAZOP
Process hazard review
LOPA and SIL determination
Plant Specific work instructions
Plant specific operation
Instructions to start up plant
Asset integrity
Technical Safety Review for new projects
Development of PSPI
Operational Sites
Management of operational change
Communication
Complains
Site Maintenance and security
Plant and Equipment – use and maintenance
Statutory inspections for plant and work equipment
Site Transport Safety
Working at Height
Working in confined spaces
Welding and flame cutting
Fugitive emissions
Mechanical and Low Voltage isolation
Safe isolation of plant and equipment
Use of hand held power tools
Procedures - Site Specific
Procedures – Divisional specific
Risk Assessments – Site specific
Risk Assessments – Divisional specific
Labs
UKAS Accreditation
ISO/IEC 17025: 2005 – Testing
Certification number 4292
Treatment
Pre-acceptance of waste
Acceptance of waste
Non-conforming and quarantine waste
Laboratory Smalls
Waste sampling
Storage of waste
Compatibility testing and bulking
Container crushing and shredder
Transfer and dispatch of waste
Landfill
Pre-acceptance of waste
Acceptance of waste
Non-conforming and quarantine waste
Transfer and dispatch of waste
Reviewed – 6 January 2014

Appendix D. Impact of Waste Disposal Using Illustrative Waste Streams

D.1. Introduction

506. Illustrative inventories have been used to demonstrate the impact of disposal of LLW at Port Clarence. These are disposal of an inventory based on current disposals to the ENRMF, disposal of waste using the specific activity of ENRMF waste and disposal of wastes based on the proportions of radionuclides in the national LLW inventory and in example LLW waste streams.

507. These calculations do not show the total impact of the whole facility, this will be dependent on the waste that is actually received for disposal. However, the calculations illustrate the dose that would arise from waste streams typical of those that might be disposed to Port Clarence. None of these inventories are assumed to contain particles, discrete items or large heterogeneously contaminated items.

508. The inventory that has already been disposed of at the ENRMF (up to June 2019), the proportion of each radionuclide in the waste disposed at the ENRMF and in the national low level waste inventory are presented in Table 45. Columns 3 and 4 of this Table provide an indication of the likely waste composition that will be disposed at Port Clarence. We note that there are some significant differences between the composition of waste disposed at the ENRMF and the national low level waste inventory.

Table 45 Activity disposed at the ENRMF and the composition of the national inventory of low level waste

Radionuclide	Activity disposed at ENRMF to June 2019 (MBq)	Composition of ENRMF disposals (percentage)	Composition of national LLW inventory (percentage)
H-3	$5.81\ 10^{4}$	19.6%	19.9%
C-14	$2.03\ 10^{4}$	6.9%	0.7%
Cl-36	$7.25\ 10^{2}$	0.2%	0.2%
Ca-41	0	0.0%	0.0%
Mn-54	0	0.0%	0.0%
Fe-55	$4.78\ 10^{3}$	1.6%	1.1%
Co-60	$1.23\ 10^{4}$	4.2%	3.5%
Ni-59	0	0.0%	0.0%
Ni-63	$1.26\ 10^{4}$	4.3%	2.0%
Zn-65	0	0.0%	0.0%
Se-79	0	0.0%	0.0%
Sr-90	$1.19\ 10^{4}$	4.0%	8.6%
Mo-93	0	0.0%	0.0%
Zr-93	0	0.0%	0.0%

Radionuclide	Activity disposed at ENRMF to June 2019 (MBq)	Composition of ENRMF disposals (percentage)	Composition of national LLW inventory (percentage)
Nb-93m	0	0.0%	0.0%
Nb-94	1.07 10^{1}	0.0%	0.0%
Tc-99	5.26 10^{3}	1.8%	0.1%
Ru-106	3.05 10^{1}	0.0%	0.0%
Ag-108m	2.24 10^{1}	0.0%	0.0%
Ag-110m	0	0.0%	0.0%
Cd-109	0	0.0%	0.0%
Sb-125	1.20 10^{1}	0.0%	0.0%
Sn-119m	0	0.0%	0.0%
Sn-123	0	0.0%	0.0%
Sn-126	0	0.0%	0.0%
Te-127m	0	0.0%	0.0%
I-129	6.33 10^{1}	0.0%	0.0%
Ba-133	3.51 10^{1}	0.0%	0.0%
Cs-134	1.28 10^{1}	0.0%	0.0%
Cs-135	0	0.0%	0.0%
Cs-137	4.43 10^{4}	15.0%	17.2%
Ce-144	0	0.0%	0.0%
Pm-147	2.56 10^{1}	0.0%	0.0%
Sm-147	0	0.0%	0.0%
Sm-151	0	0.0%	0.1%
Eu-152	1.67 10^{3}	0.6%	0.0%
Eu-154	1.73 10^{2}	0.1%	0.0%
Eu-155	2.62 10^{1}	0.0%	0.0%
Gd-153	0	0.0%	0.0%
Pb-210	1.68 10^{4}	5.7%	0.0%
Po-210	0	0.0%	0.0%
Ra-226	4.19 10^{4}	14.2%	0.2%
Ra-228	1.72 10^{2}	0.1%	0.0%
Ac-227	1.18 10^{1}	0.0%	0.0%
Th-228	0	0.0%	0.0%
Th-229	1.33 10^{1}	0.0%	0.0%
Th-230	2.21 10^{2}	0.1%	0.0%
Th-232	7.03 10^{3}	2.4%	0.0%
Pa-231	1.14 10^{1}	0.0%	0.0%
U-232	1.18 10^{2}	0.0%	0.0%
U-233	9.89 10^{0}	0.0%	0.0%
U-234	1.51 10^{4}	5.1%	0.4%
U-235	3.52 10^{2}	0.1%	0.2%
U-236	3.04 10^{2}	0.1%	0.1%
U-238	1.69 10^{4}	5.7%	0.1%

Radionuclide	Activity disposed at ENRMF to June 2019 (MBq)	Composition of ENRMF disposals (percentage)	Composition of national LLW inventory (percentage)
Np-237	$4.56\ 10^{1}$	0.0%	0.0%
Pu-238	$5.43\ 10^{2}$	0.2%	2.2%
Pu-239	$2.44\ 10^{3}$	0.8%	3.1%
Pu-240	$5.49\ 10^{3}$	1.9%	0.8%
Pu-241	$1.16\ 10^{4}$	3.9%	5.5%
Pu-242	$3.16\ 10^{0}$	0.0%	0.1%
Pu-244	0	0.0%	0.0%
Am-241	$4.36\ 10^{3}$	1.5%	5.1%
Am-242m	0	0.0%	0.0%
Am-243	0	0.0%	0.0%
Cm-242	0	0.0%	0.0%
Cm-243	$4.02\ 10^{1}$	0.0%	0.0%
Cm-244	$1.22\ 10^{2}$	0.0%	0.0%
Cm-245	0	0.0%	0.0%
Cm-246	0	0.0%	0.0%
Cm-248	0	0.0%	0.0%

509. The first test is whether the activity concentration in these streams meets the activity concentration sum of fractions test. The results of the test are shown in Table 46 .

Table 46 Activity concentration sum of fractions for illustrative inventories

Illustrative inventory	Specific activity (Bq/g)	Sum of fractions for activity concentration	Pass or fail?
Extrapolated from specific activity of current ENRMF disposals	$4.64\ 10^{1}$	0.044	Pass
Extrapolated from national inventory	$7.14\ 10^{5}$	3.46	Fail

510. **Error! Reference source not found.** shows that the activity concentration of the ENRMF disposals would also be suitable for disposal at Port Clarence whereas the composition of the national LLW inventory would not.

511. The second test is to identify whether the site has sufficient radiological capacity for the acceptable waste stream, in this case the waste stream with the same specific activity as the ENRMF disposals.

512. Applying these compositions and the radiological capacities for the individual radionuclides (MBq) indicates that disposal of the inventory in Table 47 would meet the dose criteria.

Table 47 Quantity of illustrative waste stream that could be disposed of at Port Clarence

Illustrative inventory	Specific activity (Bq/g)	Mass (t)	Inventory (MBq)
Extrapolated from specific activity of current ENRMF disposals	$4.64\ 10^{1}$	$4.75\ 10^{5}$	$2.2\ 10^{7}$

D.2. Illustrative radiological impact during the period of authorisation

513. In Table 48 the results of assessment calculations for the period of authorisation are applied to the illustrative inventories to indicate the potential radiological impact of waste disposal. The doses to members of the public and workers from both likely and unlikely events are considered. The doses from the NORM waste stream that has been disposed of at the site are shown in Table 180. Doses to the Fisherman are not shown because these are orders of magnitude lower than the Farming family.

Table 48 Total doses arising during the period of authorisation based on illustrative inventories

Illustrative inventory	Inventory (GBq)	Dose (µSv y^{-1})				
		Off-site gas (Operations)	Leachate spillage - Farming family	Leachate treatment – Facility worker	Leachate treatment - Farming family	Recreational
ENRMF inventory	$2.96\ 10^{5}$	$8.39\ 10^{-3}$	$3.88\ 10^{-9}$	$2.50\ 10^{-2}$	$1.02\ 10^{-3}$	$2.34\ 10^{-3}$
Extrapolated from specific activity of current ENRMF disposals	$2.20\ 10^{7}$	$3.70\ 10^{-1}$	$6.91\ 10^{-7}$	$4.4\ 10^{0}$	$3.73\ 10^{-2}$	$5.52\ 10^{-2}$

D.3. Illustrative radiological impact after the period of authorisation

514. The results for the scenarios after the period of authorisation are given below.

Table 49 Total doses arising after the period of authorisation based on illustrative inventories

Illustrative inventory	Inventory (GBq)	Dose (µSv y^{-1})		
		Groundwater to estuary	Coastal erosion - beach user	Coastal erosion - fishing family
ENRMF inventory	$2.96\ 10^{5}$	$2.36\ 10^{-6}$	$8.23\ 10^{-2}$	$2.23\ 10^{-1}$
Extrapolated from specific activity of current ENRMF disposals	$2.20\ 10^{7}$	$1.38\ 10^{-4}$	$9.78\ 10^{0}$	$1.42\ 10^{1}$

D.4. Illustrative Radiological Impact for Intrusion Scenarios

508. The results for the intrusions scenarios are given below.

Table 50 Total doses arising from intrusion scenarios based on illustrative inventories

Illustrative inventory	Inventory (GBq)	Dose (µSv y^{-1})	
		Borehole	Smallholder
ENRMF inventory	$2.96\ 10^{5}$	$3.14\ 10^{-4}$	$6.97\ 10^{-3}$
Extrapolated from specific activity of current ENRMF disposals	$2.20\ 10^{7}$	$2.58\ 10^{-2}$	$3.65\ 10^{-1}$

D.5. Activity concentration sum of fractions for the illustrative inventories

515. The disposal inventory of exempt NORM waste is also considered and the dose implications of these disposals are shown for the different scenarios. About 305,400 tonnes of low activity NORM waste have been disposed in the non-hazardous landfill. This NORM waste contains about 1.8 Bq g^{-1} Th-232 and 0.4 Bq g^{-1} U-238.

516. The results are given in Table 51.

Table 51 Total doses arising from NORM disposals to July 2019

NORM head of chains	Disposed (MBq)	Activity concentration (Bq g^{-1})	Intrusion - Smallholder (60y) All ages (µSv y^{-1} per MBq)	Intrusion - Borehole excavator (60y) - worker(µSv y^{-1} per MBq)	Gas + Ext. (Recreational 0y) All ages (µSv y^{-1} per MBq)	Erosion to coast (2540y) All ages (PC-Cream) (µSv y^{-1} per MBq)	Erosion - Dog walker (2540y) All ages (µSv y^{-1} per MBq)	Leachate spillage (0y) All ages (µSv y^{-1} per MBq)	Fire in non-hazardous cell (all ages) (µSv y^{-1} per MBq)
Th-232	$5.19\ 10^{5}$	1.7	$1.84\ 10^{-6}$	$4.15\ 10^{-6}$	$1.16\ 10^{-15}$	$3.92\ 10^{-7}$	$2.52\ 10^{-6}$	$1.80\ 10^{-8}$	$3.26\ 10^{-6}$
U-238	$5.17\ 10^{4}$	0.2	$4.47\ 10^{-8}$	$8.04\ 10^{-8}$	$9.52\ 10^{-24}$	$1.44\ 10^{-9}$	$9.90\ 10^{-9}$	$2.43\ 10^{-9}$	$1.54\ 10^{-7}$
U-234	$5.17\ 10^{4}$	0.2	$4.03\ 10^{-8}$	$9.34\ 10^{-8}$	$2.63\ 10^{-45}$	$1.38\ 10^{-7}$	$1.35\ 10^{-8}$	$2.31\ 10^{-9}$	$1.81\ 10^{-7}$
Th-230	$5.17\ 10^{4}$	0.2	$1.97\ 10^{-6}$	$1.07\ 10^{-6}$	$2.56\ 10^{-38}$	$1.01\ 10^{-5}$	$2.93\ 10^{-6}$	$1.32\ 10^{-9}$	$1.92\ 10^{-6}$
Ra-226	$5.17\ 10^{4}$	0.2	$1.31\ 10^{-4}$	$4.92\ 10^{-6}$	$5.36\ 10^{-11}$	$5.14\ 10^{-6}$	$1.49\ 10^{-6}$	$2.81\ 10^{-8}$	$3.76\ 10^{-7}$
Total dose µSv y^{-1}			$7.81\ 10^{0}$	$2.47\ 10^{0}$	$2.77\ 10^{-6}$	$1.00\ 10^{0}$	$1.54\ 10^{0}$	$1.11\ 10^{-2}$	$1.83\ 10^{0}$

D.6. Detailed Illustration of the sum of fractions approach

517. This Subsection illustrates the sum of fractions approach in more detail using two nominal waste streams.

518. Waste stream A consists of 2457 m^3 non-hazardous waste with a density of 1.4 t m^{-3}. The radiological composition is illustrated in Table 52.

Table 52 Radiological composition of waste stream A.

Radionuclide	Activity concentration (TBq m^{-3})	Specific activity (Bq g^{-1})	Total activity (MBq)
Ni-63	$1.36\ 10^{-7}$	$9.71\ 10^{-2}$	$3.34\ 10^{2}$
Sr-90	$5.99\ 10^{-7}$	$4.28\ 10^{-1}$	$1.47\ 10^{3}$
Cs-137	$1.28\ 10^{-6}$	$9.14\ 10^{-1}$	$3.14\ 10^{3}$
Pu-239	$1.21\ 10^{-8}$	$8.64\ 10^{-3}$	$2.97\ 10^{1}$
Pu-240	$1.65\ 10^{-8}$	$1.18\ 10^{-2}$	$4.05\ 10^{1}$

519. Waste stream B consists of 949 m^3 hazardous waste with a density of 4.6 t m^{-3}. The radiological composition is illustrated in Table 53.

Table 53 Radiological composition of waste stream B.

Radionuclide	Activity concentration (TBq m^{-3})	Specific activity (Bq g^{-1})	Total activity (MBq)
H-3	$3.65\ 10^{-6}$	$7.93\ 10^{-1}$	$3.46\ 10^{3}$
C-14	$3.33\ 10^{-6}$	$7.24\ 10^{-1}$	$3.16\ 10^{3}$
Cl-36	$1.43\ 10^{-6}$	$3.11\ 10^{-1}$	$1.36\ 10^{3}$
U-234	$3.32\ 10^{-9}$	$7.22\ 10^{-4}$	$3.15\ 10^{0}$
U-238	$3.32\ 10^{-9}$	$7.22\ 10^{-4}$	$3.15\ 10^{0}$

D.6.1. Activity concentration sum of fractions

520. First, we demonstrate that the waste streams comply with the limits set for specific activities. We assess both normal operations and loose tipping in the examples.

521. Table 54 illustrates the sum of fractions approach applied to specific activities in waste stream A. This table demonstrates that waste stream A would be suitable for normal operations and for loose tipping.

Table 54 Illustration of sum of fractions approach to assess the specific activity of waste stream A for normal operations and loose tipping.

Radionuclide	Normal operations		Loose tipping	
	Specific activity limit (Bq g^{-1})	Fraction	Specific activity limit (Bq g^{-1})	Fraction
Ni-63	$1.00\ 10^{4}$	$9.71\ 10^{-6}$	$1.00\ 10^{2}$	$9.71\ 10^{-4}$
Sr-90	$2.00\ 10^{2}$	$2.14\ 10^{-3}$	$1.00\ 10^{2}$	$4.28\ 10^{-3}$
Cs-137	$2.00\ 10^{2}$	$4.57\ 10^{-3}$	$1.00\ 10^{2}$	$9.14\ 10^{-3}$
Pu-239	$1.00\ 10^{2}$	$8.64\ 10^{-5}$	$5.00\ 10^{0}$	$1.73\ 10^{-3}$
Pu-240	$1.00\ 10^{3}$	$1.18\ 10^{-5}$	$5.00\ 10^{0}$	$2.36\ 10^{-3}$
Sum of fractions	$6.82\ 10^{-3}$		$1.85\ 10^{-2}$	

Table 55 illustrates the sum of fractions approach applied to specific activities in waste stream B. This table demonstrates that waste stream B would also be suitable for normal operations and for loose tipping.

Table 55 Illustration of sum of fractions approach to assess the specific activity of waste stream B for normal operations and loose tipping.

Radionuclide	Normal operations		Loose tipping	
	Specific activity limit (Bq g^{-1})	Fraction	Specific activity limit (Bq g^{-1})	Fraction
H-3	$1.00\ 10^{4}$	$7.93\ 10^{-5}$	$1.00\ 10^{2}$	$7.93\ 10^{-3}$
C-14	$1.00\ 10^{4}$	$7.24\ 10^{-5}$	$1.00\ 10^{2}$	$7.24\ 10^{-3}$
Cl-36	$1.00\ 10^{4}$	$3.11\ 10^{-5}$	$1.00\ 10^{2}$	$3.11\ 10^{-3}$
U-234	$2.00\ 10^{3}$	$3.61\ 10^{-7}$	$1.00\ 10^{2}$	$7.22\ 10^{-6}$
U-238	$2.00\ 10^{2}$	$7.22\ 10^{-6}$	$1.00\ 10^{2}$	$7.22\ 10^{-6}$
Sum of fractions	$1.87\ 10^{-4}$		$1.83\ 10^{-2}$	

D.6.2. Site capacity sum of fractions

522. Next, we look at the site capacity for the different assessment scenarios, as listed in the proposed Permit and below.

Intrusion - Smallholder (60y) All ages, Ra-226 at 5m depth

Intrusion - Borehole excavator (60y) - worker Ra-226 at 5m depth

Gas + Ext. (Recreational 0y) All ages Ra-226 at 5m depth

Erosion to coast (2540y) All ages (PC-Cream)

Erosion - Dog walker (2540y) All ages

Leachate spillage (0y) All ages

Landfill fire (only non-hazardous)

ERICA small burrowing

523. In this example, we have only considered the scenario capacity for two scenarios. The test would be made for all the scenarios listed in the Permit table. We assume that the non-hazardous landfill already contains waste stream A and investigate whether waste stream B can now be accepted for disposal at the hazardous waste site.

524. Table 56 illustrates the sum of fractions approach applied to total activities in waste stream A (non-hazardous waste) for two scenarios.

Table 56 Illustration of sum of fractions approach to assess the total activity of waste stream A for two scenarios (non-hazardous waste landfill)

Radionuclide	Intrusion - Smallholder (60y) All ages, Ra-226 at 5m depth		Gas + Ext. (Recreational 0y) All ages Ra-226 at 5m depth	
	Scenario radiological capacity (MBq)	Fraction	Scenario radiological capacity (MBq)	Fraction
Ni-63	$3.10\ 10^{11}$	$1.08\ 10^{-9}$	ND	ND
Sr-90	$3.83\ 10^{8}$	$3.84\ 10^{-6}$	$6.21\ 10^{26}$	$2.37\ 10^{-24}$
Cs-137	$1.38\ 10^{10}$	$2.28\ 10^{-7}$	$4.47\ 10^{20}$	$7.03\ 10^{-18}$
Pu-239	$2.59\ 10^{10}$	$1.15\ 10^{-9}$	$1.08\ 10^{32}$	$2.76\ 10^{-31}$
Pu-240	$2.60\ 10^{10}$	$1.56\ 10^{-9}$	$8.77\ 10^{54}$	$4.62\ 10^{-54}$
Sum of fractions	$4.07\ 10^{-6}$		$7.03\ 10^{-18}$	

525. Table 57 illustrates the sum of fractions approach applied to total activities in waste stream B for two scenarios.

Table 57 Illustration of sum of fractions approach to assess the total activity of waste stream B for two scenarios.

Radionuclide	Intrusion - Smallholder (60y) All ages, Ra-226 at 5m depth		Gas + Ext. (Recreational 0y) All ages Ra-226 at 5m depth	
	Scenario radiological capacity (MBq)	Fraction	Scenario radiological capacity (MBq)	Fraction
H-3	$1.01\ 10^{11}$	$3.41\ 10^{-8}$	$6.43\ 10^{9}$	$5.39\ 10^{-7}$
C-14	$2.33\ 10^{8}$	$1.35\ 10^{-5}$	$1.87\ 10^{8}$	$1.69\ 10^{-5}$
Cl-36	$1.56\ 10^{8}$	$8.68\ 10^{-6}$	$5.27\ 10^{29}$	$2.58\ 10^{-27}$
U-234	$7.44\ 10^{10}$	$4.23\ 10^{-11}$	$7.61\ 10^{45}$	$4.14\ 10^{-46}$
U-238	$6.71\ 10^{10}$	$4.69\ 10^{-11}$	$2.10\ 10^{24}$	$1.50\ 10^{-24}$
Sum of fractions	$2.22\ 10^{-5}$		$1.74\ 10^{-5}$	

526. The total sum of fractions for the first scenario (intrusion-Smallholder (60y)) is therefore the sum of the sum of fractions for each waste stream: $4.07\ 10^{-6} + 2.22\ 10^{-5} = 2.43\ 10^{-5}$. This is <1 so the radiological capacity for this scenario is met.

527. The total sum of fractions for the second scenario (Gas +Ext (recreational 0y) is obtained in a similar way: $7.03\ 10^{-18} + 1.74\ 10^{-5} = 1.74\ 10^{-5}$. This is <1 so the radiological capacity for this scenario is met.

528. The sum over waste streams is repeated for all scenarios listed. If they are all <1 then waste stream B could be accepted for disposal (assuming it meets all waste acceptance criteria) and the site dose constraint is met.

529. Finally, we check the overall impact of the LLW and NORM disposed of at the site against the dose constraint. This example shows the calculation for the scenario “Treatment of leachate offsite.

530. Table 58 illustrates the dose constraint calculation for waste stream A.

Table 58 Dose calculation for waste stream A in the scenario “Treatment of leachate offsite”.

Radionuclide	Total activity (MBq)	Dose (µSy y^{-1} MBq^{-1})	Dose at total activity (µSy y^{-1})
Ni-63	$3.34\ 10^{2}$	$7.26\ 10^{-12}$	$2.42\ 10^{-9}$
Sr-90	$1.47\ 10^{3}$	$4.30\ 10^{-9}$	$6.33\ 10^{-6}$
Cs-137	$3.14\ 10^{3}$	$4.17\ 10^{-8}$	1.3110^{-4}
Pu-239	$2.97\ 10^{1}$	$4.78\ 10^{-8}$	$1.42\ 10^{-6}$
Pu-240	$4.05\ 10^{1}$	$4.78\ 10^{-8}$	$1.94\ 10^{-6}$
Total Dose			$1.41\ 10^{-4}$

531. Table 59 illustrates the dose calculation for waste stream B.

Table 59 Dose calculation for waste stream B in the scenario “Treatment of leachate offsite”.

Radionuclide	Total activity (MBq)	Dose (µSy y^{-1} MBq^{-1})	Dose at total activity (µSy y^{-1})
H-3	$3.46\ 10^{3}$	$2.60\ 10^{-10}$	$9.02\ 10^{-7}$
C-14	$3.16\ 10^{3}$	$2.65\ 10^{-11}$	$8.39\ 10^{-8}$
Cl-36	$1.36\ 10^{3}$	$3.29\ 10^{-8}$	$4.47\ 10^{-5}$
U-234	$3.15\ 10^{0}$	$3.35\ 10^{-9}$	$1.06\ 10^{-8}$
U-238	$3.15\ 10^{0}$	$2.93\ 10^{-9}$	$9.24\ 10^{-9}$
Total dose			$4.57\ 10^{-5}$

532. Table 60 illustrates the dose calculation for disposed NORM waste to July 2019.

Table 60 Dose calculation for disposed NORM waste (July 2019) in the scenario “Treatment of leachate offsite”.

Radionuclide	Total activity (MBq)	Dose (µSy y^{-1} MBq^{-1})	Dose at total activity (µSy y^{-1})
Ra-226	$5.17\ 10^{4}$	$1.20\ 10^{-7}$	$6.20\ 10^{-3}$
Th-230	$5.17\ 10^{4}$	$2.77\ 10^{-8}$	$1.43\ 10^{-3}$
Th-232	$5.19\ 10^{5}$	$1.89\ 10^{-7}$	$9.81\ 10^{-2}$
U-234	$5.17\ 10^{4}$	$3.35\ 10^{-9}$	$1.73\ 10^{-4}$
U-238	$5.17\ 10^{4}$	$2.93\ 10^{-9}$	$1.52\ 10^{-4}$
Total dose			$1.06\ 10^{-1}$

533. The total dose from waste stream A, waste stream B and disposed NORM waste is $1.06\ 10^{-1}$ µSv y^{-1}, which is well below the dose constraint of 300 µSv y^{-1}.