

Monitoring our Environment

Discharges and Environmental Monitoring

Annual Report 2016



SI Units

Quantity	SI unit and abbreviation
Absorbed dose	Gray (Gy)
Dose equivalent	Sievert (Sv)
Radioactivity	Becquerel (Bq)

Multiples and submultiples of SI units

Factor	Prefix and abbreviation	Factor	Prefix and abbreviation
10^{18}	exa (E)	10^{-3}	milli (m)
10^{15}	peta (P)	10^{-6}	micro (μ)
10^{12}	tera (T)	10^{-9}	nano (n)
10^9	giga (G)	10^{-12}	pico (p)
10^6	mega (M)	10^{-15}	femto (f)
10^3	kilo (k)	10^{-18}	atto (a)

The tonne (metric ton) has the official abbreviation 't'.

However, in this report 'te' has been used to avoid confusion with the British ton.

Front cover photograph: Calder Hall at night - in recognition of the 60th anniversary of the commissioning of Calder Hall

Executive Summary

This 2016 report has been produced by Sellafield Ltd and covers the Sellafield site in Cumbria. It provides detailed information on radioactive discharges and disposals, monitoring of the environment and radiological impact, and also includes information on non-radioactive discharges and disposals. The report provides a summary of the comprehensive data that are available for inspection by members of the public on the Public Registers maintained by the Environment Agency. This report is also available on the Sellafield Ltd website (<https://www.gov.uk/government/organisations/sellafield-ltd>).

There were no instances in 2016 of non-compliance with the numerical limits of permits regulating discharges and disposals of radioactive wastes at Sellafield.

Radioactive discharges (aerial and liquid) were generally similar to those in 2015 and were well below the permitted limits.

The estimated doses in 2016 are summarised in the table below. Doses due to discharges to sea from Sellafield to adult members of the critical group who consume fish and shellfish from the local area were about 57 microSieverts (μSv). Taking into account doses due to beach occupancy and aerial pathways, the total dose to this group was about 110 μSv , similar to 2015. The most significant radionuclides contributing to this dose are Pu-alpha and Am-241 (33 μSv) - the environmental

concentrations of these radionuclides are mostly due to historic discharges.

The estimated dose in 2016 due to discharges to the atmosphere to members of the critical group who consume terrestrial foodstuffs was about 5 μSv . Further dose contributions to this group from inhalation, immersion, external radiation from beach occupancy and marine food consumption results in a dose from aerial discharges of about 10 μSv . Doses due to direct radiation from plants on site were estimated as being up to 5.4 μSv to the most exposed members of the public who live nearby. This is similar to 2015 due to the same calculation methodology being applied between years. The total dose to the terrestrial critical group (adults) was about 16 μSv . This dose is slightly larger than in 2015 (14 μSv). The most significant radionuclide contributing to dose received from the consumption of terrestrial foodstuffs is I-129 in domestic fruit (0.33 μSv). The environmental concentrations of these radionuclides are also mostly due to historic rather than 2016 discharges.

The estimated doses for the marine (110 μSv) and terrestrial critical groups (16 μSv) are much lower than the dose limit of 1000 μSv for exposure of members of the UK public to man-made controlled sources of radiation.

Critical group doses from operations at Sellafield (μSv)

Pathway	2015	2016
Marine critical group (adults)		
seafood consumption	52	57
aerial pathways	2.2	2.0
external radiation from beach occupancy (marine)	46	49
Total dose to marine critical group (adults)	100	110
Terrestrial critical group (adults)		
inhalation	0.58	1.0
immersion	0.63	0.40
external radiation from beach occupancy (terrestrial)	0.1	2.8
terrestrial foodstuff consumption	6.0	4.9
marine foodstuff consumption	1.2	1.1
direct radiation	5.4	5.4
Total dose to terrestrial critical group (adults)	14	16

Table of Contents

Executive Summary	iii
Introduction	1
Operations at Sellafield	2
Regulation of radioactive discharges and disposals	2
Regulation of non-radiological discharges and disposals	3
Monitoring of environmental radioactivity and dose assessment	3
Analytical measurements, limits of detection and rounding of data	4
Protection of the environment	4
Natural radioactivity	5
Environmental reporting by Sellafield Ltd	5
Acknowledgements	5
References	6
Radioactive and Non-radioactive Discharges and Disposals	9
Radioactive liquid discharges via the pipeline	10
Radioactive liquid discharges via the Factory Sewer	10
Radioactive aerial discharges	10
Solid low level radioactive wastes	11
Non-radioactive liquid and aerial discharges	11
Summary	12
Radiological and Non-radiological Monitoring of the Environment	19
Radiological monitoring of the environment	20
Marine pathways	20
External pathways	21
Beach monitoring	21
Airborne and terrestrial pathways	21
Direct radiation	22
Non-radiological monitoring of the environment	22
Environmental impact of non-radioactive discharges	23
References	23
Radiological Impact of Operations at Sellafield	35
Critical group doses	36
Direct radiation	38
Collective doses	38
Dose summary	38
Radiological impact perspective	38
References	39
Appendix A	47
Dosimetric considerations for individual and collective doses	47
Critical group doses	48
Collective doses	49
Worked example of committed effective dose calculation for an individual member of a critical group	50
References	51
Appendix B	56
Supporting monitoring and dose data	56
Appendix C	65
Representative person dose calculations	66
Glossary	70
Glossary of terms and abbreviations	71

Introduction

Discharges and Environmental Monitoring
Annual Report 2016

Operations at Sellafield

- 1 Sellafield Ltd is the company responsible for safely delivering decommissioning, reprocessing and nuclear waste management at Sellafield on behalf of the Nuclear Decommissioning Authority (NDA). The Company also has an engineering design capability based at Risley in Warrington and a number of satellite offices. Since April 2016 Sellafield Ltd has been a wholly-owned subsidiary of the NDA. The strategy and focus of Sellafield Ltd is to deliver accelerated nuclear clean-up programmes safely and cost-effectively.
- 2 Sellafield Ltd (established in April 2007) previously operated as British Nuclear Group Sellafield Ltd (BNGSL). BNGSL was established following the restructuring of its parent company British Nuclear Fuels Limited (BNFL) in response to the formation of the NDA. The NDA is the public body tasked by Her Majesty's Government with taking strategic responsibility for the decommissioning of civil public sector nuclear sites in the UK. In November 2008, Nuclear Management Partners (NMP) became the Parent Body Organisation (PBO) after a competitive process by the NDA to secure a new PBO for Sellafield Ltd. This arrangement ended on 31 March 2016. Sellafield Ltd hold the Nuclear Site Licence and Environmental Permits for the Sellafield site and is regulated by UK independent regulators including the Office for Nuclear Regulation (ONR) and the Environment Agency (EA).
- 3 Sellafield is the most complex nuclear site in the UK, home to the Thermal Oxide Reprocessing plant (Thorp) and Magnox Reprocessing plants and a wide range of waste management and effluent treatment facilities. As reprocessing nears completion, the emphasis is shifting to remediation, decommissioning and clean-up of the historical legacy.
- 4 During reprocessing operations, some effluents containing a small fraction of the radioactivity originally present in the used fuel are discharged to the sea and atmosphere, or disposed of as solid wastes to the Low Level Waste Repository (LLWR) near Drigg. Discharges of radioactivity to sea have declined significantly since the 1970s as a result of considerable investments and improvements in effluent treatment plants that have been described in previous reports in this series.
- 5 Since 1990, a number of plants that encapsulate solid intermediate-level radioactive waste in stainless steel drums have been, and continue to be, brought on line.
- 6 Sellafield also operates the Waste Vitrification Plant (WVP) which converts both historical and current arisings of liquid high-level waste into a form of glass. The molten glass is allowed to solidify inside stainless steel containers, which are then placed in a specially designed, self-cooling storage facility.
- 7 The Solvent Treatment Plant (STP), which was commissioned in 2002, treats arisings of solvent as well as historical solvent wastes currently stored at Sellafield.
- 8 Decommissioning of legacy buildings contribute to the safe and efficient acceleration of high hazard

risk reduction on site. Decommissioning has been underway for many years on the Sellafield site; such buildings include the Windscale Pile Chimneys, the Separation Purification Plant and Fuel Fabrication Facilities. Material resulting from decommissioning practices is appropriately categorised, processed and stored or disposed of. The majority of material from decommissioning efforts is in the solid phase which is either stored on site or transferred to LLWR. Any liquid or gaseous material resulting from decommissioning practices is accommodated within current liquid and aerial discharge permits.

- 9 Magnox reprocessing throughput in 2016 was higher than in 2015 (476 te compared to 428 te). Decommissioning work on older Magnox plants continued throughout the year.
- 10 Thorp reprocessing throughput in 2016 was higher than in 2015 (531 te compared to 399 te).

Regulation of radioactive discharges and disposals

- 11 The control of radioactive wastes is subject to the provisions of the environmental permit for radioactive substances. Under this permit and its supporting requirements, operators are permitted to discharge and dispose of radioactive waste only in accordance with the terms issued by the EA in England and Wales, including a range of discharge limits and requirements.
- 12 It is the policy of these agencies to review permits regularly. In establishing discharge limits for permits, they take into account the radiation protection principles presented in the latest relevant Government White Paper¹ (table 1). These principles are based on Government policy and the advice of Public Health England (PHE) (Appendix A: in the context of critical group dose limits and constraints - paragraphs 5, 6, 7 and 8; collective doses - paragraphs 18, 19, 20 and 21). Those parts of the Euratom Basic Safety Standards Directive (BSS) 1996 relating to dose limits (Appendix A: paragraph 8) were incorporated into UK law in the Radioactive Substances BSS Directive 2000, issued by the appropriate ministers to the EA. Other provisions of the BSS Directive were implemented through the Ionising Radiation Regulations 1999.
- 13 Sellafield discharges are regulated through the Environmental Permit for Radioactive Substances². The Environmental Permitting Regulations were introduced on 6 April 2010 and superseded the Radioactive Substances Act 1993 in England and Wales. The 2010 regulations were updated in December 2016. The permit covers all the discharge and disposal routes under a single permit. Additional requirements are specified by the EA in a supplementary document, the 'Compilation of Environment Agency Requirements, Approvals and Specifications' (CEAR).
- 14 As well as being subject to discharge limits, all discharges of radioactivity are subject to the requirement to use Best Available Technique (BAT) to limit the amount of radioactivity discharged. To enable the EA to monitor the application of BAT, Quarterly Notification Levels (QNLs) apply at

Sellafield to discharges of certain radionuclides. Exceeding a QNL requires the operator to submit a written justification of the BAT used to minimise discharges.

- 15 The Food Standards Agency (FSA), which reports to health ministers, was formed on 1 April 2000. Its responsibilities include the food safety implications of discharges of radioactive waste, in support of which it undertakes a substantial radiological surveillance programme both for marine and terrestrial samples. It has taken on the role, formerly exercised by the Ministry of Agriculture, Fisheries and Foods (MAFF), as statutory consultee to the EA in matters relating to radioactive discharge authorisations. The ONR has a similar role as statutory consultee because it regulates the accumulation of radioactive waste on licensed sites and the exposure of the general public to direct radiation from those sites.
- 16 The nuclear regulators employed by the EA regularly pay inspection visits to nuclear sites to critically review operations against radiological protection standards and the application of BAT. Thus the authorisation process is one of continual review (paragraph 12). This process not only reviews operations, effluent control and treatment arrangements, on-site sampling and analytical methods, but also the results of environmental monitoring, habits surveys and advances in the methodology for assessing radiological impacts.
- 17 Therefore the permit and inspection process embraces important aspects of radiation protection by:
 - controlling, monitoring and recording discharges to the environment in accordance with BAT;
 - monitoring of the environment to establish resultant radionuclide concentrations;
 - carrying out appropriate research, investigations and assessments to determine pathways for the transport of radioactivity through the environment;
 - assessing radiation doses to the public; and,
 - predictive assessment of radiation doses to the public arising from future discharges to the environment.
- 18 The Company is involved in all these activities with respect to discharges from its site. Under the terms of the environmental permits, there is a statutory obligation to carry out defined monitoring programmes, both for discharges and for environmental radioactivity. In addition, the ONR requires the assessment of doses to members of the public from direct radiation.
- 19 Agencies regulating sites which discharge radioactive material also take into account other international and national commitments and policies, such as the OSPAR Convention's North-East Atlantic Environment Strategy³ and the UK Radioactive Discharges Strategy. These are also considered by Sellafield Ltd when making decisions relating to development of Sellafield's forward looking plan and effluent management at site.

Regulation of non-radiological discharges and disposals

- 20 The regulation of non-radioactive discharges and disposals is the responsibility of the EA and Local Authorities who regulate discharges under the Environmental Permitting (England and Wales) Regulations 2016². In 2007 the EPR regulations combined the Pollution Prevention and Control (PPC) and Waste Management Licensing (WML) regulations. Their scope has since been widened to include the discharges to controlled waters of sewage and trade effluent.
- 21 Sellafield Ltd's operations fall under these regulations in terms of operating Listed Activities, including Large Combustion Plant; Waste Operations (including exemptions and recovery operations) and Water Discharge Activities. Sellafield Ltd also holds a Greenhouse Gas Permit, under the Greenhouse Gas Emissions Trading Scheme Regulations 2010.
- 22 Disposals of non-radioactive wastes are regulated through EPA 1990 and the Hazardous Waste Regulations 2005. Where wastes are transferred to another organisation for treatment or disposal, there is a legal Duty of Care on producers, carriers and disposers to ensure that waste is only disposed of under the terms of an environmental permit. Where non-hazardous and inert waste is transferred, it is accompanied by a transfer note which includes a full written description of the waste. Where hazardous waste is transferred in accordance with the Hazardous Waste Regulations 2005, it is accompanied by a consignment note. Landfill disposals are subject to Landfill Regulations which implement the requirements of the Landfill Directive and place additional requirements on both landfill site operators and waste consignors.

Monitoring of environmental radioactivity and dose assessment

- 23 The structure of the Statutory Environmental Monitoring Programme (SEMP) reflects the emphasis placed on assessing radiation doses to the public in the areas local to Sellafield Ltd's site. The essential considerations are to:
 - take account of the most important pathways by which radiation exposure of the public may occur;
 - conduct appropriate sampling and analysis to determine radionuclide concentrations or radiation levels relevant to those pathways; and,
 - combine the monitoring results with data on foodstuff consumption and other habits, and with data on the biokinetic behaviour of radionuclides, to yield estimates of radiation dose to the public.
- 24 It should be noted that these dose estimates, being based on environmental concentrations, will include contributions from radionuclides discharged in earlier years. They will therefore differ from those dose estimates in technical submissions to Radioactive Substances Regulations environmental permit reviews which relate to projected doses at expected future levels of discharge and at proposed discharge limits.

- 25 A description of the concept of critical group doses and collective doses, referred to here and elsewhere within this report, is given in Appendix A along with dose per unit intake tables and manSv per Bq discharged tables. Representative person dose calculations are given in Appendix C.
- 26 Data identifying critical groups and their habits by pathway have been provided by the FSA, EA and the Centre for Environment, Fisheries and Aquaculture Science (Cefas), or their predecessors, based on published survey work^{5,6,7}. Site-specific habits data used in dose assessments may relate to single years or to five-year averages as appropriate. Generalised food consumption rates for use in radiological dose assessments (particularly for terrestrial pathways) are reviewed by PHE with current guidelines issued in 2003⁸. Where appropriate, such generalised advice may be supplemented by other PHE advice⁹, or by information from local habits surveys.
- 27 In assessing doses, the Company takes account of research studies carried out both nationally and internationally, and also sponsors environmental research focusing specifically on the behaviour of radionuclides released from the Sellafield site. In addition, throughout this report the guidance of PHE¹⁰, the National Dose Assessment Working Group¹¹ (NDAWG) and the most recent dose coefficients in the International Commission for Radiological Protection (ICRP) Publication 119¹² are adopted where available and appropriate. For the specific calculation of the dose from krypton-85, where PHE does not provide advice, a cloud immersion dose is calculated from the recommendations of the ICRP¹³. In general, default values recommended by the ICRP for each radionuclide are assumed for the purpose of dose calculations unless specific studies indicate that an alternative is appropriate as discussed in Appendix A.
- 28 In accordance with regulatory guidance¹⁴, radiation dose rates in air ('air kerma') are generally measured in primary units of $\mu\text{Gy h}^{-1}$. In order to express this as an effective dose rate, $\mu\text{Sv h}^{-1}$, a conversion factor of 1.07 μSv per μGy is appropriate in most cases¹⁴. This reflects the differing energy deposition of ionising radiation in differing media: in this case air and tissue. By expressing the radiation dose rate in $\mu\text{Sv h}^{-1}$ and making allowance for background dose rates^{5,6,10,15} a direct estimate of the dose to man can be obtained.
- 29 Independent environmental monitoring programmes and dose assessments in the areas both local to Sellafield Ltd's site and further afield are carried out and reported by government agencies and other groups^{5,6,16-19}.
- 30 Collective doses have been calculated, using a 500 year integration period (Appendix A, paragraph 20), based on the most recent European Union (EU) methodology^{20,21}.

Analytical measurements, limits of detection and rounding of data

- 31 All measurements of radioactive discharges, concentrations of radionuclides in the environment and radiation dose rates are subject, as with any other type of measurement, to uncertainties arising

from the measurement process itself. These may become important when the quantities involved are very small compared with the measurement uncertainty, and the result is then quoted as a 'limit of detection' (i.e. with a '<' sign). This value is chosen to give a high degree of confidence that the actual result is less than that value.

- 32 Results from the Company's environmental monitoring programmes are reported here as the arithmetic means of measurements taken throughout the year. The concentrations of many radionuclides in the environment are now sufficiently low that most measurements are reported as limit of detection values, as explained above. They continue to be included in the monitoring and analysis programmes for reassurance that new pathways involving, for example, remobilised historical materials, have not arisen. Dose calculations either conservatively use such 'limit of detection' values, or use more realistic estimates of concentrations derived using environmental models. For example, modelling techniques have been applied to derive the doses received by members of the critical group from the intake of ruthenium-106 in foodstuffs (Appendix B, table B10) rather than use limit of detection values.
- 33 For clarity of presentation (and after calculations have been completed), discharges, concentration and dose rate data are normally rounded to two significant figures, or just one where the numbers are very small. Dashes are shown in tables to indicate where data have not been collected.
- 34 It should also be noted that measurements of 'total alpha' and 'total beta' activity do not necessarily equate to the sum of individually measured radionuclides. This is because of differing counting efficiencies and the presence of naturally occurring radionuclides.

Protection of the environment

- 35 In its 1990 Recommendations²², the ICRP considered that 'the standard of environmental control needed to protect man to the degree presently thought desirable will ensure that other species are not put at risk.' This view is defensible in most situations, particularly where critical groups are exposed in the areas of highest environmental concentrations, close to the point of discharge, through a variety of pathways. However, ICRP acknowledges that the protection of the environment needs to be considered in the wider sense, and has work underway which is addressing this matter. The OSPAR North-East Atlantic Environment Strategy³ incorporates the guiding theme of an Ecosystem Approach and includes a requirement that effective action is to be taken when there are reasonable grounds for concern that radioactive substances introduced into the marine environment may harm living resources and marine ecosystems. Sellafield Ltd is contributing to a number of initiatives intended to develop criteria for the protection of the environment. In addition, Sellafield Ltd is carrying out assessments of exposure against the guidelines given in national and international publications²³⁻²⁶ and on the basis of work to date there is no reason to believe that radioactive discharges from Sellafield Ltd are harming the environment.

Natural radioactivity

- 36 To put into context the data presented in this report, it is important to recognise that natural radioactivity is the dominant source of radiation exposure to the population as a whole, including individuals living close to nuclear establishments. In addition, the widespread radioactive fallout from the testing of nuclear weapons and from the Chernobyl disaster make small contributions to overall doses. The subject has been reviewed comprehensively by PHE^{10,15} and others²⁷.
- 37 Individual doses from natural radioactivity in the UK range broadly from 1000 μSv to 100,000 μSv per year¹⁵. The upper end of the range stems from homes with particularly high indoor levels of radon and its decay products. Dose limits set for the industry do not apply to natural background radiation, such as that from radon. Nevertheless, it may be noted for comparative purposes only that these upper figures substantially exceed the dose limits to the public (and indeed the workforce) applicable to the operation of nuclear establishments (see paragraph 12 and Appendix A, paragraph 8, and table 1). PHE recommends that measures be taken to reduce levels of radon in homes if the average annual indoor activity concentrations exceed 200 Bq m^{-3} and suggests that a radon-222 concentration of 20 Bq m^{-3} corresponds to an annual dose of 1200 μSv from the short-lived decay products of the gas¹⁵.
- 38 The measurements in this report relate to environmental radioactivity that is mainly attributable to discharges from the Sellafield site. However, natural radioactivity makes an appreciable contribution to the reported values in some instances. Where it is practicable to do so, the appropriate correction is made and noted. Thus, gamma dose rates quoted in this report are total dose rates including natural terrestrial background and cosmic ray contributions. For dose assessment purposes, the natural contributions are deducted.
- 39 A comparison of the most recently reviewed (2010) annually averaged doses to individuals in the UK population from all sources of radioactivity is presented in table 2 and figure 1²⁸. Typically, natural background accounts for some 84% of the total dose and medical uses of radiation for a further 16%. On this basis, the annual average dose is around 2700 μSv , of which 2300 μSv is derived from natural sources (mainly cosmic rays, rocks and soils, radon gas and foodstuffs - see table 2), 440 μSv from medical exposures, 0.4 μSv from occupational exposure, 5 μSv from nuclear weapons fallout and 0.19 μSv from discharges and disposals, including those from the nuclear industry²⁸. In areas of higher natural background radiation (e.g. Cornwall), the average dose may exceed 7000 μSv per year¹⁵.

Environmental reporting by Sellafield Ltd

- 40 This 2016 report has been produced by Sellafield Ltd and covers the Sellafield Ltd site in Cumbria. It provides detailed information on radioactive discharges and disposals, monitoring of the environment and radiological impact, and also includes information on non-radioactive discharges and disposals. It may be noted that the report provides a summary of the comprehensive data

that are available for inspection by members of the public on the Public Registers maintained by the EA. This report is also available on the Sellafield Ltd website (<https://www.gov.uk/government/collections/sellafield-ltd-environmental-and-safety-reports#discharges-and-environmental-monitoring-annual-report/>).

- 41 Wherever practicable, this report continues to present annual discharge and disposal data over five years for all radionuclides specified in the environmental permit for radioactive substances; the results of environmental monitoring for the report year; information on trends; and radiological impact in terms of critical group and collective doses. Any non-compliance with numerical limits is reported.
- 42 For non-radioactive discharges, it would be impracticable to report the discharges of all chemical species and performance against every condition in all permits and consents, even more so for a five-year period (many consent conditions relate to concentrations in individual samples). Accordingly, discharges and disposals are normally reported for just the year of the report and other quantitative conditions, such as temperature, pH and volume, are only reported where non-compliances have occurred.
- 43 All current permits and consents, as well as waste disposal and waste management licences, are available for inspection on the Public Registers referred to in paragraph 40.

Acknowledgements

This report was prepared, designed and produced by Sellafield Ltd's Environmental Monitoring and Assessments Group and Sellafield Ltd's Graphics Department. The contributions of staff at Sellafield Ltd who collected the environmental samples and measured environmental dose rates are acknowledged. Cavendish Nuclear Laboratory at Westlakes Science Park, Cumbria, analysed the Sellafield samples.

Members of the public who co-operated with the staff collecting samples and making measurements are especially thanked.

References

- 1 Cmnd 2919 (1995). **Review of radioactive waste management policy: Final conclusions.** HMSO, London.
- 2 HMSO (2016). **The Environmental Permitting (England and Wales) Regulations 2016.** Her Majesty's Stationery Office, London.
- 3 Department of Energy & Climate Change (2009). **UK strategy for radioactive discharges.**
- 4 OSPAR (2010). **The North-East Atlantic Environment Strategy.** Strategy of the OSPAR Commission for the Protection of the Marine Environment of the North-East Atlantic 2010-2020.
- 5 Environment Agency, Food Standards Agency, Food Standards Scotland, Natural Resources Wales, Northern Ireland Environment Agency and Scottish Environment Protection Agency (2016). **Radioactivity in food and the environment, 2015.** RIFE-21. EA, FSA, FSS, NRW, NIEA and SEPA; Preston, London, Aberdeen, Cardiff, Belfast and Stirling.
- 6 Doddington T C, Camplin W C and Caldwell P (1990). **Investigation of external radiation exposure pathways in the eastern Irish Sea, 1989.** Fisheries Research Data Report 22. MAFF, Lowestoft.
- 7 Garrod C J and Clyne F J (2017). **Radiological habits survey: Sellafield review, 2016.** Environment Report RL03/17. CEFAS, Lowestoft (under contract to the EA and the FSA).
- 8 Smith K R and Jones, A L (2003). **Generalised habit data for radiological assessments.** NRPB Report W41.
- 9 Cabianca T, Fayers C A, Mayall A, Robinson C A and Simmonds J R (1995). **Peer review of BNFL radiological assessment methodologies.** NRPB Report M815.
- 10 Hughes J S and Shaw K B (1996). **Radiation doses from natural radiation.** NRPB Report M748.
- 11 Allott R (2005). **Assessment of compliance with the public dose limit. Principles for the assessment of total retrospective public doses.** NDAWG/2/2005. National Dose Assessment Working Group.
- 12 International Commission on Radiological Protection (2012). **Compendium of dose coefficients based on ICRP Publication 60.** ICRP Publication 119. Ann. ICRP 41 (Suppl.).
- 13 International Commission on Radiological Protection (1979, 1980). **Limits for intakes of radionuclides by workers.** ICRP Publication 30, Parts 1 and 2. Ann. ICRP 2 (3/4) and 4 (3/4).
- 14 Her Majesty's Inspectorate of Pollution (1995). **Routine measurement of gamma ray kerma rate in the environment. Technical Guidance Note (Monitoring) M5.** HMSO, London.
- 15 Watson S J, Jones A L, Oatway W B and Hughes J S (2005). **Ionising radiation exposure of the UK population: 2005 Review.** Health Protection Agency Report HPA-RPD-001, HMSO, London.
- 16 McKay W A and Stephens B A (1990). **A survey of fish and shellfish radioactivity levels in Cumbrian near-shore waters, 1989.** AEA-EE-0041, Harwell.
- 17 McKay W A and Walker M I (1990). **Plutonium and americium behaviour in Cumbrian near-shore waters.** J. Environ. Radioactivity 12: 49-77.
- 18 Walker M I and McKay W A (1991). **Radionuclide distributions in seawater around the Sellafield pipeline.** Est. Coast. Shelf Sci. 32: 385-393.
- 19 Isle of Man Government Laboratory (2011). **Radioactivity monitoring on the Isle of Man 2010.**
- 20 Smith J, Oatway W, Brown I and Sherwood J (2009). **PC-CREAM 08 user guide.** RPD-EA-9-2009. Health Protection Agency.
- 21 Smith G and Simmonds J R (2009). **The methodology for assessing the radiological consequences of routine releases of radionuclides to the environment used in PC-CREAM 08.** HPA-RPD-058. Health Protection Agency.
- 22 International Commission on Radiological Protection (1991). **The 1990 recommendations of the ICRP.** ICRP Publication 60. Ann. ICRP 21 (1-3).
- 23 Copplestone D, Bielby S, Jones S R, Patton D, Daniel P and Gize I (2001). **Impact assessment of ionising radiation on wildlife.** R&D Publication 128. Environment Agency.
- 24 Brown J, Alfonso B, Avila R, Beresford N A, Copplestone D, Proehl G and Ulanovsky A (2008). **The ERICA tool.** Journal of Environmental Radioactivity 99(9): 1371-1383.
- 25 International Atomic Energy Agency (1999). **Protection of the environment from the effects of ionizing radiation. A report for discussion.** IAEA-TECDOC-1091.
- 26 International Commission on Radiological Protection (2008). **Environmental Protection - the concept and use of reference animals and plants.** ICRP Publication 108. Ann. ICRP 38 (4-6).
- 27 Saunders P (1990). **Radiation and You.** Banson.
- 28 Oatway, W B, Jones, A L, Holmes, S, Watson, S and Cabianca, T (2016). **Ionising radiation exposure of the UK population: 2010 review.** Public Health England Report PHE-CRCE-026, Crown Copyright.

Table 1. Summary of radiation protection principles in the Government's review of radioactive waste management policy (1995)¹

Annual dose	Applicability	Comments
1000 µSv	Limits the overall exposure to the general public from man-made controlled sources of radiation (excluding medical uses), including the effects of past and current discharges and summing across all relevant exposure pathways.	The previous flexibility to average exposure over more than one year is no longer considered necessary, and this limit is now a cap on annual exposure.
500 µSv	A 'site constraint' to limit the aggregate exposure from a number of sources with contiguous boundaries at a single location.	Applies irrespective of whether different sources on the site are owned or operated by the same or different organisations.
300 µSv	A 'dose constraint' used as the principal criterion in determining applications for discharge authorisations from new facilities. It applies to the sum of all relevant exposures resulting from the operation of a single new source only.	Existing facilities may seek a higher dose constraint in certain circumstances. In most cases this should not be necessary and, in any case, the dose limit and the ALARA principle continue to apply.
10 µSv	Threshold for optimisation below which the regulators will not seek further reduction in public exposures, provided they are satisfied that 'Best Available Technique' is being applied to safeguard the public.	The introduction of this concept is consistent with the current practice of the Health and Safety Executive.

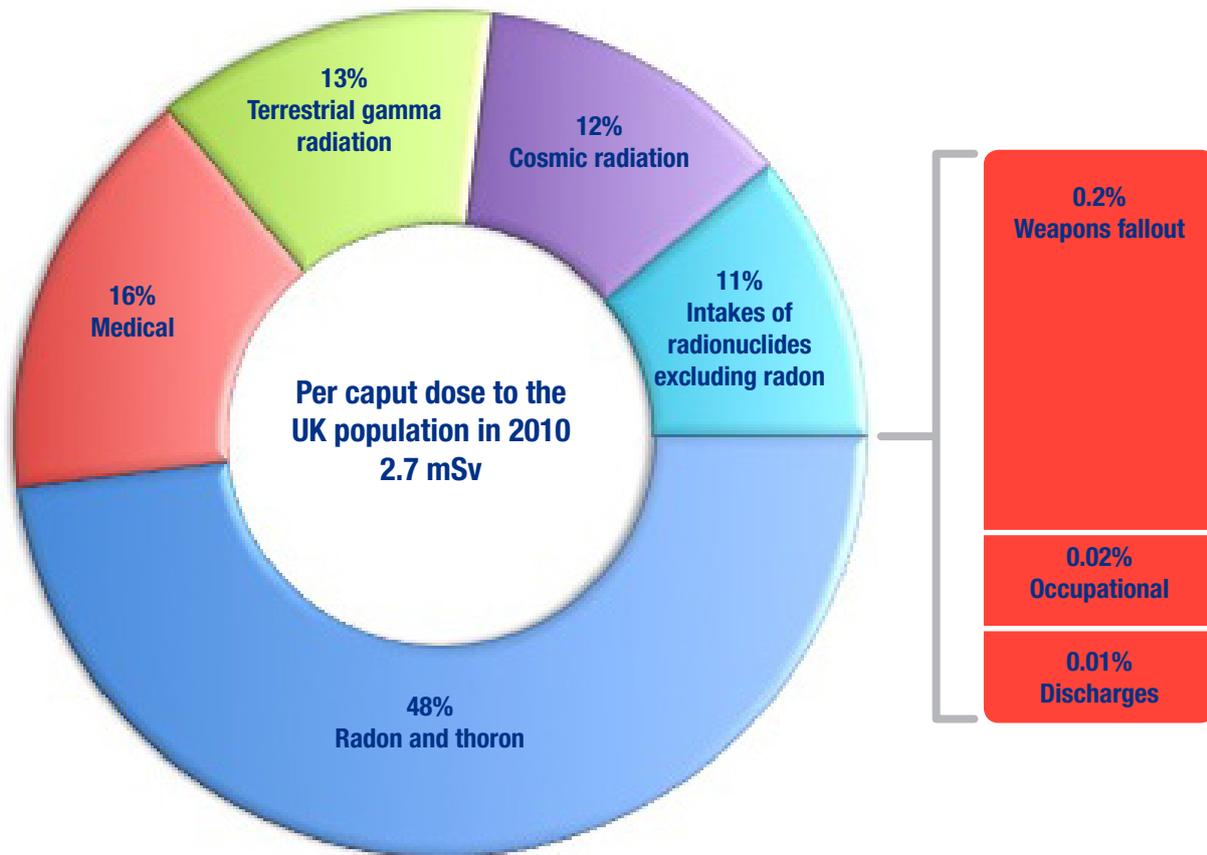
Table 2. Summary of doses to the UK population from ubiquitous radiation in the environment²⁸

Source	Per caput dose (µSv)
	Average
Radon and thoron	1300
Intake of natural radionuclides (excluding radon)	270
Terrestrial gamma radiation	350
Cosmic radiation	330
Weapons fallout	5
Other anthropogenic radioactivity in the environment*	0.8
Total	2300

*Includes exposure to radionuclides routinely discharged or accidentally released into the environment

Reproduced (with minor presentational changes) by kind permission of the PHE.

Figure 1. Sources of annual average radiation dose to the UK population²⁸



Reproduced by kind permission of the PHE.

Radioactive and Non-radioactive Discharges and Disposals

Annual Report 2016

Radioactive liquid discharges via the pipeline

- 1 Radioactive liquid effluents arise from fuel reprocessing and storage operations, on-site decommissioning operations, and Sellafield Ltd and United Kingdom Atomic Energy Authority laboratories. Liquors from the reprocessing plants that contain the highest levels of activity are routed directly to storage, pending incorporation into solid glass form in the Waste Vitrification Plant; they are not therefore discharged from the site.
- 2 Where practicable, the medium active waste streams from reprocessing are routed via the Medium Active Evaporator, or the Salt Evaporator, to interim decay storage pending treatment in the Enhanced Actinide Removal Plant (EARP) prior to discharge. Where this is not possible, the effluents are routed directly to EARP or other plants for treatment prior to discharge.
- 3 The remaining low-level liquid effluents are discharged to sea, after monitoring, via the Sellafield pipeline. The main sources of such effluents are:
 - Storage pond water from the old Magnox decanning plants and the Fuel Handling Plant (FHP). This water is treated in the Site Ion-Exchange Effluent Plant (SIXEP) to remove radioactive contaminants, principally caesium-137 and strontium-90;
 - Storage pond water from Thorp;
 - EARP bulk discharges, consisting of treated Magnox effluents and some effluents from Thorp and 'EARP Concentrate' discharges, consisting of treated batches of effluent from interim storage and other concentrates;
 - Thorp dissolver off-gas scrubber liquors following treatment to remove carbon-14 as solid waste;
 - Remaining process liquors are routed to the Segregated Effluent Treatment Plant (SETP) where effluent is adjusted for pH and held for confirmation of its composition prior to discharge. Three discharge tanks are in operation, permitting flexible effluent management and the extended retention of effluent if required; and,
 - Minor waste streams, such as surface drainage water and laundry effluent.
- 4 The liquid discharge permit includes Site Limits for liquid effluents with rolling 12 month limits and Quarterly Notification Levels for 'total alpha' and 'total beta' activity as well as for individual radionuclides. In addition, the permit has limits on individual plants. For this report, only performance against the Site Limits is considered. To comply with the permit, samples from each waste stream are analysed either daily (Thorp Receipt and Storage, SIXEP, laundry, surface drainage water) or prior to discharge (SETP, EARP Bulks and Concentrates, Thorp carbon-14 removal facility) for 'total alpha' and 'total beta'. More detailed analyses for a wide range of radionuclides, including all those listed in the schedule to the permit, are carried out on monthly or quarterly bulks of daily samples.
- 5 Data on discharges over the last five years are given in table 1 and provides a basis for comparison with current permitted limits. All discharges during 2016

were within those limits. The discharges of actinides (and hence of 'total alpha') in 2016 were slightly greater than 2015 but have remained below 0.25 TBq since 2005.

- 6 Trends in liquid effluent discharges between 1990 and 2016 from the Sellafield pipeline for radionuclides that contribute to the largest proportions of the marine critical group dose are illustrated in figures 1 and 2. Maximum annual discharges of Pu-alpha and Am-241 occurred in 1973 (65 TBq) and 1974 (120 TBq) respectively. The 2016 annual discharges are orders of magnitude lower than peak discharge rates, Pu-alpha being 0.28% and Am-241 being 0.025% of peak discharge rates. Indeed, even in more recent years, the 2016 Pu-alpha annual discharge rate is approximately 8 times lower and Am-241 30 times lower than the discharge rate in 1993 (table 1, figures 1 and 2).

Radioactive liquid discharges via the Factory Sewer

- 7 The Factory Sewer discharges into the confluence of the Rivers Calder and Ehen. The primary source of the effluent is treated sewage and surface water drainage from areas of the Sellafield site to the north of the River Calder. This water may contain trace amounts of radioactivity and therefore discharges are included in the Environmental Permit for Radioactive Substances for the Sellafield site. Total quantities of radioactivity discharged over the last five years and current permitted limits are shown in table 2.
- 8 During 2016, the Factory Sewer beta-emitting liquid discharges peaked at >99% of its plant limit but did not exceed the limit. The increase in discharge levels was arising from groundwater which contained levels of historic contamination entering the ground drainage system. Elevated groundwater levels, due to high winter rainfall, enabled the groundwater to enter the site's surface water drains.
- 9 Sellafield Ltd applied for a variation to the Permit which the EA granted on 1 December 2016. This variation increased the Factory Sewer Total Beta limit from 6.1 to 60 GBq. However, the overall site limit which includes the main sealines was also reduced from 200,000 GBq to 180,000 GBq for beta-emitting radionuclides.
- 10 In March 2015 the Calder Interceptor Sewer was included in the Site Permit. Monitoring of this discharge route was performed throughout 2016 with no radioactive discharges being detected during this time.

Radioactive aerial discharges

- 11 Aerial effluents are discharged from a number of stacks (chimneys) on the Sellafield site. They mainly consist of ventilation air from the process plants. Their radioactive constituents comprise of noble gases (e.g. krypton), other gases and vapours (e.g. hydrogen, water vapour, iodine and carbon dioxide) and suspended particulates. Most release points are monitored continuously and fitted with appropriate abatement equipment, such as high efficiency particulate air filters or scrubbers.

- 12 The aerial discharge permit has annual Site Limits and individual Stack Limits. The individual stack discharges are summed to produce the site discharge. In this report, only performance against the Site Limits is presented (see table 3).
- 13 Discharges of radioactivity to the atmosphere also take place from Open Fuel Storage Ponds and other approved outlets (OFSPs and OOs) (previously MOOs, "Miscellaneous and Other Outlets"). These are largely associated with the re-suspension of radioactivity from open fuel storage ponds and other approved places. As in previous years, releases in 2016 from OFSPs and OOs were calculated by a methodology agreed with the EA using data on activity concentrations in air at the site perimeter. These data are included in the total alpha and total beta discharges detailed in table 3.
- 14 Discharges for the years 2012 to 2016 are summarised in table 3. The discharges of krypton-85, iodine-129, tritium and carbon-14 generally reflect the reprocessing throughput (Introduction: paragraphs 9 and 10). Most of the remaining radionuclides are associated with particulate material and their annual discharges are not directly related to annual reprocessing rates.
- 15 Figure 3a and b shows the annual aerial discharge trends for carbon-14 and iodine-129 since 2000. These trends will be used as a baseline record for future discharges during the post-reprocessing phase (beyond 2020) of the Sellafield site.

Solid low level radioactive wastes

- 16 A number of inter-site transfer authorisations cover the transfer of radioactive waste between Sellafield and the LLWR. Details of these waste disposals are described below.
- 17 Solid low level radioactive waste arises on the Sellafield site from process operations and decommissioning. Arisings of process wastes have been reduced in recent years to a fairly constant level so that fluctuations in total arisings now mainly reflect decommissioning operations. The wastes are sent to the LLWR under the terms of the Environmental Permit, which also covers use of the Waste Monitoring and Compaction (WAMAC) facility at Sellafield. This facility reduces the volume of waste being sent for disposal at the LLWR. It also offers a compaction service to other generators of low level radioactive waste across the UK. Therefore, the Environmental Permit (and Limits) also includes allowances for the transfer of non-Sellafield Ltd waste from WAMAC to the LLWR. The Sellafield site seeks to minimise the amount of waste disposed to LLWR by applying the waste management hierarchy and by seeking to utilise other resources. In 2016, 3% of site LLW (4% in 2015) was disposed of to LLWR, although there was a 42% increase in the total of site generation of LLW. The remaining 97% was reused/ recycled or disposed of to other facilities, including on-site disposal to the Calder Landfill Extension Segregated Area (CLESA). The low level radioactive waste and non-radioactive waste arisings from Sellafield for 2012 - 2016 are presented in table 4.

- 18 Historically contaminated soil arising at Sellafield from construction and excavation has been disposed of at permitted landfill sites. Only one of these sites, CLESA, is now permitted. The previous landfill sites are now in closure and aftercare status. CLESA received 8,200 m³ in 2016. These disposals are included in the Site's Environmental Permit, which includes an activity limit of 37 kBq kg⁻¹ (dry weight) for total alpha and total beta, above which soil has to be disposed of at the LLWR as low level radioactive waste.

Non-radioactive liquid and aerial discharges

- 19 Non-radioactive liquid effluent discharges between 2012 and 2016 are summarised in table 5 and include all discharges for which annual mass limits are specified. Aerial discharges between 2012 and 2016 are summarised in table 6 and 7.
- 20 There was one permit breach in 2016 under the Environmental Permit for the Sellafield PPC installation. On 24th November 2016 the total suspended solids released from the Sewage Treatment Works was 4270 mg l⁻¹ against a limit of 45 mg l⁻¹. Typical total suspended solids values were less than 20 mg l⁻¹. To avoid repetition of this event in 2016, measures were taken to optimise the sampling procedure as well as to improve the capability by training several samplers.

Disposals made under the terms of Waste Disposal or Waste Management Licences

- 21 Radioactive wastes were historically disposed to the LLWR, now managed by LLWR Ltd. It should be noted that radioactive hazardous waste is also included in the LLWR disposal figures. A number of landfill disposal facilities were developed on site, to provide alternative disposal routes to the LLWR. These were operated under RSA authorisations and Waste Management Licences. There are five of these licensed landfill sites at Sellafield, although four are closed. Calder Landfill Extension Segregated Area (CLESA) is the only operational landfill and is permitted to take a range of Very Low Level Radioactive Wastes (VLLW) / Low Active – Low Level Waste (LA-LLW), such as concrete, soil and stones. Additionally, in order to reduce the amount of LLW sent for disposal at the LLWR, a national resource with limited capacity, some wastes arising on the site and particularly from radiologically controlled areas, are carefully monitored and assessed to confirm that they are not radioactive. Such wastes are 'Out of Scope' under the Environmental Permitting Regulations. All wastes assessed as 'Out of Scope' under the Environmental Permitting Regulations 2016, as well as wastes deemed to be clean, are sent for disposal off-site as controlled wastes (paragraph 24).

Ozone depleting substances and fluorinated greenhouse gases

- 22 The Company is committed to minimising the use of ozone depleting substances and fluorinated greenhouse gases and replacing equipment containing them. Routine releases are estimated from the amounts of refrigerants used to top-up systems on site. Site releases between 2012 and 2016 of ozone depleting substances and fluorinated greenhouse gases are summarised in table 8.

Carbon dioxide and other greenhouse gases

- 23 Sellafield's discharges of carbon dioxide and methane are mainly from Fellside Combined Heat and Power plant (CHP), which is managed and operated by Sellafield Ltd and its emissions controlled by the Sellafield Environmental Permit and an Emissions Trading Permit. Carbon dioxide may also be emitted from standby generators on Sellafield site which also have an Emissions Trading Permit. In addition, small amounts of carbon dioxide are released from the process plants (table 7).

Off-site disposals of solid waste

- 24 Non-radioactive (controlled) wastes consisting of, for example concrete, soil and stones, office/canteen or workshop waste (predominantly solid but including sludges and liquids) are disposed of off-site via the Site Waste Management Contractor, where possible, utilising the Waste Management

Hierarchy. Such wastes are reused or recycled where possible. Consideration is given by Sellafield Ltd to avoid the production of the waste in the first instance or whether the waste can be reduced in either classification or volume. Hazardous waste is usually unable to be reused/recycled, with some exceptions (e.g. fluorescent tubes, batteries and oil wastes for example), and are normally disposed of to specially licensed disposal facilities. In 2016 70% of Sellafield inert, non-hazardous and hazardous waste was reused or recycled (table 9). In addition, various improved waste management practices are being introduced at Sellafield. Introduction of operations such as bailing and composting have commenced. More recycling bins have been introduced in offices and mixed waste bins have been removed from those areas. Further improvements are actively being sought to continuously improve the waste management practices on the site.

Summary

- 25 There were no instances in 2016 of non-compliance with the numerical limits of permits regulating discharges and disposals of radioactive wastes at Sellafield.
- 26 Radioactive discharges (aerial and liquid) were generally similar to those in 2015 and were well below the permitted limits.

Table 1. Radioactive discharges to the Irish Sea via the pipeline, 2012 - 2016

Radionuclides	Annual discharge (TBq)					Authorised Limits
	2012	2013	2014	2015	2016	
Tritium	1,100	1,400	1,300	1,500	2,000	18,000 ^c
Carbon-14	4.1	5.5	4.7	4.9	4.8	21
Cobalt-60	0.05	0.05	0.05	0.05	0.04	3.6
Zinc-65	0.008	0.007	0.01	0.007	0.01	
Strontium-90	1.2	1.1	1.6	1.6	2.0	45 ^b
Zirconium-95	0.06	0.05	0.05	0.06	0.05	} 2.8
Niobium-95	0.05	0.04	0.03	0.04	0.04	
Technetium-99	0.93	1.1	1.3	1.7	1.9	10
Ruthenium-106	0.65	0.58	1.1	0.70	1.1	51
Antimony-125	1.0	1.0	0.90 ^e	1.1	1.2	
Iodine-129	0.21	0.29	0.36	0.36	0.52	2.0
Caesium-134	0.06	0.08	0.06	0.07	0.07	1.6
Caesium-137	3.6	3.2	2.6	3.1	3.7	34
Cerium-144	0.25	0.19	0.16	0.19	0.21	4.0
Europium-152	0.01	0.01	0.02	0.01	0.02	
Europium-154	0.01	0.01	0.01	0.007	0.009	
Europium-155	0.01	0.01	0.02	0.009	0.01	
Neptunium-237	0.04	0.03	0.04	0.04	0.03	0.73
Plutonium-alpha	0.14	0.15	0.15	0.14	0.18	0.70
Plutonium-241	3.0	3.2	2.9	2.4	3.0	25
Americium-241	0.02	0.02	0.02	0.03	0.03	0.30
Curium-243+244	0.002	0.002	0.002	0.001	0.003	0.05
Total alpha ^a	0.14	0.16	0.17	0.19	0.25	0.90 ^c
Total beta ^a	9.5	9.0	9.7	9.5	13	180 ^d
Uranium (kg)	340	350	360	330	340	2,000

- a. 'Total alpha' and 'Total beta' are control measures relating to specified analytical determinations. They do not reproduce precisely the contributions from all individual isotopes.
- b. Limit changed in June 2012 from 48 TBq for Strontium-90.
- c. Limit changed in March 2015 from 20,000 TBq for Tritium, 1.0 TBq for Total alpha.
- d. Limit changed in December 2016 from 200 TBq for Total Beta.
- e. Antimony-125 liquid discharge for 2014 updated from previous reports in line with statutory discharge records.

Table 2. Radioactive discharges to the Irish Sea via the Factory Sewer, 2012 - 2016

Radionuclides	Annual discharge (GBq)					Authorised Limits (all sources)
	2012	2013	2014	2015	2016	
Total alpha	0.11	0.05	0.06	0.09	0.08	0.30
Total beta	3.9	1.9	1.8	2.6	5.2	60 ^a
Tritium	9.9	6.6	4.6	7.4	7.9	68

- a. Limit changed in December 2016 from 6.1 GBq for Total Beta.

Table 3. Total airborne radioactive discharges, 2012 - 2016

Radionuclides	2012	2013	2014	2015	2016	Authorised Limits (all sources)
	Annual discharge (TBq)					
Tritium	100	180	95	84	120	1,100
Carbon-14	0.38	0.52	0.34	0.42	0.44	3.3
Krypton-85	38,000	50,000	56,000	68,000	88,000	440,000
	Annual discharge (GBq)					
Strontium-90	0.03	0.04	0.03	0.03	0.03	0.71
Ruthenium-106	0.70	0.70	0.78	0.73	0.70	23
Antimony-125	3.2 ^a	9.3	8.8	12	10	30
Iodine-129	7.8	9.0	12	11	13	70
Iodine-131	0.24	0.40	0.35	0.44	0.42	37
Caesium-137	0.14	0.19	0.15	0.09	0.10	5.8
Radon-222	43	43	43	43	43	500
Plutonium-alpha	0.02	0.02	0.02	0.03	0.02	0.19
Plutonium-241	0.24	0.14	0.20	0.29	0.15	3.0
Americium-241 + Curium-242	0.01	0.01	0.01	0.02	0.01	0.12
Total alpha	0.10	0.07	0.08	0.08	0.11	0.88
Total beta	1.0	0.72	0.71	0.62	1.2	42

a. Antimony-125 aerial discharge for 2012 updated from previous reports in line with statutory discharge records.

Table 4. Solid low level waste arisings from Sellafield, 2012 - 2016

Low Level Waste Arisings (m ³)	2012	2013	2014	2015	2016
LLW produced on site which has been reused, recycled or disposed of	20,000	11,000	8,800	9,800	14,000
LLW which has been reused or recycled	780	Nil	Nil	Nil	Nil
LLW metal waste recycled	1,600	3,100	2,400	2,300	2,300
Combustible LLW treated	69	280	800	1,300	1,200
LLW to landfill (as HV LLW or exempt/out of scope) ^a	12,000	-	-	-	-
LLW disposed of directly to landfill (as LLW, HV-VLLW or exempt waste but excluding waste that is out of scope of regulation) ^a	-	490	610	370	770
LLW disposed of on site	3,300	4,500	3,400	4,100	8,200
Volume of LLW disposed of at LLWR	1,600	2,600	1,700	1,800 ^b	1,600

a. Waste arising description changed in 2013.

b. Volume now includes volume of compactable LLW.

Table 5. Non-radioactive liquid effluent discharges (kg), 2012 - 2016

Substance	Release points	2012	2013	2014	2015	2016	Annual Limit ^a
Mercury	SETP, SIXEP, EARP, Laundry, Inactive Tank Farm Neutralising Pit, Thorp-C14 Removal Plant, Water Treatment Plant	0.35	0.58	0.14	0.12	0.04	10
Chromium	SIXEP, SETP, EARP	230	4.3 ^b	5.7 ^b	47	110	1,200
N as NO ₂ and NO ₃	SETP, EARP	920,000	1,000,000	1,000,000	900,000	1,000,000	4,080,000
N as NO ₂ and NO ₃	Thorp-C14 Removal Plant	3,800	3,600	4,800	4,500	7,000	26,900
Glycol	SETP, SIXEP, EARP, Lagoon	850	1,400	260	530	590	12,000

a. Annual mass limits reported under the Environmental Permit.

b. Discharge reduction in 2013 and 2014 due to very low throughput in EARP.

Table 6. Non-radioactive aerial effluent discharges (kg), 2012 - 2016

Substance	Release points	2012	2013	2014	2015	2016	Annual Limit ^a
Oxides of nitrogen (as NO ₂)	Vitrification Test Rig	40	37	53	20	54	1,000
Oxides of nitrogen (as NO ₂)	NNL Central Laboratory	23	36	15	30	54	500
Particulate matter	Fellside CHP (as PM ₁₀)	380	480	420	510	450	-

a. Annual mass limits reported under the Environmental Permit.

Table 7. Non-radioactive aerial effluent discharges (tonne), 2012 - 2016

Substance	Release points	2012 ^b	2013 ^b	2014 ^b	2015 ^b	2016 ^b
Oxides of nitrogen (as NO ₂)	Site Total ^a	330	370	330	530	450
Carbon dioxide	Site Total ^a	320,000	410,000	360,000	430,000	390,000
Carbon monoxide	Site Total ^a	14	21 ^c	21 ^c	21 ^c	21 ^c
Non-Methane Volatile organic compounds (NMVOCs)	Site Total ^a	75	76	85	86	71
Methane	Site Total ^a	11	13	13	27	23

a. Site Total includes Fellside CHP plant.

b. No annual limits apply.

c. EA agreed reporting value as carbon monoxide discharges significantly below reporting threshold (BRT) values.

Table 8. Discharges of ozone depleting substances and fluorinated greenhouse gases (kg), 2012 - 2016

Substance ^a	2012	2013	2014	2015	2016
R22 HCFC	5	120	44	1.4	-
R134A HFC	460	75	51	100	120
R407C HFC	260	80	270	120	44
R404A HFC	69	-	0.8	0.1	0.1
R410A HFC	31	3.8	35	61	4.9
R417A HFC	6.5	-	5	5	8.1

a. HCFCs are ozone depleting substances and HFCs are fluorinated greenhouse gases.

Note: the range of substances discharged varies each year depending on which equipment is topped up with refrigerants.

Table 9. Non-radioactive solid waste arisings from Sellafield, 2012 - 2016

	Non-Radioactive Waste Arisings (te)^a	2012	2013	2014	2015	2016
Inert Waste Arisings	Inert waste produced on site	Nil	Nil	Nil	Nil	Nil
	Inert waste reused or recycled	Nil	Nil	Nil	Nil	Nil
	% of inert waste reused or recycled	0 %	0 %	0 %	0 %	0 %
Non-Hazardous Waste Arisings	Non-hazardous waste produced on site	4,700	26,000	7,500	12,000	12,000
	Non-hazardous waste reused or recycled	2,800	4,200	3,800	9,600	8,500
	% of non-hazardous waste reused or recycled	60 %	16 %	51 %	78 %	70 %
Hazardous Waste Arisings	Hazardous waste produced on site	400	240	660	370	590
	Hazardous waste reused or recycled	93	94	140	160	140
	% of hazardous waste reused or recycled	23 %	39 %	22 %	43 %	24 %

a. Whilst every effort is made to centrally record all Non-Rad waste arisings, some sub-contractors may not provide this information, so the actual quantity produced may be higher than the centrally recorded figure.

Figure 1. Pu-alpha discharge from marine pipeline and concentration in winkles, mussels and *Nephrops*

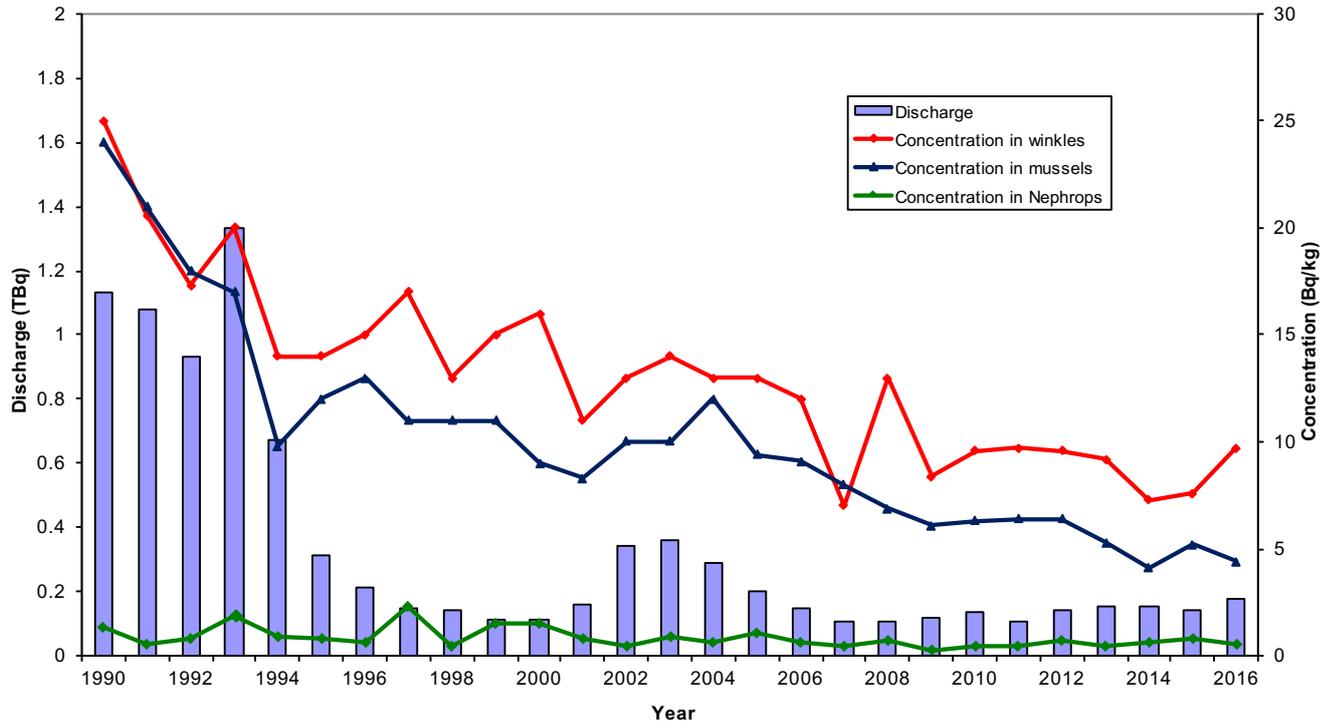


Figure 2. Am-241 discharge from marine pipeline and concentration in winkles, mussels and *Nephrops*

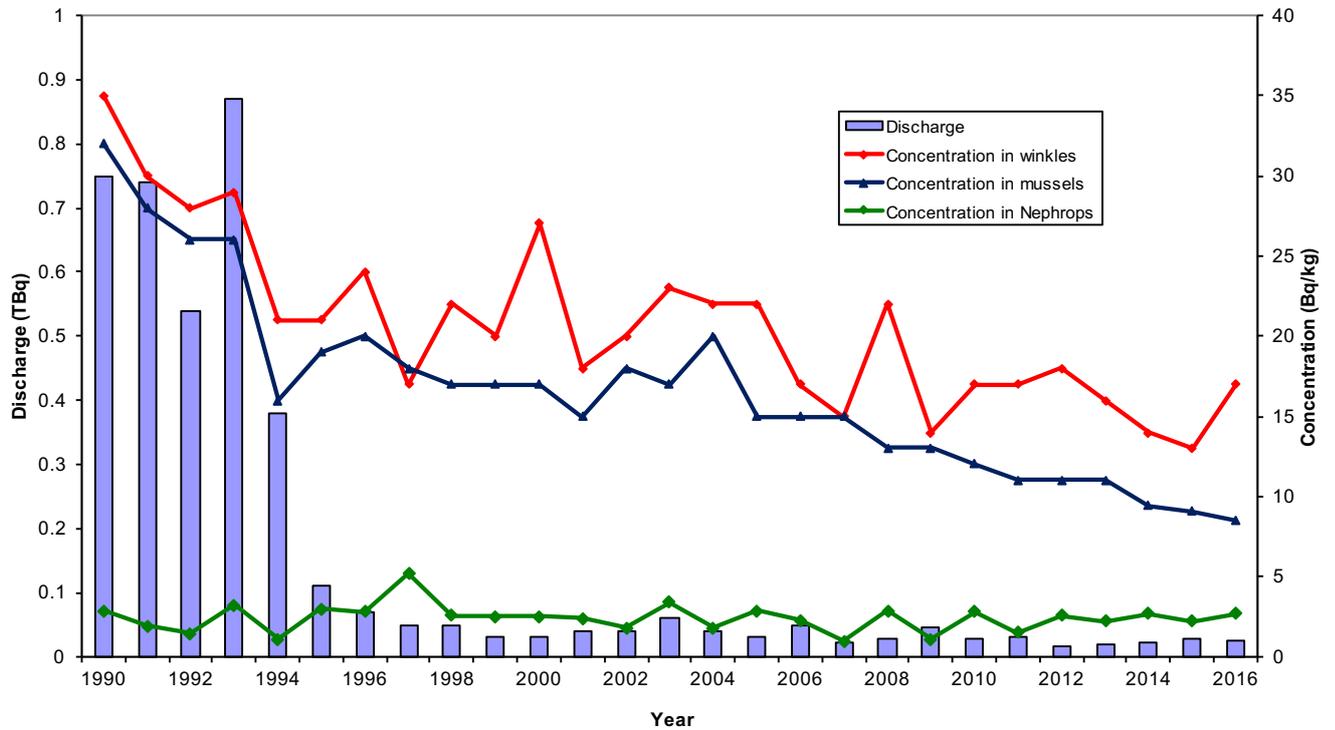


Figure 3a. Annual aerial discharges of Carbon-14 (TBq)

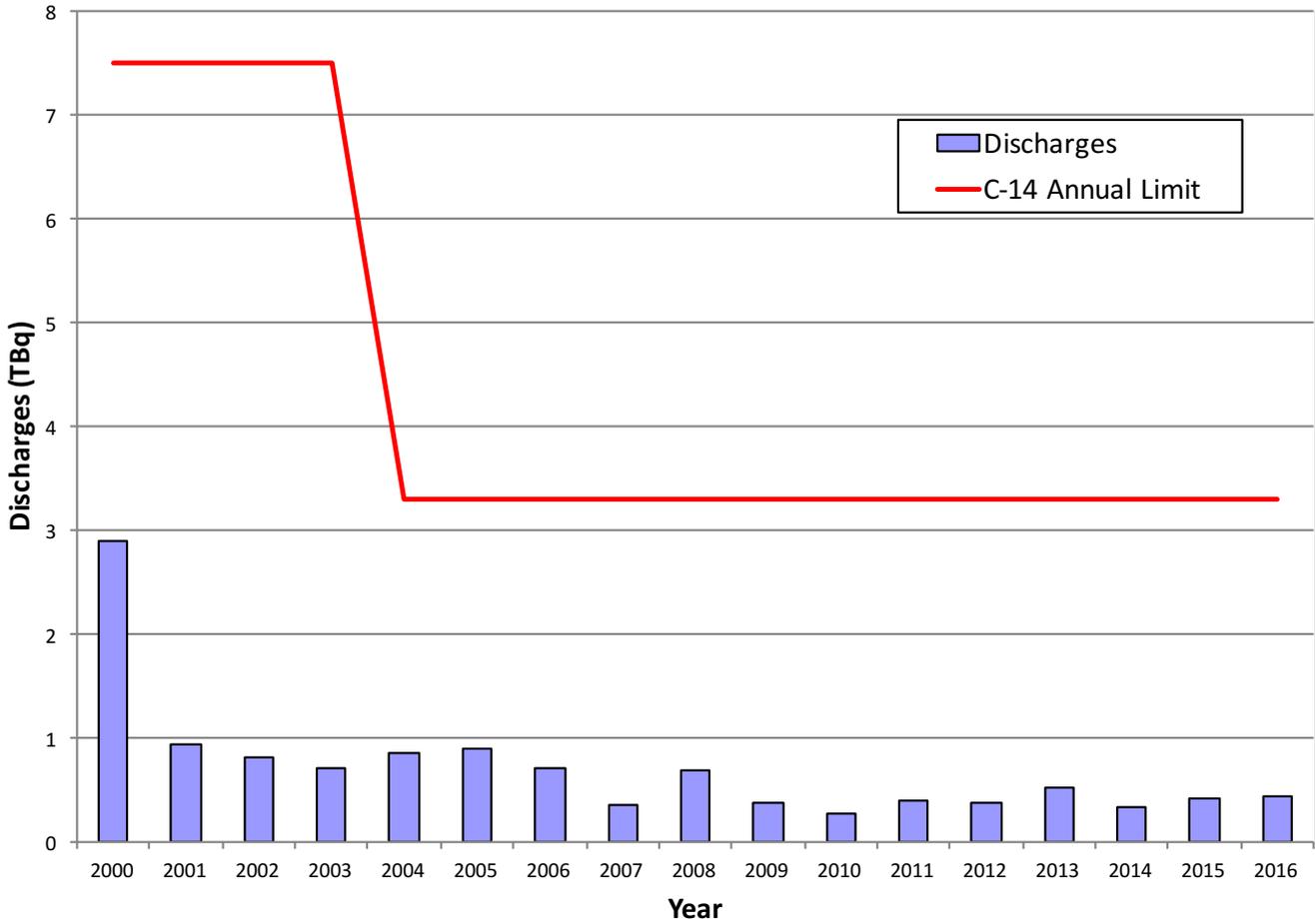
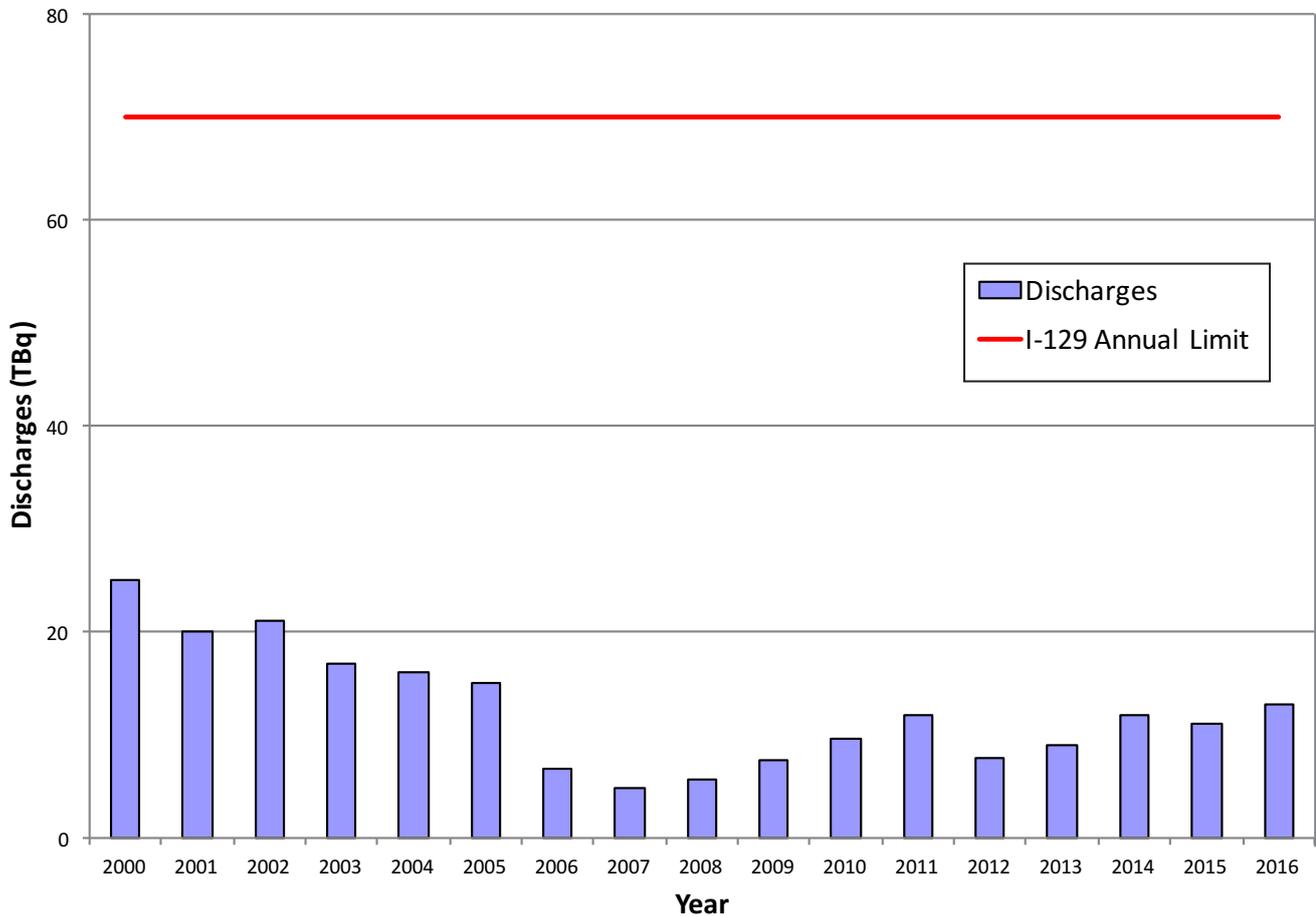


Figure 3b. Annual aerial discharges of Iodine-129 (GBq)



Radiological and Non-radiological Monitoring of the Environment

Annual Report 2016

Radiological monitoring of the environment

1 The results of the Sellafield Ltd environmental monitoring programme for 2016 are presented within this report alongside supplementary data, for foodstuffs and radionuclides pertinent to dose calculations, published by the FSA (tables 11 and 12). Further background information relating to analytical measurements, limit of detection and rounding of data is given in the Introduction.

2 The main pathways identified by Sellafield Ltd, the EA and FSA as relevant to calculating critical group doses attributable to radioactive discharges from Sellafield are:

- Internal exposure from the high rate consumption of seafood (particularly crustaceans and shellfish) and of local agricultural produce;
- External gamma radiation from exposed intertidal sediments, particularly the silts and muds of estuaries and harbours; and,
- Inhalation of, and exposure to, airborne radioactivity.

The habits and consumption rates relating to each pathway are kept under regular review^{1,2,3}. The SEMP, as supplemented by data from the EA and FSA monitoring programmes, reflects these pathways. In addition to pathways of radiation exposure, the monitoring programme also includes the analysis of 'indicators'. These are usually biological materials which accumulate radioactivity and therefore are more likely to produce positive analytical results and provide trends in environmental concentrations; examples are grass and seaweed. Doses from direct radiation, as distinct from discharges, are discussed elsewhere (paragraphs 28 and 29).

3 Concentrations of radioactivity in the marine environment reflect discharges from the Sellafield pipelines, whereas radioactivity in the terrestrial environment generally reflects discharges to atmosphere. Some overlap does occur however, with sea to land transfer processes^{4,5} and on tidally inundated pastures⁶. Concentrations of caesium-137, plutonium and americium-241 in most environmental materials are predominantly as a consequence of historical discharges.

Marine pathways

4 The extent of the marine environmental monitoring programme is illustrated in figure 1. Samples are regularly collected from the Cumbrian coast. The precise locations are reviewed periodically. In certain cases, additional samples are obtained through commercial suppliers, representing foodstuffs available for general consumption.

Foodstuffs

5 The concentrations of radionuclides in the edible parts of fish, molluscs and crustaceans from the Sellafield Area are given in tables 1, 2 and 3 and summarised in table 4. Temporal trends are shown in the Discharge and Disposals chapter, figures 1 and 2 alongside the discharges from the sea pipeline. Trends in the seafood generally reflect the annual discharges from the pipeline and as such were generally similar to those in recent years. Plutonium-alpha and americium-241 concentrations

in mussels were slightly lower to those in 2015 whereas in winkles these activity concentrations were slightly higher than those in 2015. Overall, the general downward trend in actinide concentrations in molluscs has continued, with concentrations in 2016 being around half the values reported in the early 1990s.

6 Since *Nephrops* now contributes as much dose to the critical group as mussels (Radiological chapter, table 1), concentrations of plutonium-alpha and americium-241 in *Nephrops* have been included in the Discharge and Disposal chapter figures 1 and 2. In general, concentrations of plutonium-alpha and americium-241 in *Nephrops* have remained constant since 1990. During that time plutonium-alpha concentrations peaked at 2.5 Bq kg⁻¹ in 1997 and have been consistently below 1 Bq kg⁻¹ since 2000. Similarly, americium-241 concentrations peaked at 5 Bq kg⁻¹ in 1997 with concentrations being below 3 Bq kg⁻¹ since 2003. The *Nephrops* concentration data for americium-241 have been derived using Sellafield Ltd reported data. Data gaps exist for plutonium-alpha which have been filled using subsequent RIFE data and normalising to the Sellafield Ltd americium-241 data.

7 Data for carbon-14 presented in tables 1 to 4 are not corrected for the levels which are present naturally⁷. However, background corrected values for carbon-14 in fish, molluscs and crustaceans have been used in the assessment of radiation doses to critical groups. For these marine foodstuffs, natural concentrations of carbon-14 have been taken from data published by the EA and FSA¹.

Indicators

8 Seaweeds are useful marine indicators (see paragraph 2). *Fucus vesiculosus* is collected because it accumulates many radionuclides (particularly technetium-99) and is sensitive to fluctuations in their concentrations in seawater. Thus, the reduction in discharges from 2002 onwards was soon reflected in the levels in this species (Appendix B, figure B1). *Porphyra umbilicalis* is also collected and monitored as an indicator species (Appendix B, table B1) due to its historical exposure pathway role for ruthenium-106.

Seawater and sediments

9 Sellafield Ltd routinely collects samples of seawater from the shore at locations close to Sellafield. Concentrations of radioactivity in seawater (Appendix B, table B2) were broadly similar to those of recent years. Specific examples of concentration trends in seawater filtrate from 2000 are given for caesium-137 and plutonium-alpha at Sellafield beach in Appendix B, figures B2 and B3 respectively. A gradual decrease over time is observed for caesium-137 whereas plutonium-alpha has remained at a consistently low level over this time period despite there being an increase in plutonium-alpha discharges between 2002 and 2004 due to increased pond water activity concentrations in the FHP.

10 Concentrations of radioactivity in sediments (Appendix B, table B4) were generally similar to those of recent years. Redistribution of sub-surface sediments may have led to small fluctuations in radionuclide concentrations.

External pathways

- 11 Gamma dose rate surveys are carried out in the areas most often frequented by members of the public (table 5). Particular attention is paid to areas where silt or mud accumulates, such as in harbours or estuaries, where dose rates tend to be higher because of the presence of finely-divided sediments. Several measurements are made in each area allowing temporal and geographical trends to be observed. The gradual decline in external gamma dose rates at Newbiggin saltmarsh between 1993 and 2016 is shown in Appendix B, figure B4. This decline is consistent with the decline in activity concentrations of cobalt-60, ruthenium-106 and caesium-137 reported in Newbiggin sediment (due to a combination of discharge trends and radioactive decay). The major external gamma dose rate contributor in recent years is from caesium-137 due to the reduction in discharges and decay of cobalt-60 (5.27 year half life) and ruthenium-106 (373 day half life). Consequently the external gamma dose rates here will now decrease according to the presence of caesium-137 (30.1 year half life combined with potential burial rate due to sediment accretion). Gamma dose rate surveys are also conducted around the site perimeter and the surrounding district (tables 6 and 7 and paragraph 28-29). In general dose rates are declining towards background levels.
- 12 Beta-gamma ground level monitoring is undertaken just above the surface on local beaches to ascertain the general levels of radioactivity and to remove items of higher than normal activity if necessary. In addition to the routine monitoring programme, extra monitoring is carried out in the event of exceptionally high tides or severe storms. During 2016, approximately 30 man-hours of effort were spent monitoring 82 km of coastline. Monitoring was concentrated on recent tide-lines and wind-blown debris in near-shore areas.

Beach monitoring

- 13 In 2003, a radioactive particle containing strontium-90 activity was found during a routine beach monitoring survey. The unusual nature of the particle prompted a review of beach monitoring and, as a result, trials of a large area monitoring technique were agreed with the EA. The trial was undertaken by a contractor on behalf of Sellafield Ltd using their Groundhog™ monitoring system and proved successful in finding a number of radioactive items on Sellafield and Braystones beaches. Following the trial, Sellafield Ltd and the EA agreed a programme of large area beach monitoring. This was specified as a reporting requirement by the EA in the CEAR document.
- 14 The current monitoring programme is determined by taking account of the find rates (both particles and objects) and the occupancy information for each beach. The programme is reviewed annually and its scope and extent are agreed with the EA. Stakeholder views are also considered during the review process.
- 15 In 2016, Sellafield Ltd monitored the required beach area in line with EA CEAR recommendations. Appendix B, table B4 shows which beaches were monitored during the 2016 calendar year in addition

to the number of finds recovered and associated find rates. More detailed information on beach monitoring can be found at <https://www.gov.uk/government/publications/particles-in-the-environment-annual-report>

- 16 Particle and object find rates were similar in 2016 compared to 2015. The same detection system, Synergy2™, was used in both years' monitoring programme. The majority of finds were recovered from Sellafield beach (79 %).
- 17 The types of material being recovered during 2016 remained consistent with those retrieved since commencement of the monitoring programme. The distribution of Cs-137 and Am-241 activities of current particles remain within observed ranges of all particles to date, providing reassurance that they are part of the same general population.
- 18 PHE has advised the EA on the particle risks associated with using the beaches around Sellafield. The current advice is reproduced below⁸.
- PHE confirms that the advice provided in 2009, that "no special precautionary actions are required at this time to limit access to or use of beaches" remains valid.

Airborne and terrestrial pathways

- 19 The extent of the terrestrial environmental monitoring programme is illustrated in figure 2.

Airborne

- 20 High flow rate air sampling equipment, located close to the site perimeter (table 8) and in nearby centres of population (table 9), is used to sample airborne particulates for radiochemical analysis. Levels off-site were generally below the limit of detection, with most positive values reflecting sea to land transfer from marine discharges. The Whitehaven sampler was damaged in storms during December 2013 and returned to service in 2016.
- 21 Total deposition collectors are located in the vicinity of each of the five high flow rate air samplers close to the site perimeter. Higher activity concentrations for beta-emitters are measured at North Gate (Appendix B, table B5), reflecting its close proximity to the open ponds.
- 22 Continuous sampling for atmospheric krypton-85 was analysed fortnightly at the Met. station on the edge of Sellafield site. Concentrations ranged from 2.2 to 183 Bq m⁻³ and averaged 47 Bq m⁻³. This is equivalent to an immersion dose of <1 µSv a⁻¹ for all age groups (Radiological impact chapter, table 7). Significant variation in atmospheric krypton-85 concentrations were observed due to discontinuities in reprocessing operations on the Sellafield site combined with the variability in meteorological conditions.

Foodstuffs and water

- 23 Locations sampled for milk include local farms (in the range 0 to 4 km from the Sellafield site). The average concentrations of radioactivity in milk are summarised in table 10. The figures include the residual effects of weapons testing and the 1986 Chernobyl reactor accident. Data for carbon-14 includes the contribution

from natural background. However, estimates of effective dose have been made by subtracting natural background levels of carbon-14. For milk and other terrestrial foodstuffs, vegetation and soil, a background level of 226 Bq carbon-14 per kg carbon is used¹. The milk results for 2016 are broadly similar to or lower than those observed for previous years, with many analyses at the limit of detection. In recent years, milk consumption was a main contributor to the critical group dose from terrestrial foodstuffs. In 2016, this was not the situation due to strontium-90 activity concentrations being lower than previous years.

- 24 The results of the Sellafield environmental monitoring programme for 2016 are presented alongside supplementary data published by the FSA in tables 11 and 12. The Sellafield Ltd samples were mainly collected from within 4 km of the Sellafield site as they became available throughout the year. Direct comparison with the results of earlier years is difficult due to the relatively small numbers of samples and their locations. Data for carbon-14 are presented as total and net (background subtracted) values¹. For terrestrial foodstuffs no longer monitored by Sellafield Ltd, natural carbon-14 background concentrations have been taken from data published by the EA and FSA¹. For 2016, the consumption of domestic fruit and potatoes has been calculated to be the main contributors to the critical group dose from terrestrial foodstuffs.
- 25 Water samples are collected from the River Calder and River Ehen, lakes and domestic supplies. The results (table 13) are all very low and rarely above the limits of detection, except for strontium-90 which is generally present in rain water and surface water at levels typical of those throughout the UK¹.

Indicators

- 26 Grass and soil sampling are included in the monitoring programme as they provide time trend data on environmental concentrations of radioactivity. Grass samples (Appendix B, table B6) are collected quarterly from five locations on the Sellafield site and also from the Ravenglass Estuary. Soil samples (5 cm cores) are collected annually from the same locations (Appendix B, table B7). Concentrations in soil are similar to previous years with exception of the Ravenglass site. Here caesium-137, plutonium-alpha and americium-241 activities are generally higher than in 2015. The deposition of natural debris (e.g. seaweed) as well as fine sedimentary material occurs at the Ravenglass site as it is tidally inundated. This process can significantly affect the radionuclide content of soils and grass in the deposited region. Therefore the suitability of this site is currently under review in conjunction with the EA.

Groundwater

- 27 Part of the statutory monitoring programme includes the routine monitoring of groundwater from 15 locations around the perimeter of the site so that any significant migration of radioactivity in groundwater will be detected. These groundwater monitoring wells are shown in figure 3. The routine results in 2016 (Appendix B, table B8) were similar to those reported in recent years; however, elevated results for beta emitting radionuclides continue to be recorded at 6948p1 and are subject to ongoing

review and investigation. Most other results were close to or below limits of detection, except for tritium and technetium-99 in the vicinity of the main gate and southwest of the site (figure 3). The Windscale Trenches, which were used before disposal operations commenced at the LLWR, may form part of the source of the tritium in this area and also of that monitored in groundwater up-welling on the Sellafield beach, however the source term up gradient of this area is complex. A redundant sea discharge storage tank is believed to be the source of the technetium-99. These concentrations are in line with groundwater modelling that predicted peak concentrations of 0.1 MBq m⁻³ technetium-99 between 2000 and 2010. More detailed information on groundwater monitoring at the Sellafield sites can be found at <https://www.gov.uk/government/publications/groundwater-monitoring-at-sellafield-2014-data-review>.

Direct radiation

- 28 Some of the older Magnox buildings, including the Calder reactors, have lower levels of radiation shielding than the modern buildings, such as Thorp. Consequently, it is possible to measure radiation dose rates above natural background at the site perimeter fence. These dose rates were largely due to direct radiation from the unshielded heat exchangers on the Calder reactors and therefore were dependent upon the amount of power being produced by the reactors (until they were shut down in March 2003). The perimeter radiation levels are still affected by radiation from contamination within the heat exchangers but at a much lower level.
- 29 Gamma dose rates are monitored continuously and analysed quarterly using thermoluminescent detectors (TLDs) at 31 locations around the site perimeter (table 6) and at a further 7 locations in the surrounding district (table 7). Dose rates at the site perimeter averaged 0.11 µSv h⁻¹, significantly lower than when the Calder Hall reactors were fully operational. Dose rates in the surrounding district averaged 0.07 µSv h⁻¹. These are total dose rates, which include contributions from natural terrestrial background and cosmic rays. For dose assessment purposes the natural contributions are deducted.

Non-radiological monitoring of the environment

- 30 The Environmental Permit includes a non-radiological monitoring programme (see Monitoring chapter, figure 3). Compared to the radiological environmental monitoring programme, its scope is limited and comprises local air sampling on the Sellafield site, water sampling from the Rivers Calder and Ehen and seawater sampling from local beaches. A more comprehensive summary of non-radioactive releases to air, controlled waters, land and off-site transfers of waste is given in the pollution inventory supplied to the EA each year and is available from their website <https://www.gov.uk/check-local-environmental-data>

Air sampling

- 31 Measurements of nitrogen dioxide concentrations in air are made at five locations on the Sellafield site: West Ring Road, Meteorological Station, North Group roundabout, Calder Gate and South Side.

Measurements are made using passive diffusion tubes which are exposed for one month before being analysed. Air sampling results are summarised in table 14.

Water sampling

- 32 Water samples are obtained from the Rivers Calder and Ehen at locations both upstream and downstream of the site (table 15). The downstream samples are taken above the confluence of the two rivers, and at times which minimise contamination with seawater. Seawater samples are obtained from the shoreline areas given in table 16 rather than from offshore sites as was performed up to 2006.

Monitoring of Sellafield's landfill sites

- 33 The Waste Management Licences for the North Landfill Site and Calder Floodplain Landfill Extensions require that environmental monitoring be carried out in the vicinity of the two sites. The monitoring comprises water sampling from the River Calder and New Mill Beck upstream and downstream of the tips and gas monitoring over their surfaces. The results are summarised in tables 17 and 18.

Environmental impact of non-radioactive discharges

- 34 In this report, the impact of aerial discharges has been addressed (table 14) by comparing the measured environmental concentrations with the most stringent (annual mean) national air quality limit values¹ for nitrogen dioxide. The interpretation of these results is not straightforward since discharges are made not only from Sellafield but also from other industrial sites in West Cumbria and from natural sources. The data in table 14 show that the measured concentrations in air on the Sellafield site were all below the air quality limit value.
- 35 The results in table 15 and 16 confirm that the liquid discharges from Sellafield are not causing the Environmental Quality Standards (EQS) and Environmental Assessment Levels (EAL)⁹ to be exceeded and therefore should be of negligible impact.
- 36 Environmental monitoring results (table 17 and 18) confirm that the impact of Sellafield's landfill sites remains negligible. No significant concentrations of carbon dioxide or methane have been measured at these sites.

References

1. Environment Agency, Food Standards Agency, Food Standards Scotland, Natural Resources Wales, Northern Ireland Environment Agency and Scottish Environment Protection Agency (2016). **Radioactivity in food and the environment, 2015**. RIFE-21. EA, FSA, FSS, NRW, NIEA and SEPA; Preston, London, Aberdeen, Cardiff, Belfast and Stirling.
2. Food Standards Agency (2010). **Radiological Habits Survey: Cumbrian coast beach occupancy, 2009**. Environment Report RL 01/10.
3. Garrod CJ and Clyne FJ (2017). **Radiological habits survey: Sellafield review, 2016**. Environment Report RL03/17. CEFAS, Lowestoft (under contract to the EA and the FSA).
4. Peirson DH (1988). Artificial radioactivity in Cumbria: **A summary of an assessment by measurement and modelling**. J. Env. Radioactivity 6: 61-75.
5. Howarth JM and Eggleton AEJ (1988). **Studies of environmental radioactivity in Cumbria. Part 12: Modelling of sea-to-land transfer of radionuclides and an assessment of the radiological consequences**. AERE-R11733, HMSO, London.
6. Howard BJ (1987). **Cs137 uptake by sheep grazing tidally inundated and inland pastures near the Sellafield reprocessing plant**. In: Coughtrey P J et al (Eds) Pollutant Transport and Fate in Ecosystems, pp 371-383. Blackwell Scientific Publications, Oxford.
7. Cook GT and McKenzie AB (1996). **Marine background of carbon-14**. Project RP/GNSR/5003, Scottish Universities Research and Reactor Centre, East Kilbride.
8. Etherington G, Youngman M J, Brown J and Oatway W (2012). **Evaluation of the Groundhog Synergy beach monitoring system for detection of alpha-rich objects and implications for the health risks to beach users**, HPA-CRCE-038.
9. Environment Agency (2010). **Horizontal Guidance Note H1- Environmental risk assessment**. Environment Agency, Bristol.

Table 1. Radioactivity in fish (Bq kg⁻¹ wet weight), 2016

Species	Location	Mean radionuclide concentration (Bq kg ⁻¹ wet weight)					
		¹⁴ C ^a	⁹⁹ Tc	¹⁰⁶ Ru	¹³⁷ Cs	Pu(α)	²⁴¹ Am
Cod	Sellafield coastal area	86	0.31	<0.26	3.8	<0.003	0.004
	Sellafield offshore area	86	0.32	<0.31	4.2	<0.002	<0.004
	Sellafield area ^b	86	0.31	<0.27	3.9	<0.003	<0.004
	Whitehaven	64	<0.26	<0.27	3.6	0.01	0.02
Plaice	Sellafield coastal area	81	2.2	<0.20	1.8	0.006	0.009
	Sellafield offshore area	73	2.0	<0.19	1.7	0.008	0.01
	Sellafield area ^b	79	2.2	<0.20	1.8	0.007	0.01
	Whitehaven	87	2.1	<0.20	2.0	0.006	0.01

a. ¹⁴C data include natural background.

b. Combined average for Sellafield coastal and offshore areas, this is consistent with the St Bees-Selker location described in previous reports.

Table 2. Radioactivity in molluscs (Bq kg⁻¹ wet weight), 2016

Species	Location	Mean radionuclide concentration (Bq kg ⁻¹ wet weight)																		
		Total Alpha	Total Beta	¹⁴ C ^a	⁶⁰ Co	⁹⁰ Sr	⁹⁹ Tc	¹⁰⁶ Ru	¹²⁵ Sb	¹²⁹ I	¹³⁷ Cs	U(α)	²³⁷ Np	Pu(α)	²³⁸ Pu	²³⁹⁺²⁴⁰ Pu	²⁴¹ Pu	²⁴¹ Am	Cm(α)	
Mussels	Ravenglass Garth Musselbed - Annual	-	-	110	-	-	-	-	<0.09	-	-	-	-	-	-	-	-	-	-	
	Ravenglass Garth Musselbed - Quarterly	19	28	-	0.34	0.23	110	1.0	0.31	-	0.94	1.8	0.01	4.6	0.84	3.7	26	10	<0.002	
	Ravenglass Garth Musselbed - Quarterly	21	52	-	0.43	<0.22	91	1.3	<0.35	-	0.83	2.0	0.01	4.7	0.77	3.9	22	9.8	<0.06	
	Ravenglass Garth Musselbed - Quarterly	12	44	-	0.29	0.72	74	1.6	-	-	0.74	1.6	0.009	3.4	0.71	2.7	18	6.8	<0.05	
	Ravenglass Garth Musselbed - Quarterly ^b	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
	Ravenglass Garth Musselbed Average	17	42	110	0.35	0.39	90	1.3	<0.33	<0.09	0.84	1.8	0.01	4.2	0.77	3.4	22	8.9	<0.04	
	Sellafield coastal area (north) - Annual	-	-	140	-	-	-	-	-	<0.10	-	-	-	-	-	-	-	-	-	-
	Sellafield coastal area (north) - Quarterly	18	58	-	0.71	1.5	77	3.6	0.43	-	5.7	0.93	0.008	4.8	0.91	3.9	26	7.7	<0.11	
	Sellafield coastal area (north) - Quarterly	22	66	-	0.99	0.60	66	3.4	0.63	-	2.5	1.0	0.01	5.8	1.1	4.7	36	11	<0.07	
	Sellafield coastal area (north) - Quarterly	9.3	63	-	0.47	0.25	40	7.9	0.50	-	1.2	0.76	0.006	3.4	0.56	2.8	18	6.3	<0.004	
Sellafield coastal area (north) - Quarterly ^b	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Sellafield coastal area (north) Average	16	62	140	0.72	0.80	61	5.0	0.52	<0.10	3.1	0.91	0.008	4.7	0.86	3.8	27	8.2	<0.06		
Sellafield coastal area Average	17	52	120	0.54	0.59	76	3.1	0.44	<0.10	2.0	1.4	0.01	4.4	0.82	3.6	24	8.5	<0.05		
Winkles	Sellafield coastal area (north) - Annual	-	-	64	-	-	-	-	<0.14	-	-	-	-	-	-	-	-	-	-	
	Sellafield coastal area (north) - Quarterly	40	120	-	0.86	2.9	36	2.9	-	8.9	2.0	0.02	16	2.4	13	65	23	<0.41		
	Sellafield coastal area (north) - Quarterly	61	150	-	1.4	6.3	17	5.2	-	17	2.7	0.04	24	3.9	20	120	45	<0.13		
	Sellafield coastal area (north) - Quarterly	15	91	-	0.77	1.5	32	6.3	-	3.9	1.2	0.002	5.0	0.66	4.4	24	9.1	<0.06		
	Sellafield coastal area (north) - Quarterly	15	120	-	0.52	1.2	29	4.4	-	3.3	1.1	0.003	3.9	0.68	3.2	15	8.5	<0.02		
	Sellafield coastal area (north) Average	33	120	64	0.88	3.0	29	4.7	0.85	<0.14	8.2	1.8	0.02	12	1.9	10	55	22	<0.16	
	Sellafield coastal area (south) - Annual	-	-	95	-	-	-	-	-	<0.13	-	-	-	-	-	-	-	-	-	
	Sellafield coastal area (south) - Quarterly	26	110	-	0.76	1.2	53	<1.9	0.43	-	4.8	1.8	0.01	7.5	1.2	6.3	33	14	<0.007	
	Sellafield coastal area (south) - Quarterly	30	97	-	0.99	1.0	88	2.7	0.50	-	3.1	2.3	0.01	8.6	1.3	7.3	46	17	<0.08	
	Sellafield coastal area (south) - Quarterly	17	85	-	1.2	<0.42	85	5.7	<0.62	-	2.5	1.9	0.006	7.0	1.2	5.8	31	11	<0.008	
Sellafield coastal area (south) - Quarterly	16	96	-	0.91	1.1	100	8.6	0.37	-	1.8	2.0	0.006	5.6	0.92	4.7	24	9.3	<0.06		
Sellafield coastal area (south) Average	22	96	95	0.96	0.93	82	4.7	0.48	<0.13	3.1	2.0	0.009	7.2	1.2	6.0	33	13	<0.04		
Sellafield coastal area Average	27	110	80	0.92	2.0	55	4.7	0.60	<0.13	5.6	1.9	0.01	9.7	1.5	8.2	44	17	<0.10		

a. ¹⁴C data include natural background.
b. No sample available

Table 3. Radioactivity in crustaceans (Bq kg⁻¹ wet weight), 2016

Species	Location	Mean radionuclide concentration (Bq kg ⁻¹ wet weight)									
		¹⁴ C ^a	⁶⁰ Co	⁹⁰ Sr	⁹⁹ Tc	¹⁰⁶ Ru	¹²⁹ I	¹³⁷ Cs	U Alpha	Pu(α)	²⁴¹ Am
Edible Crab	Sellafield coastal area (north) - Early	110	0.20	0.08	5.5	<1.2	-	0.59	0.14	0.20	0.72
	Sellafield coastal area (north) - Late	160	-	0.08	4.3	<2.5	-	0.88	0.15	0.31	1.1
	Sellafield coastal area (north) Average	140	0.20	0.08	4.9	<1.9	-	0.74	0.14	0.26	0.88
	Sellafield coastal area (south) - Early	110	0.20	0.13	6.8	<1.4	-	0.79	0.16	0.27	1.0
	Sellafield coastal area (south) - Late	140	-	0.07	3.0	<2.0	-	0.63	0.20	0.25	1.3
	Sellafield coastal area (south) Average	130	0.20	0.10	4.9	<1.7	-	0.71	0.18	0.26	1.2
	Sellafield coastal area Average	130	0.20	0.09	4.9	<1.8	-	0.72	0.16	0.26	1.0
Lobster	Sellafield coastal area (north) - Early	120	-	-	94	-	<0.25	1.2	0.03	0.14	0.81
	Sellafield coastal area (north) - Late	110	-	-	230	-	1.6	1.7	0.04	0.20	1.1
	Sellafield coastal area (north) Average	120	-	-	160	-	<0.93	1.5	0.04	0.17	0.96
	Sellafield coastal area (south) - Early	140	-	-	110	-	1.0	1.8	0.03	0.19	2.2
	Sellafield coastal area (south) - Late	98	-	-	130	-	<0.20	1.1	0.03	0.17	0.69
	Sellafield coastal area (south) Average	120	-	-	120	-	<0.60	1.4	0.03	0.18	1.4
	Sellafield coastal area Average	120	-	-	140	-	<0.76	1.4	0.03	0.17	1.2
<i>Nephrops</i> (Scampi)	Sellafield coastal area - Early	89	-	-	36	-	-	1.2	-	0.50	2.8
	Sellafield coastal area - Late	-	-	-	55	-	-	1.3	-	0.67	2.6
	Sellafield coastal area Average	89	-	-	46	-	-	1.3	-	0.58	2.7

a. ¹⁴C data include natural background.

Table 4. Summary of radioactivity in marine seafood (Bq kg⁻¹ wet weight), 2016

Radionuclide	Cod ^b	Plaice ^b	Lobster ^c	Crab ^c	<i>Nephrops</i> ^c	Winkles ^c	Mussels ^c
Carbon-14 ^a	86	79	120	130	89	80	120
Cobalt-60	-	-	-	0.20	-	0.92	0.54
Strontium-90	-	-	-	0.09	-	2.0	0.59
Technetium-99	0.31	2.2	140	4.9	46	55	76
Ruthenium-106	<0.27	<0.2	-	<1.8	-	4.7	3.1
Antimony-125	-	-	-	-	-	0.60	0.44
Iodine-129	-	-	<0.76	-	-	<0.13	<0.10
Caesium-137	3.9	1.8	1.4	0.72	1.3	5.6	2.0
Neptunium-237	-	-	-	-	-	0.01	0.01
Plutonium-alpha	<0.003	0.007	0.17	0.26	0.58	9.7	4.4
Plutonium-241	-	-	-	-	-	44	24
Americium-241	<0.004	0.01	1.2	1.0	2.7	17	8.5
Curium-alpha	-	-	-	-	-	<0.10	<0.05

a. ¹⁴C data include natural background.

b. Combined average for Sellafield coastal and offshore areas. This is consistent with the St Bees-Selker location reported in previous reports.

c. Sellafield coastal area average.

Table 5. Mean gamma dose rates measured in air in intertidal and other coastal areas of Cumbria, 2016

Area of survey	Description	Nature of ground	Number of observations	Mean dose rate ($\mu\text{Gy h}^{-1}$) ^a
Whitehaven	North shore	sand	1	0.14
Whitehaven Harbour (north)	outer harbour	mud/silt	4	0.11
Whitehaven Harbour (south)	outer harbour	soft mud	4	0.13
St Bees (beach)	beach	sand	1	0.11
St Bees (groynes)	groynes	pebbles/rocks	1	0.16
St Bees	promenade and car park	concrete / grass	1	0.11
St Bees	Seamill Lane car park	car park	1	0.13
Coulderton	grassed areas/beach bungalows	grass banks	1	0.15
Nethertown	beach	pebbles/shingle	1	0.16
Nethertown	car park	concrete / grass	1	0.12
Nethertown	grassed area/beach bungalows	grass banks	1	0.15
Braystones	beach	pebbles/shingle	1	0.14
Braystones	grassed areas/beach bungalows	grass banks	1	0.14
Sellafield Beach	beach		1	0.15
Sellafield Dunes	dunes		1	0.13
Sellafield	pipeline 3	sand	12	0.11
Sellafield	pipeline 4	sand	12	0.11
Factory Sewer	outfall	rocks / boulders / sand / shingle	4	0.14
Seascale Beach	north of pipeline	sand	4	0.13
Seascale Beach	south of pipeline	rocks/sand	4	0.13
Seascale Dunes	dunes		1	0.10
Drigg	Barn Scar	mussel beds / silt / rocks	1	0.13
Drigg Beach	beach	sand	1	0.13
Ravenglass	Raven Villa	saltmarsh	1	0.16
Ravenglass	River Mite Ford		1	0.13
Ravenglass	small boat area	firm silt / pebbles	1	0.14
Ravenglass	Salmon Garth	mussel beds	1	0.12
Ravenglass	Salmon Garth (saltmarsh)	sand / firm silt	1	0.15
Ravenglass	grassed area	grass	1	0.13
Eskmeals Viaduct	saltmarsh	saltmarsh	1	0.13
Newbiggin	saltmarsh	saltmarsh	4	0.18
Muncaster Road Bridge	riverbank	grass	1	0.14
Hall Waberthwaite	saltmarsh	saltmarsh turf	1	0.15

a. Figures include contributions from natural background, typically $0.05 \mu\text{Gy h}^{-1}$ over sandy areas and $0.07 \mu\text{Gy h}^{-1}$ over silt.

Table 6. Mean gamma dose rates measured in air at Sellafield site perimeter, 2016

Area of survey	Number of locations	Mean dose rate ($\mu\text{Sv h}^{-1}$) ^a
North	4	0.008
East	5	0.04
South	3	0.003
West	4	0.05
River Ehen	2	0.01
River Calder	12	0.24
River Calder critical group ^b	1	0.09
Mean annual average	-	0.11

a. Figures exclude contribution from natural background (approximately $0.06 \mu\text{Sv h}^{-1}$).

b. Calder fence adjacent to Combined Heat and Power plant.

Table 7. Mean gamma dose rates measured in air in the vicinity of Sellafield, 2016

Location	Mean dose rate ($\mu\text{Sv h}^{-1}$) ^a
Calderbridge	0.07
Beckermest	0.07
Seascale	0.06
Ravenglass	0.07
Braystones	0.07
Whitehaven	0.06
Gosforth	0.07

a. Figures include contribution from natural background (approximately $0.06 \mu\text{Sv h}^{-1}$).

Table 8. Radioactivity in air in the vicinity of Sellafield - Site Perimeter Locations, 2016

Radionuclide	Mean radionuclide concentration (mBq m^{-3})				
	Calder Gate	Met. Station	North Gate	West Ring Road	South Side
Total Alpha	0.02	0.02	<0.02	0.02	0.02
Total Beta	0.17	0.21	0.26	0.25	0.17
Strontium-90	0.004	0.007	0.01	0.02	0.002
Ruthenium-106	<0.04	<0.04	<0.04	<0.04	<0.04
Antimony-125	<0.03	<0.02	<0.04	<0.02	<0.02
Caesium-134	<0.004	<0.005	<0.004	<0.005	<0.005
Caesium-137	0.01	0.02	0.05	0.04	<0.005
Plutonium-alpha	0.001	0.0009	0.002	0.0005	<0.0003
Plutonium-241	<0.03	<0.03	<0.03	<0.03	<0.02
Americium-241	0.0006	0.0008	0.002	0.001	0.0004
Uranium-234	<0.0004	<0.0005	<0.0005	<0.0006	0.0006
Uranium-235	<0.00002	<0.00002	<0.00002	<0.00003	0.00003
Uranium-236	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Uranium-238	0.0002	0.0003	0.0004	0.0005	0.0005

Table 9. Radioactivity in air in the vicinity of Sellafield - Residential Locations, 2016

Radionuclide	Mean radionuclide concentration (mBq m^{-3})						
	Beckermest	Braystones	Calderbridge	Gosforth	Ravenglass	Seascale	Whitehaven ^a
Strontium-90	0.002	0.001	0.001	0.0008	<0.0004	0.001	<0.0009
Antimony-125	<0.02	<0.02	<0.03	<0.02	<0.01	<0.01	<0.01
Caesium-134	<0.005	<0.005	<0.004	<0.004	<0.004	<0.004	<0.004
Caesium-137	<0.006	<0.006	<0.004	<0.004	<0.004	<0.004	<0.004
Plutonium-alpha	0.0003	<0.0002	<0.0002	<0.0001	<0.0001	0.001	<0.0002
Plutonium-241	<0.02	<0.03	<0.03	<0.02	<0.02	<0.03	<0.03
Americium-241	<0.0002	<0.0003	<0.0001	<0.0001	0.0002	0.002	0.0002
Uranium-234	<0.0003	<0.0004	<0.0003	<0.0003	<0.0003	<0.0004	<0.0004
Uranium-235	<0.00002	<0.00002	<0.00002	<0.00002	<0.00002	<0.00004	<0.00004
Uranium-236	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0002	<0.0003
Uranium-238	0.0003	0.0002	0.0001	0.00009	<0.00006	0.0002	0.0002

a. Whitehaven sampler returned to service in May 2016.

Table 10. Radioactivity in milk from farms near Sellafield, 2016

Location	Mean radionuclide concentration (Bq litre^{-1})										
	Total Alpha	Total Beta	³ H	¹⁴ C Total ^a	¹⁴ C Net ^b	⁹⁰ Sr	¹⁰⁶ Ru	¹²⁵ Sb	¹²⁹ I	¹³¹ I	¹³⁷ Cs
Farm A ^c	<0.13	40	<3.7	15	<0.60	0.03	<0.36	<0.10	0.01	<0.04	0.08
Farm B	<0.12	42	<3.2	16	<0.63	0.03	<0.36	<0.10	<0.007	<0.04	<0.05
Farm C	<0.11	39	<2.9	16	<0.63	0.03	<0.35	<0.09	<0.01	<0.04	0.06

a. Including natural background. b. Excluding natural background. c. Milk from Farm A has been used in the radiological assessment

Table 11. Radioactivity in animal produce from farms near Selliafield, 2016

Species	Mean Radionuclide concentration (Bq kg ⁻¹ wet weight) ^a														
	³ H Total	¹⁴ C Total ^b	¹⁴ C Net ^c	⁶⁰ Co	⁹⁰ Sr	⁹⁹ Tc	¹⁰⁶ Ru	¹²⁵ Sb	¹²⁹ I	¹³⁴ Cs	¹³⁷ Cs	²³⁸ Pu	²³⁹⁺²⁴⁰ Pu	²⁴¹ Pu	²⁴¹ Am
Bovine muscle	<12	27	-	<0.06	<0.04	<0.09	<0.34	<0.14	<0.02	<0.07	0.18	<0.00006	0.0001	<0.26	0.0001
Bovine liver	<4.3	27	-	<0.05	<0.05	<0.09	<0.45	<0.08	<0.02	<0.04	<0.06	<0.00003	0.002	<0.25	0.002
Bovine kidney	<4.3	16	-	<0.03	<0.05	<0.09	<0.35	<0.12	<0.02	<0.04	0.11	<0.00006	<0.0003	<0.25	0.0009
Ovine muscle	<7.1	30	-	<0.06	<0.04	<0.10	<0.52	<0.16	<0.02	<0.07	2.2	<0.00007	0.0002	<0.22	0.0003
Ovine kidney/liver	<5.8	32	5.4	<0.04	<0.05	<0.10	<0.34	<0.12	<0.02	<0.05	0.73	0.001	0.007	<0.29	0.008
Deer	<3.8	29	-	<0.08	<0.05	<0.10	<0.21	<0.11	0.06	<0.10	0.65	<0.0001	<0.0002	<0.21	0.00009
Duck ^d	<2.0	35	-	<0.07	<0.05	<0.21	<0.58	<0.13	<0.06	<0.05	<0.09	<0.0005	<0.0002	<0.34	0.00005
Pheasant	<4.9	37	3.0	<0.06	<0.06	<0.10	<0.40	<0.10	<0.02	<0.05	0.06	<0.00009	0.00006	<0.45	0.0001
Wild wood pigeon	<4.6	41	7.0	<0.07	<0.04	-	<0.46	<0.11	<0.02	<0.05	<0.06	<0.0001	0.0002	<0.21	0.0001
Rabbit	23	15	-	<0.09	<0.04	<0.09	<0.56	<0.17	<0.02	<0.09	7.5	0.00003	0.0001	<0.28	0.0002
Eggs - General	<6.6	34	-	<0.04	<0.04	-	<0.28	<0.10	<0.03	<0.05	<0.04	<0.00003	0.00007	<0.21	0.0002

a. Values shown in pale blue boxes are from measurements performed by the FSA.

b. Including natural background.

c. Excluding natural background (values taken from RIFE-21). Measured concentrations that are smaller than background value are indicated by a hyphen.

d. Year sampled - 2014

Table 12. Radioactivity in fruit and vegetable produce collected near Sellafield, 2016

Species	Mean Radionuclide concentration (Bq kg ⁻¹ wet weight) ^a														
	³ H Total	¹⁴ C Total ^b	¹⁴ C Net ^c	⁶⁰ Co	⁹⁰ Sr	⁹⁹ Tc	¹⁰⁶ Ru	¹²⁵ Sb	¹²⁹ I	¹³⁴ Cs	¹³⁷ Cs	²³⁸ Pu	²³⁹⁺²⁴⁰ Pu	²⁴¹ Pu	²⁴¹ Am
Potato	<2.8	17	<0.65	<0.04	0.03	-	<0.26	<0.12	<0.02	<0.06	0.09	<0.00007	0.0007	<0.37	0.0006
Cabbage	<2.3	13	6.0	<0.08	0.10	-	<0.68	<0.17	<0.02	<0.06	<0.06	<0.00007	0.0001	<0.20	0.0001
Broccoli	<2.6	17	10	<0.07	<0.06	-	<0.55	<0.09	<0.02	<0.07	<0.06	<0.0001	<0.0002	-	0.0001
Cauliflower ^d	<2.1	9.2	2.2	<0.10	-	-	<0.68	<0.16	<0.04	<0.07	<0.07	-	-	-	-
Carrots	<2.5	13	6.0	<0.04	0.04	<0.10	<0.63	<0.12	<0.03	<0.08	0.13	-	-	-	-
Beetroot	<2.4	17	10	<0.08	0.12	-	<0.71	<0.14	<0.02	<0.08	<0.07	-	-	-	-
Onion ^d	<4.2	14	7.0	<0.06	0.20	-	<0.29	<0.10	<0.04	<0.05	0.07	-	-	-	-
Runner beans ^d	<2.0	17	-	<0.06	0.33	-	<0.52	<0.11	<0.06	<0.06	<0.06	<0.0001	0.0003	-	0.0007
Mushroom	<3.4	11	7.0	<0.05	<0.05	-	<0.36	<0.10	<0.02	<0.04	0.39	0.003	0.02	<0.23	0.04
Apple ^d	<2.7	18	9.0	<0.06	<0.04	-	<0.47	<0.13	<0.05	<0.07	<0.08	<0.00007	0.0005	-	0.001
Blackcurrants ^d	<4.0	17	8.0	<0.20	0.08	-	<1.2	<0.30	<0.02	-	0.11	0.0002	0.0005	<0.08	0.002
Strawberries ^d	<2.0	15	6.0	<0.06	0.14	-	<0.64	<0.16	<0.05	<0.07	<0.06	<0.0001	<0.0003	-	<0.0002
Blackberries ^d	<5.1	18	9.0	<0.05	0.24	<0.10	<0.63	<0.18	<0.04	<0.09	0.15	0.00009	0.0008	<0.22	0.001
Elderberries ^d	<2.0	26	17	<0.11	0.04	-	<0.52	<0.18	<0.08	<0.08	0.14	0.001	0.004	-	0.008
Honey ^d	<2.0	78	8.0	<0.02	<0.04	-	<0.31	<0.08	<0.02	<0.03	<0.06	<0.0002	<0.0002	<0.26	0.0001

a. Values shown in pale blue boxes are from measurements performed by the FSA.

b. Including natural background.

c. Excluding natural background (values taken from RIFE-21). Measured concentrations that are smaller than background value are indicated by a hyphen.

d. Year sampled - cauliflower (2013); onion (2014); runner beans (2013); apple (2013); blackcurrants (2012); strawberries (2013); elderberries (2013); honey (2014).

Table 13. Radioactivity in local waters, 2016

Location	Mean radionuclide concentration (Bq litre ⁻¹)							
	Total alpha	Total beta	³ H	⁹⁰ Sr	⁹⁹ Tc	¹³⁷ Cs	Pu(α)	Am+Cm
River water: River Calder at Sellafield	<0.01	0.23	<3.8	0.04	-	<0.005	<0.001	<0.001
River Calder at Calderbridge	<0.01	<0.12	<3.9	0.003	-	<0.005	<0.0008	<0.002
R Ehen, 5m upstream of Factory Sewer outfall	<0.06	0.69	<5.4	0.003	<0.02	0.05	<0.001	<0.002
R Ehen, 100m north of pipeline	<0.02	0.19	<3.8	0.003	<0.02	<0.005	<0.001	<0.001
Lake water: Ennerdale Water	<0.01	0.13	<3.7	0.009	-	<0.004	<0.0002	<0.002
Wastwater	<0.01	0.14	<3.9	0.007	-	<0.004	<0.0002	<0.002
Tap water: Domestic water - Calderbridge	<0.01	<0.09	<3.7	0.002	-	<0.005	<0.0001	<0.0008
Domestic water - Sellafield	0.02	<0.07	<3.7	0.002	-	<0.005	<0.0009	<0.001
Domestic water - Ravenglass	<0.01	<0.08	<3.7	0.002	-	<0.004	<0.0002	<0.001
Domestic water - Seascale	<0.01	<0.08	<3.9	0.002	-	<0.004	<0.0002	<0.002
Domestic Water - Whitehaven	<0.01	<0.08	<3.8	0.002	-	<0.005	<0.0001	<0.002
Spring water: Sellafield Beach (South) ^a	-	-	59	0.13	0.27	1.1	0.01	0.10
Sellafield Beach (Maximum) ^a	-	-	520	-	2.7	-	-	-
Sellafield Beach (Average) ^a	-	-	230	-	0.95	-	-	-

a. Results corrected for seawater content.

Table 14. Non-radioactive monitoring of air in the vicinity of Sellafield, 2016

	Mean concentration in air (µg m ⁻³) NO ₂
Calder Gate	9.9
Met. Station	12
North Gate	11
West Ring Road	12
South Side	9.3
NAQS Objective ^a	40

a. National Air Quality Standard (annual mean)⁹

Table 15. Non-radioactive monitoring of river waters, 2016

Location	pH	mg per litre NO ₃ ⁻
River Calder - downstream of site	7.7	0.87
River Calder - upstream of site	7.4	0.50
River Ehen - downstream of Seaburn outfall	8.2	0.99
River Ehen - upstream of pipebridge	7.9	1.1
EQS ^a	6.0 - 9.0	N/A

a. National Environmental Quality Standard.

Table 16. Non-radioactive monitoring of coastal waters, 2016

Location	mg per litre		
	NO ₂ ⁻	NO ₃ ⁻	B
St Bees	<0.05	0.29	3.9
Sellafield	<0.05	<0.08	4.0
Seascale Neb	<0.05	0.18	3.7
Drigg Barnscar	<0.05	0.09	4.1

Table 17. Non-radioactive monitoring of surface water around Sellafield's landfill sites, 2016

Location	pH	Temperature (°C)	Conductivity (microS cm ⁻¹)	Dissolved O ₂ (ppm)	NH ₄ ⁺ (mg l ⁻¹)	Chloride (ppm)	C.O.D. (mg l ⁻¹)	Suspended Solids (mg l ⁻¹)
North Landfill Site and Extension								
Stream to north	7.6	5.5	230	10	<0.01	22	22	60
River Calder upstream A	7.5	4.5	96	12	<0.006	11	2.8	1.7
River Calder upstream B	7.5	4.5	96	12	<0.004	11	3.1	0.46
River Calder downstream ^a	7.7	4.5	100	12	<0.004	12	3.7	2.1
Calder Landfill Complex ^b								
New Mill Beck upstream	7.9	6.0	230	11	<0.12	25	29	7.0
New Mill Beck toad ponds	7.9	4.5	280	12	<0.12	40	26	6.9
New Mill Beck overflow drain ^c	7.4	6.0	180	11	0.39	19	47	31
River Calder upstream ^a	7.7	4.5	100	12	<0.004	12	3.7	2.1
River Calder downstream	-	-	120	12	0.05	-	8.3	-

- a. The River Calder downstream site for the North Landfill Site and Extension, is the same as the upstream location for the Calder Landfill Complex.
- b. Calder Landfill Complex refers to the Calder Tip, Calder Tip Extension and the Calder Landfill Extension Segregated Area (CLESA).
- c. Sample only available under flood conditions.

Table 18. Non-radioactive monitoring of gases on Sellafield's landfill sites, 2016

Gas spike probe monitoring	Mean concentration (% volume)		
	CH ₄	CO ₂	O ₂
Calder Landfill Complex	0.0	1.3	19

Figure 1 Marine environmental monitoring around Sellafield

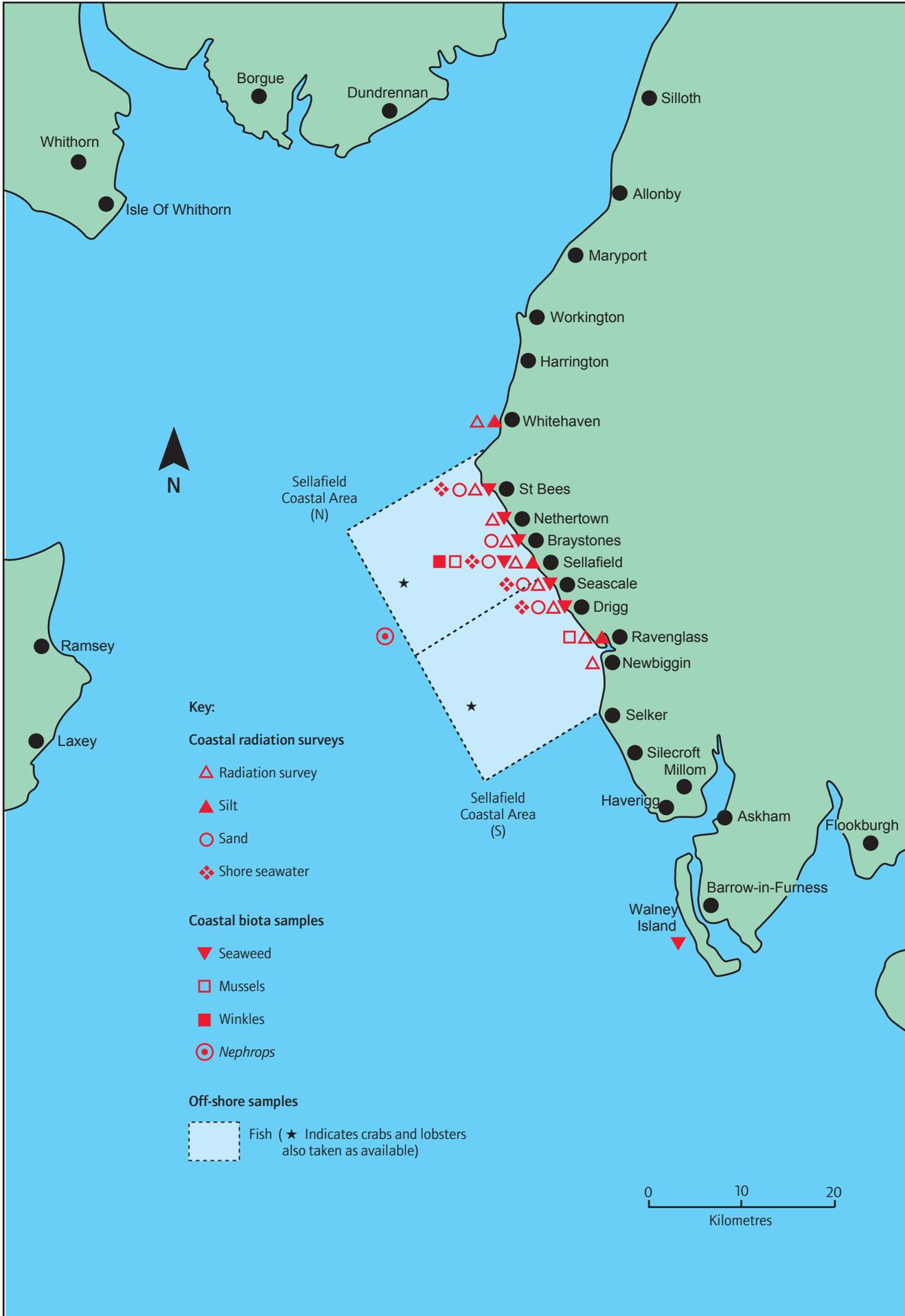


Figure 2 Terrestrial environmental monitoring around Sellafield

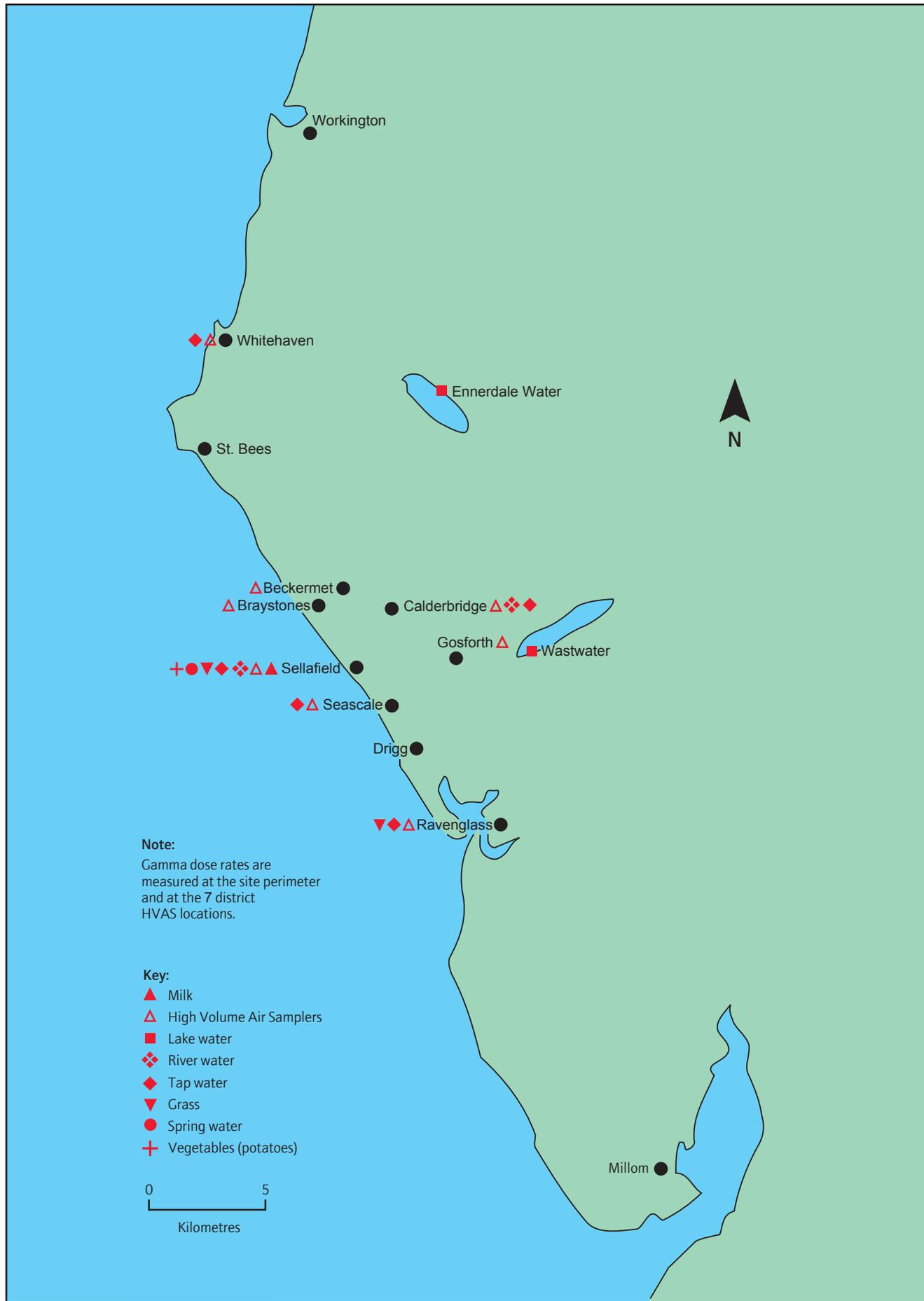
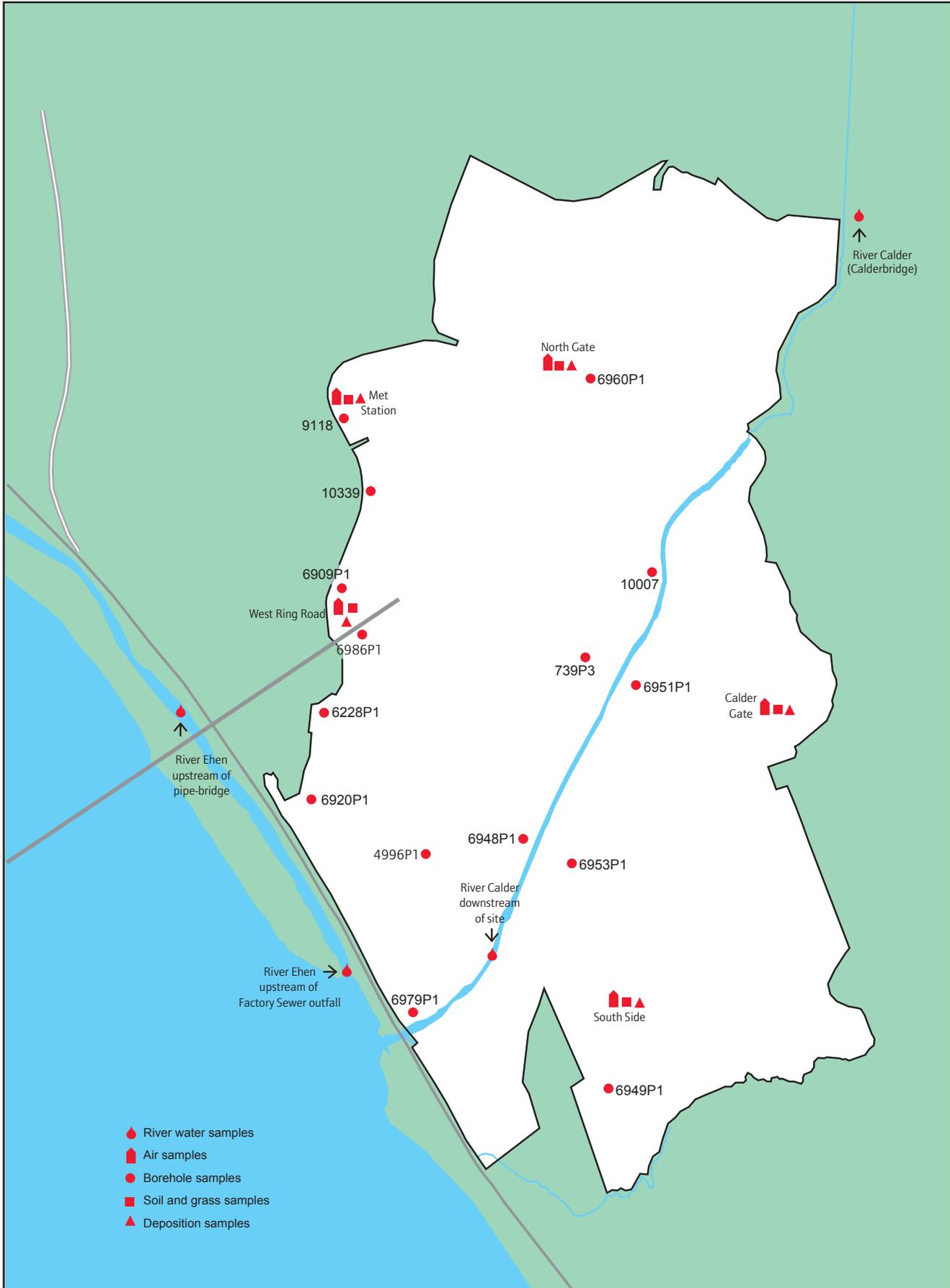


Figure 3 Terrestrial environmental monitoring at Sellafield



Radiological Impact of Operations at Sellafield

Annual Report 2016

Critical group doses

- 1 Critical group doses have been calculated following the Principles for Total Retrospective Dose Assessment¹, which is consistent with last year's report. In 2005 several changes were made to the dose calculation methodology in order to make the Sellafield Ltd dose calculations more consistent with these principles, the methodology for which is presented in the NDAWG Paper 11-03². These changes in methodology include:
- Milk dose is based on the mean concentration at a nearby farm with the highest individual result;
 - The age groups considered for terrestrial critical group dose now include pre-natal (foetal) dose, which has been calculated as an extension to the adult dose assessment using relevant dose coefficients;
 - Dose per unit intake factors for ingestion and inhalation have been taken from the latest values published by the EA and FSA. These factors differ from those used in previous reports prior to 2013 because they include the presence of short-lived daughter radionuclides assumed to be in equilibrium with their parent at the time of ingestion, inhalation etc.;
 - The EA and FSA methodology does not use an Irish Sea specific dose per unit intake factor for technetium-99 in lobsters which was used in previous assessments; and,
 - Doses from inhaled and ingested tritium have been assessed using the more conservative dose factor for organically bound tritium, rather than that for tritiated water, which was used in previous reports.

Marine pathways

- 2 Using habits surveys, the FSA has identified the marine critical group for seafood consumption as a small number of people in the Cumbrian coastal community who are high-rate consumers of fish and shellfish obtained from the Sellafield area between St Bees and Selker. Consumption and occupancy rates are kept under regular review and are published annually³. In this report, the consumption rates used by Sellafield Ltd for dose assessment purposes (Appendix A, table A1) are taken from the most recent data provided by FSA for the five years 2012-2016 with updated consumption rates for crustaceans and molluscs and occupancy rates from 2016. In reports published prior to 2005 the consumption of 'other molluscs' was equally divided between limpets, mussels and cockles. Since 2005, they are all ascribed to mussels. For the dose assessment, "Other fish" reported by the FSA are assumed to be plaice.
- 3 The marine critical group is adult members consuming seafood caught locally between St Bees and Selker (table 1). The estimated critical group dose to adults was about 57 μSv which is slightly more than was estimated in 2015 (52 μSv) and is due to the change in the 5-year rolling average consumption rates between 2015 and 2016. The annual doses to child, infant and foetal members of the marine critical group are calculated to be

13, 6 and 11 μSv respectively. The adult critical group may also receive doses from other pathways, such as inhalation and consumption of agricultural produce. An assessment has shown that these would increase the dose by about 2 μSv . The doses from the consumption of molluscs are likely to be overestimated because no account has been taken of the effects of food preparation procedures, such as the soaking of winkles to eliminate their gut contents which contain most of the actinide radioactivity (adsorbed onto silt particles). Doses to typical fish-eating members of the public were, as usual, very low (1.1 μSv). Doses to consumers associated with the Whitehaven fishery remained similar to last year (11 μSv).

- 4 Figures 1, 2 and 3 show doses to the marine critical group from seafood (for radionuclides contributing the highest proportions of dose) against the consumption rate of these foods. Consumption of winkles has fallen in the last six years. This has resulted in a reduction in dose from plutonium-alpha and americium-241, despite stable discharges of these radionuclides and concentrations in winkles from 2010. Consumption of mussels increased steadily between the mid 1990s and mid 2000s. Therefore this resulted in an increased dose up to 2006 from plutonium-alpha and americium-241, despite stable discharges and concentrations of these radionuclides in mussels. Since 2006/7 the dose has fallen sharply due to a combination of reduced consumption and reduced plutonium-alpha concentration in mussels. Contrary to mussels, the consumption of *Nephrops* has risen steadily since 2011 to a highest recorded rate in 2016 of 14.4 kg y^{-1} (figure 3). This rise has resulted in the dose contribution from *Nephrops* now being similar to the dose contributed from the consumption of mussels (table 1). There is particular interest as to how the mussel and *Nephrops* consumption trends fare in the next few years.
- 5 Figure 4 shows the contribution of individual radionuclides to the marine critical group's dose. Over the last 17 years the main contributors to marine dose have been americium-241, plutonium-alpha and technetium-99. The decrease in dose in the last decade has largely been caused by a reduction in technetium-99 dose resulting from decreased technetium-99 discharges and, more recently, from reduced consumption of molluscs leading to lower actinide dose.
- 6 Figure 5 shows the contribution of individual foodstuffs to the marine critical group's dose. Over the last 17 years the main contributors to marine dose have been from mussels, winkles, *Nephrops* and lobster. Variations in the proportion of dose from each food reflect changes in both consumption rate and radionuclide concentrations. In 2016, for the first time, *Nephrops* contributed a similar dose to the critical group as mussels. Doses to adult, child, infant and foetal members of the critical group, through the consumption of seafood, are summarised in Appendix B, Table B9.
- 7 The FSA and the EA^{3,4} continue to keep under review the amount of time spent by members of the public on inter-tidal areas of the coastline bordering the north-east Irish Sea and more inland locations. In particular it was considered that members of the

critical group received an external contribution to their radiation exposure from spending up to 900 hours each year on local beaches (Parton to Eskmeals) for 2012-2016. This additional dose was estimated to be 49 μSv using the 900 hours beach occupancy habit data.

- 8 PHE^{5,6} continues to keep under review the numbers and radionuclide content of particles that are detected by monitoring on beaches near the Sellafield site. However, PHE advised the EA in 2012⁶ that no special precautionary actions were necessary regarding access to, or use of, these beaches.

Airborne and terrestrial pathways

- 9 For some years Sellafield Ltd has used consumption rates obtained from the approach used by PHE⁷, whereby dose assessments are carried out to establish which foodstuffs contribute the maximum dose at higher critical group consumption rates. Using this process, the two food groups identified as making the highest contribution to dose are assigned critical group (higher) consumption rates. The remainder are assigned national mean consumption rates.

The two food groups assigned at critical group rates in recent years have been:

- milk and domestic fruit in 2010 and 2013;
- milk and green vegetables in 2011;
- milk and potatoes in 2012;
- milk and root vegetables in 2014; and,
- beef and root vegetables in 2015.

For 2016 these two food groups are domestic fruit and potatoes (Appendix B, table B10). The consumption rates used for 2016 are summarised in Appendix A, table A2. In addition to changes in food consumption rates, Sellafield Ltd has adopted the generic advice of PHE on parameters relating to external radiation pathways (Appendix A, table A3)^{8,9}. In previous years, the dose from terrestrial foodstuffs has been based only on the foods sampled by Sellafield Ltd and FSA in that year. In the dose assessment reported here, where 2016 data were not collected, the most recent data available were used.

- 10 The doses from ruthenium-106 in all terrestrial foodstuffs, (shown in Appendix B, table B10), are assessed using standard modelling techniques^{8,10,11} (as used by PHE and others) which are based on knowledge of the transfer of these radionuclides through the food chain. This is considered to be more realistic than using the limits of detection from the radiochemical analysis.
- 11 This year is the third year in many where milk is not a major contributor to the terrestrial critical group dose (see paragraph 13). The dose to critical group adults from the consumption of milk is 0.34 μSv whereas from all foodstuffs is 4.9 μSv . The higher dose contributions to adults were 1.2 μSv from domestic fruit and 0.99 μSv from potatoes (table 2). Based on the average concentrations of radioactivity reported in air and in terrestrial foodstuffs (Monitoring chapter, tables 8 to 12 and 13), adults would have received an estimated dose of 4.9 μSv (4.5, 4.1 and 3.5 μSv for children, infants and foetuses) from all terrestrial

foodstuffs and 1.0 μSv (0.54, 0.29 and 0.02 μSv for children, infants and foetuses) from inhalation. Detailed data are provided in Appendix B, table B10 and summarised in tables 2, 3 and 4. Doses assessed as being less than 0.001 μSv have been presented as "<0.001".

- 12 Figure 6 and Appendix B, table B11 show that between 1999 and 2013, the main radionuclides contributing to doses from consumption and inhalation are strontium-90, iodine-129 and caesium-137 (all dominated by consumption). This is still the case for 2014 to 2016 and an addition to this group is americium-241. This is a direct result of the critical group member of interest changing from infant (1999 – 2013) to adult (2014 – present). Doses from strontium-90, caesium-137 and americium-241 are dominated by pre-1980 discharges, the testing of nuclear weapons in the 1960s and (for caesium-137) the Chernobyl accident in 1986. The relative proportions of radionuclides in recent years can largely be explained by changes in reprocessing rates and improvements in the analytical limits of detection.

- 13 Figure 7 shows the contribution of individual foodstuffs to the terrestrial critical group's dose. Between 2002 and 2013 the highest critical group dose was estimated to be received by infants and hence the terrestrial dose was dominated by milk consumption. In 2014 to 2016, the highest terrestrial critical group dose was estimated to be received by adults. This change has been a consequence of the reduction in dose received by infants from milk consumption and the increased dose received by adults from direct radiation (paragraph 17). In figure 7, the domestic fruit contribution is contained within the green 'Other foodstuffs' sections.

- 14 Members of the terrestrial critical group also received a dose of up to 3.9 μSv , arising from marine pathways. This dose contained an external component (up to 2.8 μSv) from radioactivity deposited on local beaches, based on an average beach occupancy of terrestrial practices published by the EA and FSA of 41 hours, and an internal component (1.1, 0.25, 0.11, 0.90 μSv respectively to adults, children, infants and foetuses) from an assumed consumption of locally caught fish (table 3 and in more detail in Appendix B, table B12). It is the external dose component for adults in 2016 that maintains the terrestrial critical group member being adult since 2014.

- 15 In addition to exposure from the consumption of local produce, the critical group also receives exposure from immersion in a plume containing krypton-85 discharged from the reprocessing plants. The doses in 2016 to adults, children, infants and foetuses living near to Sellafield would have been respectively 0.40, 0.28, 0.28 and 0.40 μSv using modelling and dosimetry data published by the EU and the ICRP^{10,11} (table 3).

- 16 The doses to the terrestrial critical group are summarised in table 3. If all the above pathways are considered to be additive, the highest 2016 dose, of 10.3 μSv , was to adults. The dose to child, infant and foetus were lower at 7.0, 4.9 and 7.6 μSv respectively. The changes to the dose assessment

methodology (paragraph 1) are the reason that the terrestrial doses reported after 2005 increased. These doses are however considerably lower than in earlier years when the Calder Hall reactors were operational. The reduction in dose from 2009 is a consequence of changes in farming practice, with those farms closest to the Sellafield site ceasing milk production.

Direct radiation

- 17 Members of the terrestrial critical group are also exposed to direct radiation. Due to the closure of Calder Hall in March 2003 (Monitoring: paragraph 28), direct radiation doses to local residents have reduced significantly. There was a change in methodology from recent years in the habit assumptions made in 2016. The upper bound of the dose range to adults living closest to the site has been assessed to be 5.4 μSv .

Collective doses

- 18 Collective doses resulting from the effects of discharges from Sellafield in 2016, integrated over 500 years, have been calculated in accordance with paragraphs 18 to 21 of Appendix A and Introduction paragraph 30. The results (table 5) give collective dose commitments (combined aerial and marine) of about 2.4 manSv to the UK population, 8.6 manSv to the European population (including the UK) and 66 manSv to the world population.
- 19 Most of the collective dose commitment from Sellafield discharges results from carbon-14 because of its long radioactive half-life (5730 years) and its incorporation into the global carbon cycle. However, concentrations of carbon-14 in the atmosphere which are attributable to Sellafield are indistinguishable from naturally occurring background concentrations at distance from the site. The natural background results in collective doses that are many orders of magnitude higher than the doses resulting from Sellafield's discharges. This reflects the fact that natural sources of radiation constitute the largest source of public radiation exposure on a national or global scale¹².

Dose summary

- 20 The estimated dose in 2016 due to discharges to sea from Sellafield to members of the critical group who consume fish and shellfish from the local area was about 57 μSv (table 1). Taking into account doses due to beach occupancy and aerial pathways, the total dose to this group was about 110 μSv , similar to 2015. Doses due to direct radiation from plants on site were estimated as being 5.4 μSv to the most exposed members of the public who live nearby. This is similar to 2015 due to the same calculation methodology being applied between years. This group may, in addition, have received up to 10.3 μSv from aerial discharge pathways.

Radiological impact perspective

- 21 In their most recent review of ionising radiation exposure to the UK population¹³, PHE provided information relating to the dose received due to cosmic radiation from return flights to popular global destinations from the UK. Typically a return flight time of 2.5 hours, e.g. a return flight to Paris, provides an exposure of 10 μSv , greater than the annual dose received by a terrestrial critical group member in the vicinity of Sellafield from authorised discharges. A return flight of 24 hours, e.g. to Cape Town or Tokyo, provides an exposure of 100 μSv , similar to the annual dose received by a marine critical group member.
- 22 There are other typical practices in the UK that result in ionising radiation exposure similar to the rates above. A typical individual dose of 80 $\mu\text{Sv y}^{-1}$ is received through the use of conventional radiology (including dental examinations)¹³.
- 23 Such comparisons provide an interesting perspective in that some routine activities of the UK public (e.g. flying abroad on holidays, receiving medical and dental x-rays), result in as much ionising radiation exposure to that received by the marine and terrestrial critical group members in the vicinity of the Sellafield site in 2016.

References

1. Allott R (2005) **Principles for the assessment of total retrospective public doses**, NDAWG/2/2005. Environment Agency, Food Standards Agency, NRPB, NII, Chilton
2. NDAWG Paper 11-03 (2007) **Use of measurements in determining retrospective dose assessments in RIFE**
3. Garrod C J and Clyne F J (2017). **Radiological habits survey: Sellafield review, 2016**. Environment Report RL03/17. CEFAS, Lowestoft (under contract to the EA and the FSA).
4. Environment Agency, Food Standards Agency, Food Standards Scotland, Natural Resources Wales, Northern Ireland Environment Agency and Scottish Environment Protection Agency (2016). **Radioactivity in food and the environment, 2015**. RIFE-21. EA, FSA, FSS, NRW, NIEA and SEPA; Preston, London, Aberdeen, Cardiff, Belfast and Stirling.
5. Health Protection Agency (2011). **Centre for Radiation, Chemical and Environmental Hazards. Letter to Mr S Page, Environment Agency from Dr J Cooper, Director for Centre of Radiation, Chemical and Environmental Hazards, Health Protection Agency**. Health Protection Agency, Oxfordshire.
6. Etherington G, Youngman M J, Brown J and Oatway W (2012). **Evaluation of the Groundhog Synergy beach monitoring system for detection of alpha-rich objects and implications for the health risks to beach users**, HPA-CRCE-038.
7. Byrom J, Robinson CA, Simmonds JR, Walters B and Taylor RR (1995). **Food consumption rates for use in generalised radiological dose assessments**. J. Radiol. Prot. 15(4): 335-342.
8. Cabianca T, Fayers CA, Mayall A, Robinson CA and Simmonds JR (1995). **Peer review of BNFL radiological assessment methodologies**. NRPB Report M815.
9. Smith KR and Jones AL (2003). **Generalised habit data for radiological assessments**. NRPB Report W41.
10. Simmonds JR et al. (1995). **Methodology for assessing the consequences of routine releases to the environment**. EUR 15760. Office for the Publication of the European Communities.
11. International Commission on Radiological Protection (1996). **Age-dependent doses to members of the public from intakes of radionuclides: Part 5. Compilation of ingestion and inhalation dose coefficients**. ICRP Publication 72. Ann. ICRP 26 (1).
12. Watson SJ, Jones AL, Oatway WB and Hughes JS (2005). **Ionising radiation exposure of the UK population: 2005 Review**. Health Protection Agency Report HPA-RPD-001, HMSO, London.
13. Oatway, W B, Jones, A L, Holmes, S, Watson, S and Cabianca, T (2016). **Ionising radiation exposure of the UK population: 2010 review**. Public Health England Report PHE-CRCE-026, Crown Copyright.

Table 1. Summary of adult doses associated with marine discharges (μSv), 2016

Radionuclide	Cod	Plaice	Lobster	Crab	<i>Nephrops</i>	Winkles	Mussels	Total for radionuclide
Carbon-14	0.64	1.3	0.53	0.55	0.53	0.27	0.23	4.0
Cobalt-60	-	-	-	0.006	-	0.02	0.007	0.04
Strontium-90	-	-	-	0.02	-	0.48	0.07	0.58
Technetium-99	0.003	0.05	0.86	0.03	0.42	0.27	0.19	1.8
Ruthenium-106	0.03	0.05	-	0.11	-	0.26	0.09	0.54
Antimony-125	-	-	-	-	-	0.005	0.002	0.007
Iodine-129	-	-	0.80	-	-	0.11	0.04	0.96
Caesium-137	0.86	0.88	0.17	0.08	0.24	0.57	0.10	2.9
Neptunium-237	-	-	-	-	-	0.009	0.004	0.01
Plutonium-alpha	0.01	0.07	0.41	0.59	2.1	7.6	4.4	15
Plutonium-241	-	-	-	-	-	0.66	0.46	1.1
Americium-241	0.01	0.08	2.3	1.8	7.8	11	6.8	29
Curium-alpha	-	-	-	-	-	0.12	0.03	0.15
Total for species	1.6	2.4	5.1	3.2	11	21	12	57
Total for group	57							

Table 2. Summary of adult doses associated with aerial discharges (μSv), 2016

Radionuclide	Milk	Beef Muscle	Beef Offal	Sheep Muscle	Sheep Offal	Poultry	Eggs	Game	Honey	Mushroom	Potato	Root Vegetables	Green Vegetables	Domestic Fruit	Wild Fruit	Legumes	Drinking Water	Inhalation	Total for radionuclide
Total tritium	0.01	0.008	<0.001	0.002	<0.001	<0.001	0.002	0.003	<0.001	<0.001	0.01	0.001	0.001	0.009	0.001	0.002	0.09	-	0.14
Carbon-14	0.03	-	-	-	0.009	-	-	0.01	0.01	0.01	0.05	0.04	0.05	0.33	0.05	-	-	-	0.59
Cobalt-60	-	0.003	<0.001	0.002	<0.001	0.002	0.001	0.002	<0.001	<0.001	0.02	0.002	0.004	0.03	0.002	0.004	-	-	0.08
Strontium-90	0.09	0.02	0.004	0.01	0.004	0.02	0.01	0.009	0.003	0.005	0.11	0.04	0.04	0.20	0.03	0.20	0.04	0.003	0.84
Technetium-99	-	<0.001	<0.001	<0.001	<0.001	0.001	-	<0.001	-	-	-	<0.001	-	-	<0.001	-	-	-	0.008
Ruthenium-106	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-	0.009	0.03
Antimony-125	0.01	0.002	<0.001	0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	0.02	0.001	0.002	0.02	0.001	0.002	-	0.001	0.07
Iodine-129	0.10	0.03	0.006	0.02	0.006	0.07	0.03	0.02	0.006	0.007	0.26	0.03	0.04	0.33	0.05	0.13	-	-	1.1
Iodine-131	0.001	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.001
Caesium-134	-	0.02	0.002	0.01	0.003	0.01	0.008	0.009	0.001	0.002	0.14	0.01	0.02	0.10	0.01	0.02	-	<0.001	0.37
Caesium-137	0.10	0.04	0.003	0.23	0.03	0.01	0.004	0.21	0.002	0.02	0.14	0.01	0.01	0.08	0.01	0.02	0.04	<0.001	0.96
Plutonium-alpha	-	<0.001	<0.001	<0.001	0.005	0.002	<0.001	<0.001	<0.001	0.02	0.02	-	<0.001	0.01	0.005	0.002	0.05	0.41	0.53
Plutonium-241	-	0.02	0.003	0.008	0.004	0.02	0.009	0.009	0.003	0.003	0.21	-	0.01	0.03	0.007	-	-	0.24	0.58
Americium-241	-	<0.001	<0.001	<0.001	0.004	<0.001	<0.001	<0.001	<0.001	0.02	0.01	-	<0.001	0.02	0.006	0.003	0.16	0.35	0.58
Total for item	0.34	0.15	0.03	0.29	0.070	0.14	0.07	0.27	0.03	0.09	0.99	0.14	0.18	1.2	0.17	0.38	0.38	1.0	5.9
Total for group	5.9																		

Table 3. Summary of doses to the terrestrial critical group (μSv), 2016

Pathway	Adult	Child	Infant	Foetus
Food consumption:				
terrestrial foods	4.9	4.5	4.1	3.5
marine foods	1.1	0.25	0.11	0.90
Inhalation:	1.0	0.54	0.29	0.02
Immersion:				
Krypton-85	0.40	0.28	0.28	0.40
External ^a	2.8	1.4	0.08	2.8
Total	10	7.0	4.9	7.6

a. Taken from RIFE-22, data from 2016 Total Dose assessment. Foetus set equal to Adult.

Table 4. Critical group doses from operations at Sellafield (μSv)

Pathway	2015	2016
Marine critical group (adults)		
seafood consumption	52	57
aerial pathways	2.2	2.0
external radiation from beach occupancy (marine)	46	49
Total dose to marine critical group (adults)	100	110
Terrestrial critical group (adults)		
inhalation	0.58	1.0
immersion	0.63	0.40
external radiation from beach occupancy (terrestrial)	0.1	2.8
terrestrial foodstuff consumption	6.0	4.9
marine foodstuff consumption	1.2	1.1
direct radiation	5.4	5.4
Total dose to terrestrial critical group (adults)	14	16

Table 5. Collective doses from Sellafield's discharges, 2016

Radionuclide	Collective Dose (manSv)					
	Aerial Discharges			Marine Discharges		
	UK	Europe	World	UK	Europe	World
Tritium	0.08	0.15	0.19	0.0009	0.004	0.07
Carbon-14	0.09	0.45	5.6	0.97	3.2	33
Krypton-85	0.38	1.3	23	-	-	-
Technetium-99	-	-	-	0.005	0.01	0.02
Iodine-129	0.58	2.7	3.8	0.01	0.03	0.11
Caesium-137	0.002	0.007	0.007	0.06	0.15	0.26
Plutonium-alpha	0.02	0.02	0.02	0.05	0.15	0.18
Americium-241	0.002	0.003	0.003	0.03	0.09	0.10
Other nuclides	0.002	0.003	0.003	0.10	0.29	0.33
Total	1.2	4.7	32	1.2	3.9	34

Figure 1 Dose to marine critical group from Pu-alpha and Am-241 in winkles and consumption rate

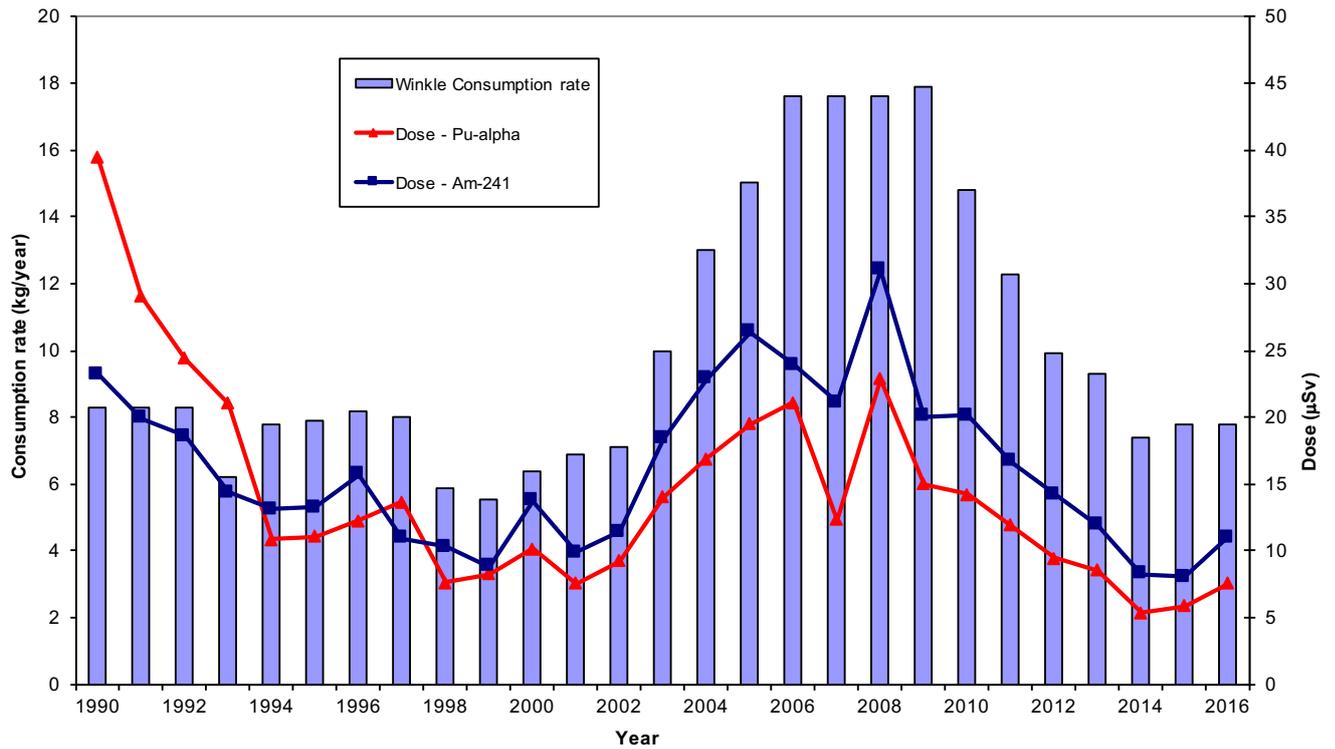


Figure 2 Dose to marine critical group from Pu-alpha and Am-241 in mussels and consumption rate

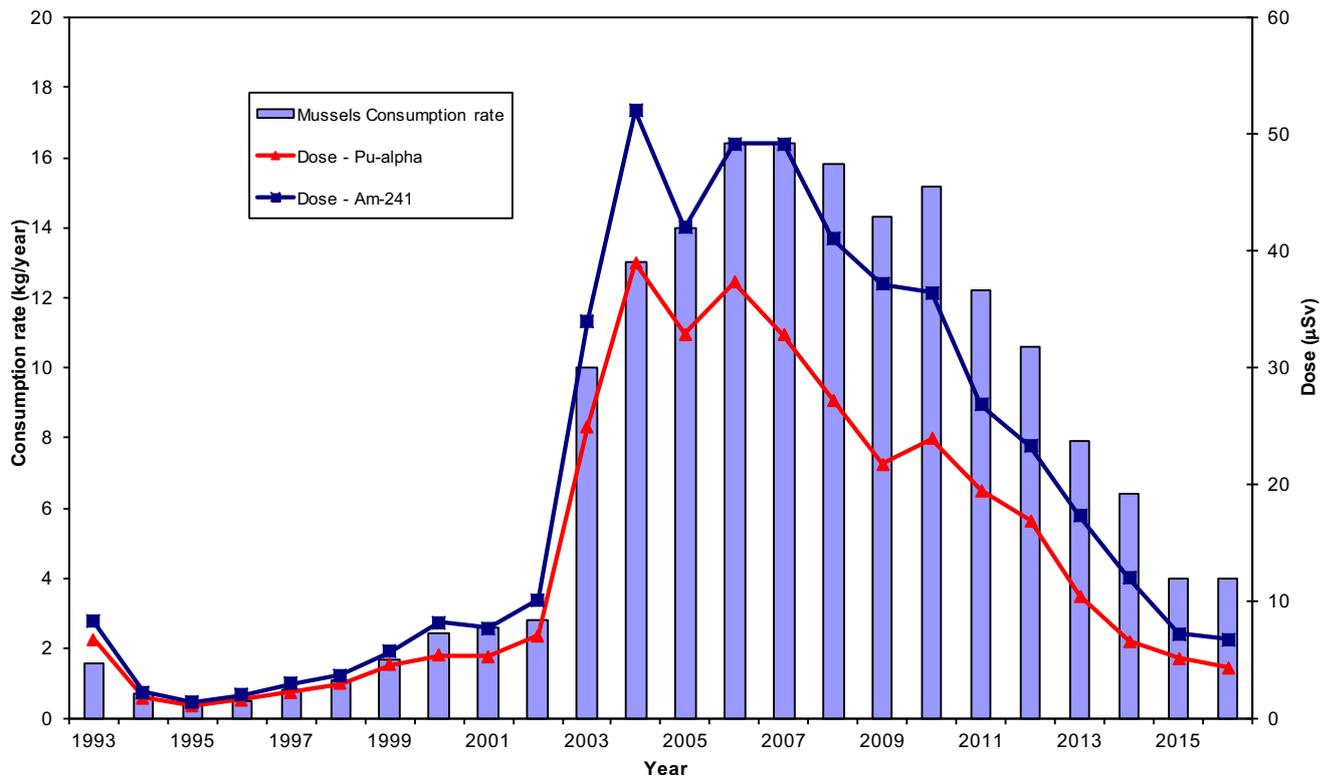


Figure 3 Dose to marine critical group from Pu-alpha and Am-241 in *Nephrops* and consumption rate

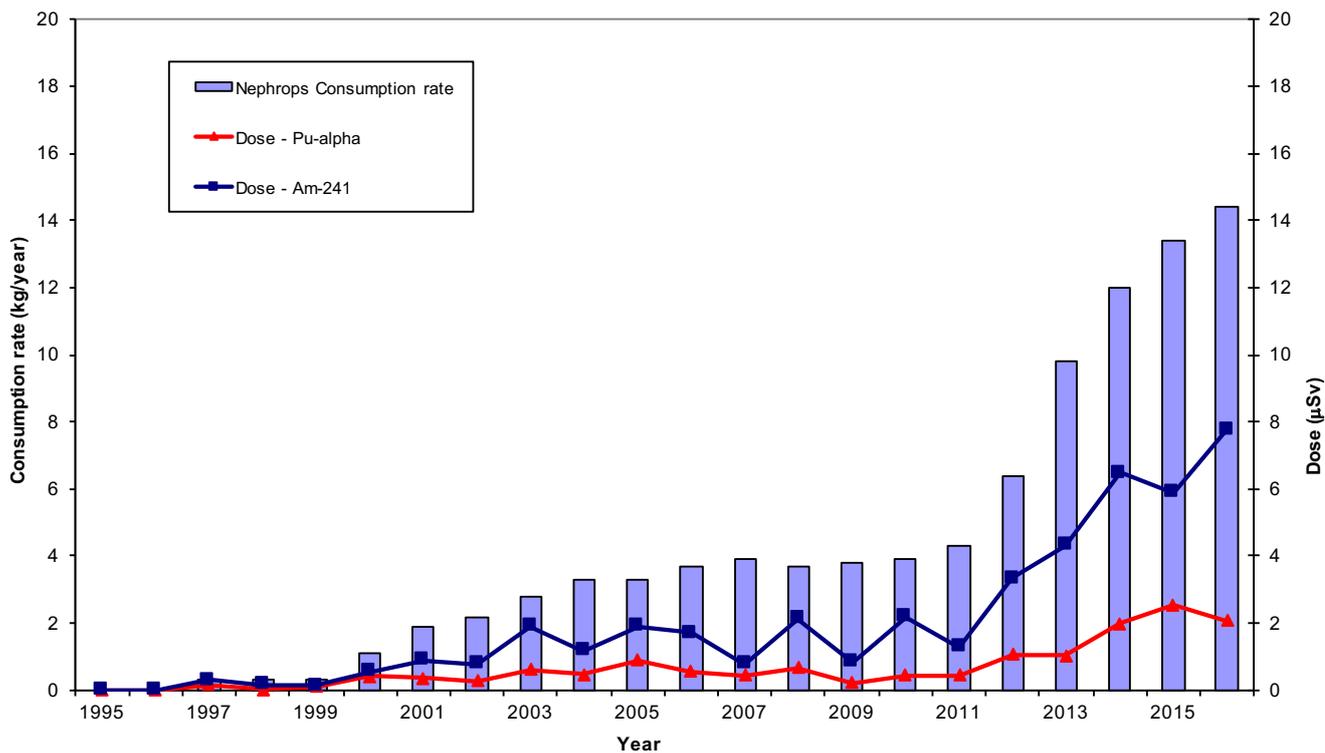


Figure 4 Marine Critical Group Dose (Adult) (Consumption pathways) by Radionuclide

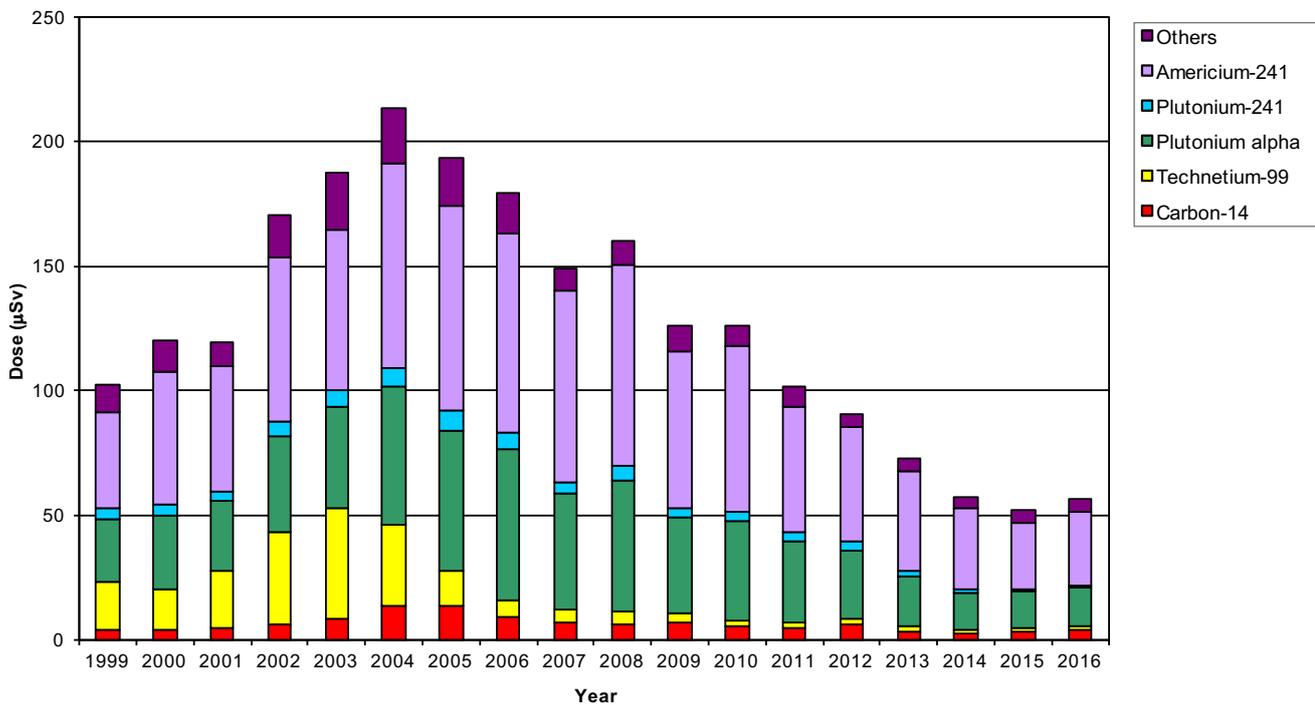


Figure 5 Marine Critical Group Dose (Adult) by Pathways

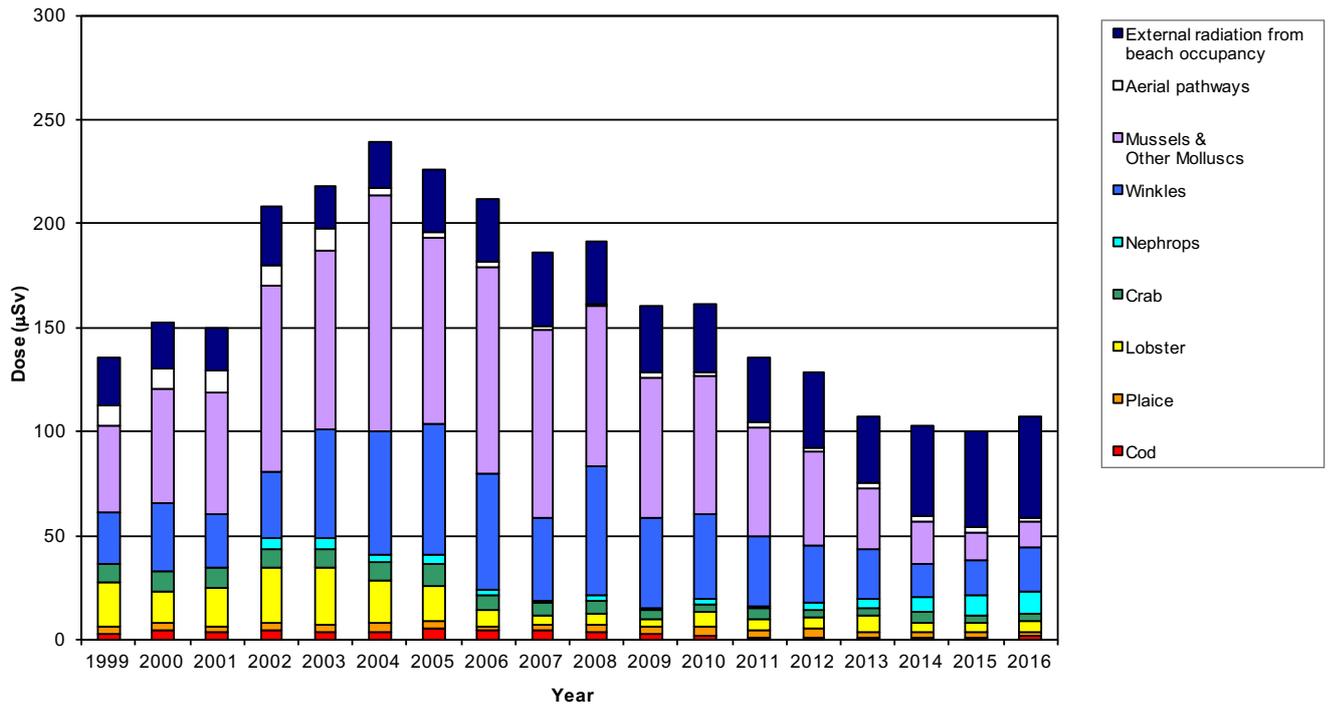


Figure 6 Terrestrial Critical Group Dose (Consumption pathways) by Radionuclide

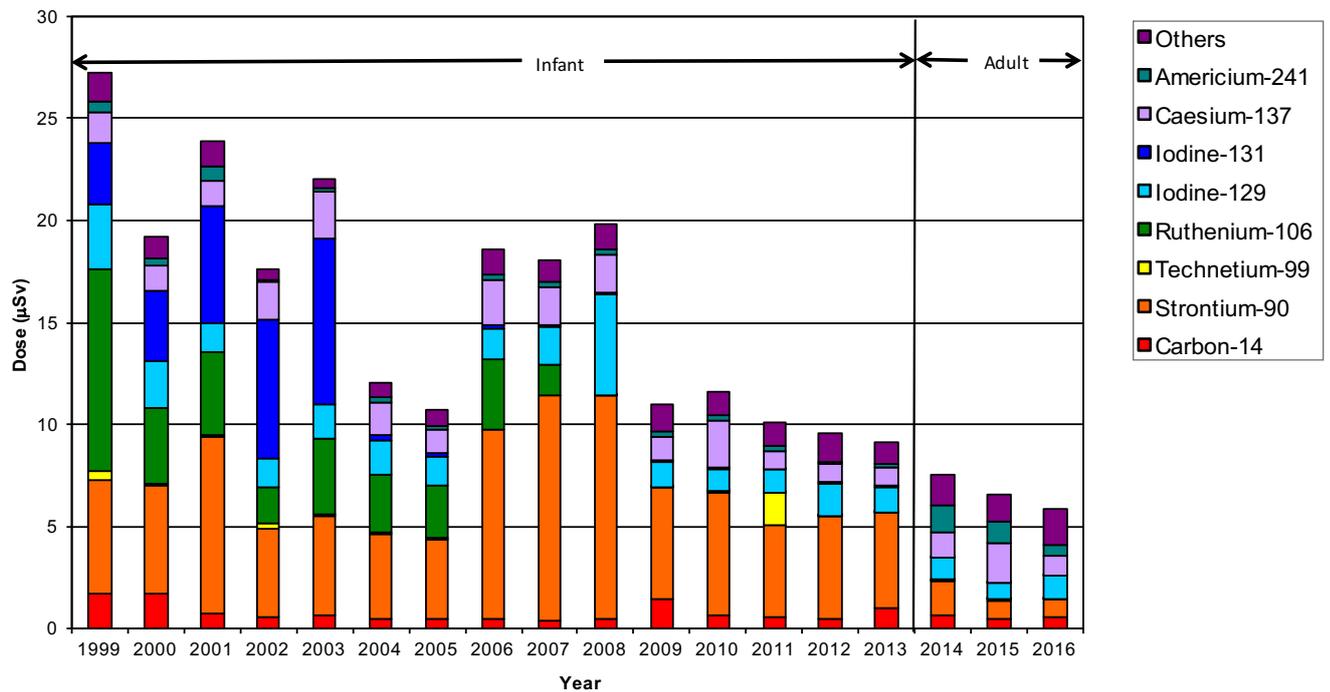
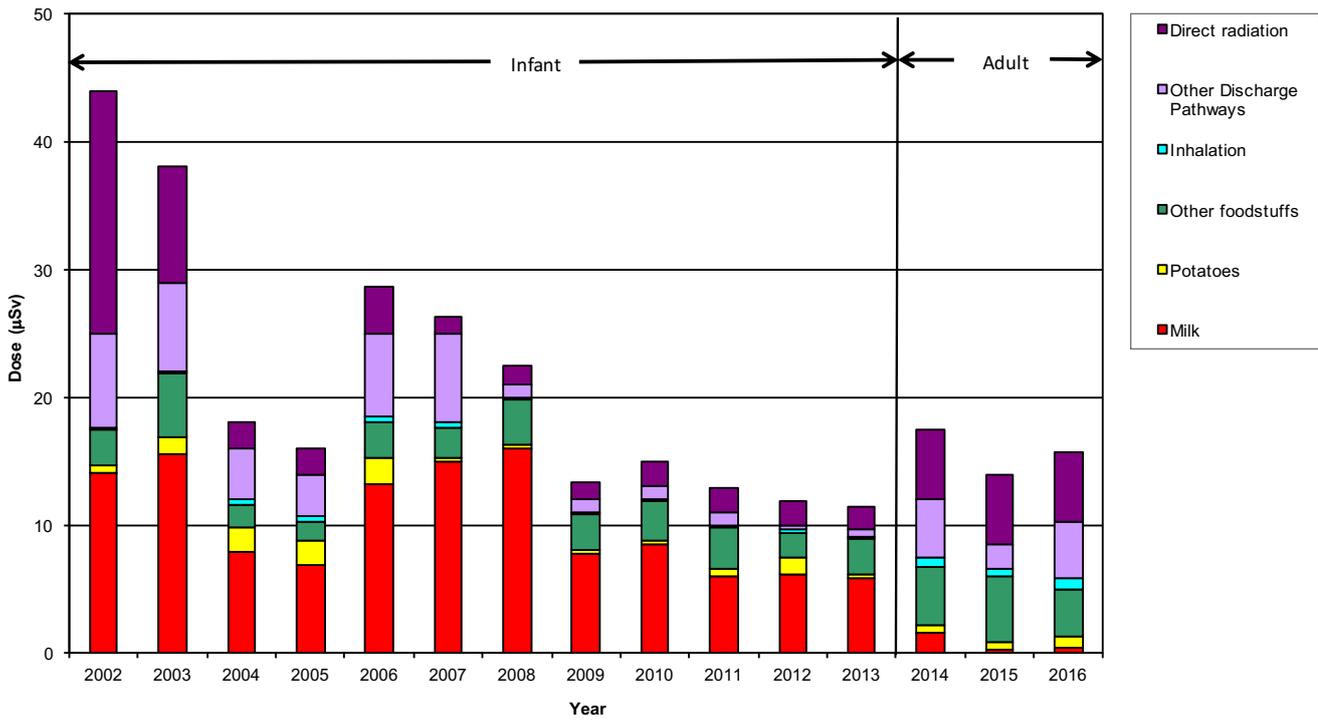


Figure 7 Terrestrial Critical Group by Pathways



Appendix A

Discharges and Environmental Monitoring Annual Report 2016

Dosimetric considerations for individual and collective doses

Critical group doses

- 1 A key concept for assessment of dose to the public is the ‘critical group’: the individual members of a population who can realistically be expected to receive the highest dose due to their lifestyle, location and habits^{1,2}. This term is equivalent to the term ‘representative person’, used by the ICRP^{3,4}. A description of the ‘representative person’ approach using recent monitoring data is given in Appendix C. The dose to members of a critical group is assessed as the mean of the sums of committed effective doses from intakes of radionuclides during the year and their effective doses from external irradiation (see Introduction paragraph 28). These sums are for convenience termed Effective Doses (see Glossary). Effective doses are calculated by combining dose per unit intake data with estimates of annual radionuclide intake by ingestion and inhalation, taking into account all relevant pathways, such as consumption of specific foods at high rates and inhalation during occupancy of certain areas^{5,6}.
- 2 In determining the critical group appropriate to a particular site, it is recognised that the relative doses from different pathways will depend on the habits of particular groups of individuals. Such doses should be summed as required to obtain the critical group dose. Therefore a high rate consumer of seafood may receive only a minor exposure via pathways such as milk consumption or proximity to the site perimeter. For another group, consumption of locally produced meat and milk may combine to result in an elevated exposure. Accordingly, it is common practice to define exposure groups in terms of a dominant pathway or habit (e.g. seafood consumers, boat dwellers, anglers, inhalation pathways etc.). For simplicity, these may at times be referred to in this report as ‘critical groups’, although strictly speaking PHE² defines only the most exposed group at any given time as the critical group.
- 3 This report focuses mainly on doses to members of critical groups; the small groups of people that are most exposed to radiation from the Sellafield Ltd site. The doses received by the rest of the population, from operations at Sellafield Ltd site, will be very much less than those received by critical groups.
- 4 Details of the critical group consumption habits used in this 2016 report are given in table A1 (seafood consumption) and table A2 (terrestrial food consumption). Other details relating to the calculation of plume immersion and inhalation dose are given in table A3.

Critical group dose limits and constraints

- 5 UK dose limits and constraints, which are applicable to controlled releases of radioactivity, are based on the ‘1990 Recommendations’ of the ICRP¹ in which it reviewed the quantities used in radiological protection, the biological effects of radiation relevant to radiological protection, the conceptual framework of radiological protection and recommendations on dose limitation. Under these recommendations, the primary dose quantity was redefined as effective dose (see paragraph 1 and the Glossary), taking into account ‘weighting factors’ which reflect the sensitivity of different body organs to induction of

cancer following exposure to radiation. For members of the public, the ICRP recommended an annual limit on effective dose of 1000 μSv .

- 6 The ‘1990 Recommendations’ also placed emphasis on the optimisation of radiological protection (see paragraph 21) and on the concept of source-related restrictions on individual dose, relating to the optimisation process, termed ‘dose constraints’. A dose constraint is an upper bound on the annual dose to the overall critical group, summed over all exposure pathways, from the planned operation of a controlled source¹. Dose constraints may introduce additional restrictions within the overall dose limit.
- 7 In 1993, the then National Radiological Protection Board (NRPB) published guidance based on ICRP’s ‘1990 Recommendations’ and recommended that for proposed new controlled sources, the maximum dose constraint should be 300 μSv per year². Constraints lower than this could be set where such doses are readily achievable. Existing facilities are expected to operate within the appropriate constraints but where it is not possible to comply with the recommended dose constraint, PHE advise that the operating regime be reviewed with the regulatory body to ensure that doses are ‘as low as reasonably achievable’. Exposures arising from past controlled releases should be included in any comparison with the 1000 μSv dose limit but not in comparison with the dose constraint of 300 μSv . PHE advice includes the caveat that doses should in any case be below the 1000 μSv limit on annual dose.
- 8 The 1000 μSv dose limit was incorporated into the Euratom Basic Standards Directive 1996 and implemented in UK law through Radioactive Substances (Basic Safety Standards) Direction 2000 (Introduction paragraph 12). Ministers have directed the EA, when discharging their duties under RSA 1993, to ensure that the Directive limit on annual dose to the public is not exceeded, and that a maximum source constraint of 300 μSv and a site constraint of 500 μSv are applied for authorising radioactive discharges. The annual dose limit of 1000 μSv should be compared with the sum of doses from the sites, from discharges from all other sources and from any historical accumulation of radionuclides in the environment from past discharges.

Critical group dose considerations

- 9 Radionuclides taken into the body, either by ingestion or by inhalation, cause exposure both to the local tissue and to the whole body. For the purposes of dosimetry, monitoring and control, it is the whole-body exposure which is often of prime concern. The actual exposure will depend on many factors, such as the solubility of the radionuclide and its characteristic retention time in the body.
- 10 The dose coefficients in tables A4 and A5 reflect the most recent advice of the ICRP⁷. They represent the committed effective dose (CED) that would be incurred by an individual up to the age of 70 years following the uptake of a unit amount of a radionuclide. Since biokinetic behaviour (and hence dose incurred) may change with age, differing values are presented depending on the age of the individual at the time of intake. The methods and parameter

- values used for the radiological assessments generally follow the values and relationships given in Annexes II and III to the Council Directive 96/29/Euratom of 13 May 1996.
- 11 In determining the dose arising from ingestion of material containing radioactivity, it is necessary to consider the fraction of the radioactivity which is likely to be absorbed across the wall of the gastro-intestinal tract. Such absorption is referred to as the gut uptake factor (f_1) and varies with the physical and chemical form of the radionuclide and with the metabolism and physiology of the individual. In general, young infants absorb some molecular species more readily than older children or adults and f_1 values tend to be correspondingly larger for infants in a number of cases. In general, more soluble elements such as caesium or tritium tend to be absorbed more readily than less soluble elements, such as plutonium, across all age ranges.
 - 12 With respect to intakes of radionuclides by ingestion, a number of studies^{8,9,10} have established more appropriate gut uptake values for the actinides present in winkles and other molluscs in the Sellafield area for use in critical group studies. For winkles, these values have been endorsed by PHE¹¹ and supported by other studies¹². These values are presented here and are used in this report to estimate doses arising from consuming winkles from the West Cumbrian coast. For seafood other than winkles close to Sellafield, PHE considers that using a gut transfer factor of 0.0005 for both plutonium and americium will not lead to underestimates of critical group doses^{10,13}. These approaches are consistent with the dose assessments performed within RIFE-21¹⁴.
 - 13 Dose per unit intake values for the inhalation of radionuclides are derived from the most recent recommendations of ICRP¹⁷. The dose following intake of radionuclides by inhalation depends upon a number of factors in addition to the radioactive properties of the nuclide(s) involved. Important factors include the particle size of the inhaled material (which influences the extent and distribution of deposition within the respiratory tract) and the rate at which deposited material can be absorbed into body fluids within the respiratory tract and subsequently enter general systemic circulation. A significant proportion of particulate material deposited in the respiratory tract is cleared directly via the gastro-intestinal tract in swallowed mucus, therefore the proportion of this swallowed material which is absorbed across the gut wall also influences the dose. Regarding particle size, ICRP recommends the calculation of doses to members of the public assuming an activity median aerodynamic diameter of 1 micron (10^{-6} m) for the inhaled material¹⁷. For most radionuclides, this maximises the resulting dose by maximising deposition in the alveolar region of the respiratory tract.
 - 14 ICRP has derived a standard classification for inhaled material (the 'lung absorption type') based on the rate of absorption of different chemical forms of radionuclides into body fluids. These absorption types are denoted as V, F, M and S, type V being the most rapidly absorbed and type S the slowest. For each absorption type ICRP recommends an appropriate factor (the ' f_1 value') for the fraction of swallowed material which is absorbed through the gut wall.
 - 15 ICRP has provided calculated values for the committed effective dose to members of the public of different ages, for inhalation of airborne particles with a median diameter of 1 micron for all the radionuclides of relevance to this report⁷. Several values are generally cited for each radionuclide, reflecting the range of absorption types which may be encountered. However, for most radionuclides, ICRP recommends a default absorption type which may be assumed in the absence of specific information about absorption behaviour; in most cases the dose per unit intake values corresponding to those default absorption types are used in the dose assessments in this report. For some radionuclides, ICRP does not specify a default absorption type and in these instances the absorption type producing the highest value of dose per unit intake is assumed for dose assessments.
 - 16 Sellafield Ltd has considered the information in ICRP Publication 88¹⁵, which provides dose coefficients for the embryo and foetus after intakes of radionuclides by the mother, but does not advise on dose limitation or dose constraints for the embryo¹⁶. A report produced by PHE¹⁷ provides guidance on the use of the ICRP dose coefficients and advice regarding the situations for which the assessment of foetal dose is required. In consulting this document, the foetal dose has been calculated by multiplying the adult dose by the ratio of the foetus to adult dose conversion factors¹⁷.
 - 17 Only radionuclides which are known to be present in Sellafield Ltd discharges from Sellafield and are listed in the discharge authorisations are included here. In the case of krypton-85 which is present in aerial discharges, no dose per unit intake value is presented since exposure for this nuclide is determined by external rather than internal dosimetry.
- ### Collective doses
- 18 In addition to estimating doses to critical groups, doses to populations as a whole can be estimated. This involves the concept of 'collective dose': the summation of all individual radiation doses received by a population over a defined period of time. Since radionuclides persist in the environment, subject to processes of dilution, dispersion, radioactive decay and ingrowth of daughter products, the public will continue to receive radiation doses (generally at a decreasing rate) for some time after a discharge is made. Calculating the collective dose therefore involves predicting the behaviour of radionuclides over extended periods following the discharge.
 - 19 In practice, collective doses are often dominated by the summation of a large number of exceedingly small doses received by individuals who are remote, in both space and time, from the point of discharge. Consequently, the calculation of collective dose relies heavily on the use of theoretical models that predict the dispersion of radionuclides over large geographical areas and long timescales. The unit for collective dose is the man Sievert (man Sv) which emphasises that the value quoted is the sum of doses received by a number of individuals.

- 20 The time and geographical area over which a collective dose is integrated is necessarily stated with the estimated value. Current PHE advice emphasises a 500 year integration period⁴ and this is used throughout this report. Doses are generally calculated to the populations of UK, Europe (including the UK) and the World. Europe is defined as the population of the member states of the European Union, including the UK. The EU population chosen is 12 countries which allow a consistent presentation between the aerial and marine model results. For this report, the collective committed dose follows the current PHE advice^{18,19}.
- 21 Collective doses play an important role in the optimisation of radiological protection using the ALARA (As Low As Reasonably Achievable) principle. This is recognised by PHE² as being a useful technique for aiding decisions between different options for radiological protection. Its advice gives monetary values for unit collective doses, which allows the cost of collective doses to be compared with the capital and operating costs of preventing those doses from arising.

Collective dose considerations

- 22 The collective committed effective dose estimates resulting from Sellafield discharges have been calculated using the 2008 upgrade of the PHE model PC CREAM²⁰. This is based on methodology for assessing the radiological consequences of routine releases to the environment published by the European Commission²¹.
- 23 Generally, the PC CREAM default dose per unit intake values has been applied. Where required, the pulmonary retention classes for radionuclides have been modified on a site-specific basis.
- 24 The values presented in tables A6 and A7 for Sellafield are site specific and are given as man Sieverts per Becquerel discharged. Only radionuclides which are known to be present in Sellafield Ltd discharges from Sellafield and are listed in the discharge authorisations, are included here.

Worked example of committed effective dose calculation for an individual member of a critical group

CED received by an adult member of the seafood consuming critical group from Am-241 in winkles

	Parameter	Value	Location in report
A	Am-241 activity concentration in winkles	17 Bq kg ⁻¹	Monitoring chapter, Table 4
B	Consumption rate of winkles by adults	7.8 kg y ⁻¹	Appendix A, Table A1
C	Committed effective dose per unit intake value for ingestion for Pu-alpha in Cumbrian winkle consumed by an adult	8.0E-08 Sv Bq ⁻¹	Appendix A, Bottom of Table A4 for the Cumbrian Winkle data

CED received by an adult member of the seafood consuming critical group from Pu-alpha in winkles is:

CED = A x B x C in units of Sv per year;

$$CED = 17 \text{ Bq kg}^{-1} \times 7.8 \text{ kg y}^{-1} \times 8.0\text{E-}08 \text{ Sv Bq}^{-1} = 1.06\text{E-}05 \text{ Sv y}^{-1},$$

which is equivalent to 10.6, rounded up to 11 μSv y⁻¹, as reported in Radiological Impact chapter, Table 1.

This approach is repeated for all radionuclides of interest in each seafood species of interest, through the incorporation of the appropriate consumption rates and committed effective dose per unit intake values. Care is needed in using the correct dose per unit intake values for Cumbrian winkles as a specific set of data for transuranic radionuclides are available (Appendix A, table A4). All other seafood species consumed use the generic data given in A4.

References

- International Commission on Radiological Protection (1991). The 1990 recommendations of the ICRP. ICRP Publication 60. Ann. ICRP 21 (1-3).
- National Radiological Protection Board (1993). **Occupational, public and medical exposure: Guidance on the 1990 recommendations of ICRP.** Documents of the NRPB 4 (2).
- International Commission on Radiological Protection (2007). **The 2007 Recommendations of the International Commission on Radiological Protection.** ICRP Publication 103. Ann. ICRP 37 (2-4).
- Health Protection Agency (2009). **Application of the 2007 Recommendations of the ICRP to the UK: Advice from the Health Protection Agency.** Documents of the Health Protection Agency.
- Hunt G J and Shepherd J G (1980). **The identification of critical groups.** Fifth International Congress of IRPA. Jerusalem. III: 149-152.
- International Commission on Radiological Protection (1977). **Recommendations of the ICRP.** ICRP Publication 26. Ann. ICRP 1 (3).
- ICRP (2012). **Compendium of Dose Coefficients based on ICRP Publication 60.** ICRP Publication 119. Ann. ICRP 41 (Suppl).
- Hunt G J, Leonard D R P and Lovett M B (1986). **Transfer of environmental plutonium and americium across the human gut.** Sci. Tot. Environ. 53: 89-109.
- Hunt G J, Leonard D R P and Lovett M B (1990). **Transfer of environmental plutonium and americium across the human gut: a second study.** Sci. Tot. Environ. 90: 273-282.
- Hunt G J (1998). **Transfer across the human gut of environmental plutonium, americium, cobalt, caesium and technetium: studies with cockles (*Cerastoderma edule L.*) from the Irish Sea.** J. Radiol. Prot. 18: 101-110.
- Harrison J D and Stather J W (1990). **Gut transfer factors - plutonium and americium in shellfish and 'best estimates' for activities in food.** Documents of the NRPB 1(2): 17-26.
- McKay W A and Halliwell C M (1994). **The levels of particulate associated nuclides in Irish Sea shellfish and the implications for dose assessment.** J. Radiol. Prot. 14: 43-53.
- Harrison J D (1998). **Gut transfer and doses from environmental plutonium and americium.** J. Radiol. Prot. 18: 73-76.
- Environment Agency, Food Standards Agency, Food Standards Scotland, Natural Resources Wales, Northern Ireland Environment Agency and Scottish Environment Protection Agency (2016). **Radioactivity in food and the environment, 2015.** RIFE-21. EA, FSA, FSS, NRW, NIEA and SEPA; Preston, London, Aberdeen, Cardiff, Belfast and Stirling.
- ICRP (2001). **Doses to the embryo and fetus from intakes of radionuclides by the mother.** ICRP Publication 88. Ann. ICRP 31 (1-3).
- Jones S R (2002). **Foetal dosimetry - is the ICRP dosimetric system for humans now complete?** J. Radiol. Prot. 22: 1-4.
- Cooper J R, Bailey M R, Fry F A, Harrison J D, McDonnell C E, Meara J R, Phipps A W, Simmonds J R, Stather J W and Tattersall P J (2005). **Guidance on the application of dose coefficients for the embryo and fetus from intakes of radionuclides by the mother.** Documents of the NRPB 16(2).
- Mayall A, Cabianca T, Morris T P, Nightingale A, Simmonds J R and Cooper J R (1993). **Collective doses from proposed Sellafield discharges.** NRPB note for COMARE. NRPB-M453.
- Bexon A (2000). Radiological impact of routine discharges from UK civil nuclear sites in the mid-1990s. Chilton, NRPB-R312. R312.
- Smith J, Oatway W, Brown I and Sherwood J (2009). **PC-CREAM 08 user guide.** RPD-EA-9-2009. Health Protection Agency.
- Smith G and Simmonds J R (2009). **The methodology for assessing the radiological consequences of routine releases of radionuclides to the environment used in PC-CREAM 08.** HPA-RPD-058. Health Protection Agency.
- Smith K R and Jones A L (2003). **Generalised habit data for radiological assessments.** NRPB Report W41.

Appendix Tables

Table A1. Seafood consumption rates from people associated with marine discharges (2012 – 2016 average data)

Seafood	Consumption rates (kg y ⁻¹)		
	Critical group (Sellafield fishing community) ^a	Consumers associated with Whitehaven fishery ^b	Typical seafood consumers (Whitehaven) ^b
Fish:			
Cod	17	20	7.5
Plaice	37.6	20	7.5
Crustacea:			
Crabs	9	-	-
Lobsters	9.6	-	-
<i>Nephrops</i>	14.4	9.7	-
Molluscs:			
Winkles	7.8	-	-
Mussels	4	-	-

a. CEFAS, 2017. Radiological Habits Survey: Sellafield Review, 2016.

b. RIFE-21.

Table A2. Consumption rates of critical group consumers associated with aerial discharges, 2016

Foodstuff ^a	Consumption rate (kg y ⁻¹) ^{b c}		
	Adult	Child	Infant
milk	95	110	130
beef	15	15	3
beef liver	2.75	1.5	0.5
mutton	8	4	0.8
poultry	10	5.5	2
game	6	4	0.8
fish (cod + plaice)	15	3	0.75
leafy vegetables	15	6	3.5
potatoes	120	85	35
root vegetables	10	6	5
legumes	20	8	3
domestic fruit	75	50	35
wild fruit	7	3	1
mushrooms	3	1.5	0.6
honey	2.5	2	2
eggs	8.5	6.5	5

a. Based on PHE/FSA recommendations.

b. Consumption rates for foetal exposure taken to be same as those of adults.

c. Domestic fruit and potatoes as high rate consumers

Table A3. Parameters for calculation of plume immersion and inhalation doses^a

	Adult	Child	Infant
Occupancy (%)	100%	100%	100%
Time Indoors (%)	50%	90%	90%
Cloud Shielding Factor	0.2	0.2	0.2
Ground Shielding Factor	0.1	0.1	0.1
Breathing rate (m ³ a ⁻¹)	9,860	5,600	1,900

a. Foetal dose is calculated from the adult dose multiplied by the ratio of the foetus to the adult dose conversion factors (following NRPB, 2003²²).

Table A4. Committed effective doses per unit intake for ingestion

Radionuclide	f_1^a	Dose per unit intake (Sv Bq ⁻¹)			
		Foetus	1 y	10 y	Adult
H-3 oxide	1E+00	3.1E-11	4.8E-11	2.3E-11	1.8E-11
H-3 organic	1E+00	6.3E-11	1.2E-10	5.7E-11	4.2E-11
C-14	1E+00	8.0E-10	1.6E-09	8.0E-10	5.8E-10
Co-60	1E-01	1.9E-09	2.7E-08	1.1E-08	3.4E-09
Zn-65	5E-01	4.1E-09	1.6E-08	6.4E-09	3.9E-09
Sr-90	3E-01	4.6E-08	9.3E-08	6.6E-08	3.1E-08
Zr-95	1E-02	7.6E-10	8.8E-09	3.0E-09	1.5E-09
Nb-95	1E-02	3.7E-10	3.2E-09	1.1E-09	5.8E-10
Tc-99	5E-01	4.6E-10	4.8E-09	1.3E-09	6.4E-10
Ru-103	5E-02	2.7E-10	4.6E-09	1.5E-09	7.3E-10
Ru-106	5E-02	3.8E-10	4.9E-08	1.5E-08	7.0E-09
Ag-110m	5E-02	2.1E-09	1.4E-08	5.2E-09	2.8E-09
Sb-125	1E-01	4.7E-10	6.1E-09	2.1E-09	1.1E-09
I-129	1E+00	4.4E-08	2.2E-07	1.9E-07	1.1E-07
I-131	1E+00	2.3E-08	1.8E-07	5.2E-08	2.2E-08
Cs-134	1E+00	8.7E-09	1.6E-08	1.4E-08	1.9E-08
Cs-137	1E+00	5.7E-09	1.2E-08	1.0E-08	1.3E-08
Ce-144	5E-04	3.1E-11	3.9E-08	1.1E-08	5.2E-09
Pm-147	5E-04	2.6E-10	1.9E-09	5.7E-10	2.6E-10
Eu-154	5E-04	2.0E-09	1.2E-08	4.1E-09	2.0E-09
Eu-155	5E-04	3.2E-10	2.2E-09	6.8E-10	3.2E-10
Ra-226	2E-01	3.2E-07	9.6E-07	8.0E-07	2.8E-07
U-234	2E-02	1.5E-08	1.3E-07	7.4E-08	4.9E-08
U-235	2E-02	1.4E-08	1.3E-07	7.1E-08	4.7E-08
U-238	2E-02	1.3E-08	1.5E-07	7.5E-08	4.8E-08
Np-237	5E-04	3.6E-09	2.1E-07	1.1E-07	1.1E-07
Pu-238	5E-04	9.0E-09	4.0E-07	2.4E-07	2.3E-07
Pu-239	5E-04	9.5E-09	4.2E-07	2.7E-07	2.5E-07
Pu-240	5E-04	9.5E-09	4.2E-07	2.7E-07	2.5E-07
Pu-241	5E-04	1.1E-10	5.7E-09	5.1E-09	4.8E-09
Am-241	5E-04	2.7E-09	3.7E-07	2.2E-07	2.0E-07
Cm-242	5E-04	4.7E-10	7.6E-08	2.4E-08	1.2E-08
Cm-243	5E-04	1.5E-07	3.3E-07	1.6E-07	1.5E-07
Cm-244	5E-04	2.2E-09	2.9E-07	1.4E-07	1.2E-07
Plutonium and americium values for application to the consumption of Cumbrian winkles					
Pu-238	2E-04	3.6E-09	1.6E-07	9.6E-08	9.2E-08
Pu-239	2E-04	3.8E-09	1.7E-07	1.1E-07	1.0E-07
Pu-240	2E-04	3.8E-09	1.7E-07	1.1E-07	1.0E-07
Pu-241	2E-04	4.4E-11	2.3E-09	2.0E-09	1.9E-09
Am-241	2E-04	1.1E-09	1.5E-07	8.8E-08	8.0E-08

a – The gastro-intestinal absorption factor does not apply to neonates or infants aged below about one year.

Table A5. Committed effective doses per unit intake for inhalation

Radionuclide	Lung absorption type	f_1^a	Dose per unit intake (Sv Bq ⁻¹)				Basis for choice of lung absorption type
			Foetus	1 y	10 y	Adult	
H-3 oxide	V	1E+00	2.6E-12	2.7E-10	8.2E-11	4.5E-11	Water vapour
H-3 organic	V	1E+00	6.3E-11	1.1E-10	5.5E-11	4.1E-11	Organically bound tritium
C-14	M	1E-01	6.6E-11	6.6E-09	2.8E-09	2.0E-09	ICRP recommended default
Co-60	M	1E-01	1.2E-09	3.4E-08	1.5E-08	1.0E-08	ICRP recommended default
Zn-65	M	1E-01	7.4E-10	6.5E-09	2.4E-09	1.6E-09	ICRP recommended default
Sr-90	M	1E-01	1.0E-08	1.2E-07	5.4E-08	3.8E-08	ICRP recommended default
Zr-95	M	2E-03	4.6E-10	2.1E-08	9.0E-09	6.3E-09	ICRP recommended default
Nb-95	M	1E-02	1.6E-10	5.2E-09	2.2E-09	1.5E-09	ICRP recommended default
Tc-99	M	1E-01	8.3E-11	1.3E-08	5.7E-09	4.0E-09	ICRP recommended default
Ru-103	M	5E-02	1.1E-10	8.4E-09	3.5E-09	2.4E-09	ICRP recommended default
Ru-106	M	5E-02	4.1E-10	1.1E-07	4.1E-08	2.8E-08	ICRP recommended default
Ag-110m	M	5E-02	1.5E-09	2.8E-08	1.2E-08	7.6E-09	ICRP recommended default
Sb-125	M	1E-02	2.6E-10	1.6E-08	6.8E-09	4.8E-09	ICRP recommended default
I-129	F	1E+00	1.5E-08	8.6E-08	6.7E-08	3.6E-08	ICRP recommended default
I-131	F	1E+00	8.1E-09	7.2E-08	1.9E-08	7.4E-09	ICRP recommended default
Cs-134	F	1E+00	3.0E-09	7.3E-09	5.3E-09	6.6E-09	ICRP recommended default
Cs-137	F	1E+00	2.0E-09	5.4E-09	3.7E-09	4.6E-09	ICRP recommended default
Ce-144	M	5E-04	4.2E-10	1.6E-07	5.5E-08	3.6E-08	ICRP recommended default
Pm-147	M	5E-04	5.0E-09	1.8E-08	7.0E-09	5.0E-09	Most restrictive ^b
Eu-154	M	5E-04	5.3E-08	1.5E-07	6.5E-08	5.3E-08	Most restrictive ^b
Eu-155	M	5E-04	6.9E-09	2.3E-08	9.2E-09	6.9E-09	Most restrictive ^b
Ra-226	M	1E-01	9.9E-08	1.1E-05	4.9E-06	3.5E-06	ICRP recommended default
U-234	M	2E-02	4.9E-08	1.1E-05	4.8E-06	3.5E-06	ICRP recommended default
U-235	M	2E-02	4.5E-08	1.0E-05	4.3E-06	3.1E-06	ICRP recommended default
U-238	M	2E-02	4.4E-08	9.4E-06	4.0E-06	2.9E-06	ICRP recommended default
Np-237	M	5E-04	4.3E-07	4.0E-05	2.2E-05	2.3E-05	ICRP recommended default
Pu-238	M	5E-04	1.1E-06	7.4E-05	4.4E-05	4.6E-05	ICRP recommended default
Pu-239	M	5E-04	1.2E-06	7.7E-05	4.8E-05	5.0E-05	ICRP recommended default
Pu-240	M	5E-04	1.2E-06	7.7E-05	4.8E-05	5.0E-05	ICRP recommended default
Pu-241	M	5E-04	1.4E-08	9.7E-07	8.3E-07	9.0E-07	ICRP recommended default
Am-241	M	5E-04	3.2E-07	6.9E-05	4.0E-05	4.2E-05	ICRP recommended default
Cm-242	M	5E-04	5.1E-08	1.8E-05	7.3E-06	5.2E-06	ICRP recommended default
Cm-243	M	5E-04	3.1E-05	6.1E-05	3.1E-05	3.1E-05	ICRP recommended default
Cm-244	M	5E-04	2.6E-07	5.7E-05	2.7E-05	2.7E-05	ICRP recommended default

a. The gastro-intestinal absorption factor does not apply to neonates or infants aged below about one year.

b. No default inhalation class recommended – most restrictive value cited by ICRP used.

Table A6. Collective dose commitment from Sellafield Ltd site (man Sv per Bq discharged, integrated to 500 years): atmospheric discharges

Radionuclide	Sellafield		
	UK	EU ^a	World
H-3	6.7E-16	1.2E-15	1.5E-15
C-14	2.0E-13	1.0E-12	1.3E-11
Kr-85	4.3E-18	1.5E-17	2.6E-16
Sr-90	1.9E-12	8.8E-12	8.8E-12
Ru-106	3.1E-13	4.2E-13	4.2E-13
Sb-125	1.2E-13	1.7E-13	1.7E-13
I-129	4.5E-11	2.1E-10	2.9E-10
I-131	7.8E-13	4.8E-13	4.8E-13
Cs-137	1.8E-12	6.1E-12	6.1E-12
Pu-239]	1.7E-10	2.4E-10	2.4E-10
Pu-240]			
Pu-241	3.0E-12	4.4E-12	4.4E-12
Am-241	1.4E-10	2.0E-10	2.0E-10

a. EU is defined as the population of the pre-expansion EU member states

Table A7. Collective dose commitment from Sellafield Ltd site (man Sv per Bq discharged, integrated to 500 years): liquid discharges^a

Radionuclide	Sellafield		
	UK	EU ^b	World
H-3	4.6E-19	1.9E-18	3.5E-17
C-14	2.0E-13	6.6E-13	6.8E-12
Co-60	6.7E-14	1.9E-13	2.4E-13
Sr-90	7.0E-16	1.8E-15	3.0E-15
Zr-95	7.3E-17	1.5E-16	1.6E-16
Nb-95	1.7E-17	3.5E-17	3.8E-17
Tc-99	2.5E-15	7.6E-15	9.5E-15
Ru-106	1.9E-14	5.1E-14	5.6E-14
I-129	1.9E-14	5.7E-14	2.2E-13
Cs-134	1.3E-14	3.0E-14	4.6E-14
Cs-137	1.6E-14	4.1E-14	7.1E-14
Ce-144	6.9E-17	1.8E-16	2.0E-16
Pu-239]	3.0E-13	8.4E-13	9.8E-13
Pu-240]			
Pu-241	2.5E-14	7.1E-14	7.9E-14
Am-241	1.3E-12	3.6E-12	3.9E-12
Cm-242	2.3E-15	6.1E-15	6.8E-15
Cm-243]	4.3E-14	1.1E-13	1.2E-13
Cm-244]			

a. The collective dose factors include the contribution from the first decay product where appropriate.

b. Please note EU is defined as the population of the pre-expansion EU member states

Appendix B

Discharges and Environmental Monitoring Annual Report 2016

Supporting monitoring and dose data

Table B1. Radioactivity in seaweed, 2016

Species	Location	Mean radionuclide concentration (Bq kg ⁻¹ wet weight)													
		Total Alpha	Total Beta	¹⁴ C ^a	⁶⁰ Co	⁹⁰ Sr	⁹⁹ Tc	¹⁰⁶ Ru	¹²⁵ Sb	¹²⁹ I	¹³⁴ Cs	¹³⁷ Cs	U(α)	Pu(α)	²⁴¹ Am
<i>Fucus vesiculosus</i>	Nethertown	15	280	36	0.53	1.2	1,700	<1.3	0.42	23	<0.10	2.5	3.3	12	2.8
	Drigg Barnscar	17	300	52	0.57	1.0	1,300	<1.3	0.43	12	<0.08	2.6	4.9	12	3.3
	Walney Island	17	260	38	0.19	0.61	820	<0.81	<0.24	3.9	<0.06	2.0	5.8	4.6	0.91
<i>Porphyra umbilicalis</i>	St Bees	7.5	170	52	-	<0.17	4.2	<2.2	-	<0.51	<0.07	0.87	0.32	3.3	4.9
	Braystones	3.7	190	56	0.14	<0.24	2.7	2.5	-	<1.7	<0.06	1.1	0.19	1.7	3.0
	Sellafield	6.4	170	73	0.10	0.21	3.7	<3.1	-	<0.85	<0.07	1.2	0.21	3.0	4.4
	Seascale Neb	7.7	160	50	0.15	<0.25	5.0	4.9	0.22	<0.75	<0.07	1.1	0.27	2.6	4.6
	St. Bees - Selker (Av)	6.3	170	58	0.13	0.22	3.9	3.2	0.22	<0.94	<0.07	1.1	0.25	2.6	4.2

a. ¹⁴C data include natural background

Table B2. Radioactivity in coastal samples of seawater from the Irish Sea, 2016

Location		Mean radionuclide concentration (Bq litre ⁻¹)												
		Total Alpha	Total Beta	³ H	¹⁴ C	⁹⁰ Sr	⁹⁹ Tc	¹²⁹ I	¹³⁷ Cs	U(α)	²³⁷ Np	Pu(α)	²⁴¹ Pu	²⁴¹ Am
St Bees	filtrate	<2.1	9.7	<9.4	<0.66	0.02	<0.03	<0.03	<0.06	0.10	<0.0006	0.004	<0.07	0.001
	solids	0.14	0.11	-	-	0.005	-	-	0.02	0.002	<0.00002	0.04	0.11	0.06
Sellafield	filtrate	<2.2	10	17	<0.66	0.05	<0.03	<0.03	0.08	0.10	<0.0005	0.005	<0.08	0.002
	solids	0.24	0.19	-	-	0.008	-	-	0.03	0.003	0.00007	0.06	0.22	0.10
Seascale Neb	filtrate	<2.1	8.9	11	<0.68	0.04	<0.03	<0.03	0.06	0.09	0.0004	0.004	0.08	0.002
	solids	0.36	0.31	-	-	0.009	-	-	0.05	0.005	0.00009	0.09	0.35	0.16
Drigg Barnscar	filtrate	<2.3	9.8	13	<0.65	0.03	<0.03	<0.03	0.05	0.10	0.0004	0.004	<0.07	0.002
	solids	0.24	0.21	-	-	0.008	-	-	0.03	0.004	0.00005	0.07	0.26	0.10

Table B3. Radioactivity in sediment from the West Cumbrian Coast, 2016

Sediment	Location	Mean radionuclide concentration (Bq kg ⁻¹ dry weight)										
		Total Alpha	Total Beta	⁶⁰ Co	⁹⁰ Sr	⁹⁹ Tc	¹⁰⁶ Ru	¹³⁴ Cs	¹³⁷ Cs	U(α)	Pu(α)	²⁴¹ Am
Sand	St Bees	500	480	0.60	-	-	<1.0	<0.11	50	-	120	130
	Braystones	380	390	0.43	-	-	<1.3	<0.12	45	-	100	120
	Sellafield	390	420	0.46	-	-	<1.0	<0.10	31	-	87	99
	Seascale Neb	440	480	0.46	-	-	<1.1	<0.11	22	-	96	120
	Drigg Barnscar	360	470	0.44	-	-	<0.92	<0.10	17	-	87	100
Silt	Ravenglass Ford	900	550	1.2	4.5	10	<9.3	<1.1	51	30	200	280
	Ravenglass Garth	460	270	<0.77	0.88	8.7	<8.1	<0.84	24	34	96	120
	Ravenglass Opp Raven Villa	1,100	460	<1.1	11	14	<9.8	<1.1	67	40	200	360
	Eskmeals, R Esk south bank downstream of viaduct	950	820	<1.1	21	15	<13	<1.3	80	54	160	280
	Eskmeals Newbiggin Marsh	1,400	1,200	2.4	35	30	<16	<1.5	220	57	440	710
	R Esk Muncaster Rd Bridge; Downstream	1,400	1,100	2.9	55	40	<19	<1.9	270	61	440	690
	Whitehaven Outer Harbour (south)	640	650	<0.85	1.6	3.3	<9.0	<1.0	64	26	130	170
	Silt from R Calder	500	670	<1.1	2.6	<2.5	<12	<1.4	23	24	25	40
	Silt from R Ehen	1,900	1,300	3.7	39	27	87	<1.7	210	54	290	440
	Waberthwaite	1,000	880	1.6	22	15	<14	<1.5	120	65	280	390

Table B4. Large area beach monitoring coverage and finds summary, 2016

Monitoring area	Area covered (ha)	Finds Recovered ^a		Find Rate (finds per hectare)	
		Particles	Objects	Particles	Objects
Allonby	11	-	-	-	-
St Bees	22	26	-	1.2	-
Braystones	25	26	-	1.0	-
Sellafield	82	136	67	1.7	0.81
Seascale	28	1	-	0.04	-
Drigg	1.1	2	-	1.8	-
Total	170	191	67	1.1	0.40

a. Finds with any dimension estimated as less than 2 mm are categorised as particles, all others are reported as objects.

Table B5. Radioactivity in Total Deposition, 2016

Location	Mean radionuclide concentration (Bq m ⁻³)									
	Total alpha	Total beta	³ H	⁹⁰ Sr	¹⁰⁶ Ru	¹²⁵ Sb	¹³⁴ Cs	¹³⁷ Cs	Pu(α)	²⁴¹ Am
Calder Gate	<16	<170	4,800	2.9	<41	<13	<4.8	13	<1.5	1.4
Met Station	<15	<230	6,600	11	<40	<10	<4.6	40	<1.2	1.3
North Gate	<16	540	9,100	120	<37	<19	<4.3	150	<1.3	<0.91
South Side	<17	<150	<4,200	5.3	<35	<10	<4.8	<4.6	<0.99	<0.81
West Ring Road	<17	<220	<5,200	8.1	<50	<12	<5.8	<6.9	<1.6	1.2

Table B6. Radioactivity in grass, 2016

Location	Mean radionuclide concentration (Bq kg ⁻¹ wet weight)													
	Total alpha	Total beta	³ H	¹⁴ C Total ^a	¹⁴ C Net ^b	⁹⁰ Sr	⁹⁹ Tc	¹⁰⁶ Ru	¹²⁵ Sb	¹³⁴ Cs	¹³⁷ Cs	U(α)	Pu(α)	²⁴¹ Am
Calder Gate	2.2	95	14	27	1.8	1.7	3.2	<0.88	1.6	<0.10	3.3	0.09	0.22	0.13
Met Station	2.4	120	7.7	23	<0.89	7.3	1.9	<0.98	<0.90	<0.11	5.5	0.12	0.66	0.27
North Gate	2.4	150	33	26	1.9	20	1.9	<1.1	3.2	<0.12	21	0.10	0.32	0.17
South Side	3.1	110	14	24	<0.93	1.1	2.5	<0.90	0.40	<0.11	0.91	0.27	0.09	0.11
West Ring Road	2.6	140	8.6	20	<0.80	0.91	0.92	<0.92	<0.39	<0.11	2.5	0.24	0.38	0.38
Ravenglass ^c	17	69	6.2	17	<0.67	0.85	1.6	<0.92	<0.22	<0.08	5.0	0.70	7.3	11

a. ¹⁴C data includes background.

b. Excluding natural background calculated assuming 226 Bq natural ¹⁴C per kg carbon.

c. Tidally inundated site.

Table B7. Radioactivity in soil, 2016

Location	Mean radionuclide concentration (Bq kg ⁻¹ wet weight)													
	Total alpha	Total beta	³ H	¹⁴ C Total ^a	¹⁴ C Net ^b	⁹⁰ Sr	⁹⁹ Tc	¹⁰⁶ Ru	¹²⁵ Sb	¹³⁴ Cs	¹³⁷ Cs	U(α)	Pu(α)	²⁴¹ Am
Calder Gate	630	620	<2.2	4.5	1.2	3.6	<3.3	<21	<5.1	<2.3	93	55	29	16
Met Station	700	840	<2.5	5.5	0.70	12	<3.0	<18	<4.7	<1.6	250	61	92	37
North Gate	690	710	<2.3	6.3	2.5	30	<5.0	<17	<5.1	<1.6	430	66	210	39
South Side	490	1,000	<2.6	9.3	<0.40	5.2	<4.8	<24	<5.6	<2.4	76	70	14	6.1
West Ring Road	470	540	5.3	3.6	<0.10	5.6	<3.0	<16	<4.3	<1.7	110	92	46	26
Ravenglass ^c	3,600	1,600	4.0	8.3	0.90	19	740	<10	<4.1	<0.75	2,300	88	1,800	2,100

a. ¹⁴C data includes background.

b. Excluding natural background calculated assuming 226 Bq natural ¹⁴C per kg carbon.

c. Tidally inundated site.

Table B8. Radioactivity in groundwater at Sellafield, 2016

Borehole number	Mean radionuclide concentration (Bq m ⁻³)					
	Total alpha	Total beta	³ H	⁹⁰ Sr	⁹⁹ Tc	¹³⁷ Cs
6909p1	<23	<240	23,000	<77	<47	<56
6960p1	19	<240	7,700	<86	<27	<100
10007	<10	<240	<4,200	-	-	-
6948p1	<18	7,500	22,000	4,000	260	-
6979p1	30	<240	13,000	98	230	-
10339	37	<240	810,000	97	6,700	-
9118	24	290	7,800	94	<35	<95
793p3	140	410	9,100	87	<40	<32
6951p1	15	<240	<4,000	93	<37	-
6920p1	<13	<250	66,000	<73	11,000	-
6953p1	34	<260	9,200	59	<34	<81
6949p1	<17	<250	<5,000	-	<48	-
6228p1	<27	<250	500,000	<69	17,000	-
4996p1	<24	<250	42,000	<73	340	-
6986p1	65	<270	88,000	<73	820	-

Table B9. Summary of doses to marine critical group from marine foodstuffs (μSv), 2016

Radionuclide	Cod				Plaice				Lobsters				Crabs			
	Adult	Child	Infant	Foetus	Adult	Child	Infant	Foetus	Adult	Child	Infant	Foetus	Adult	Child	Infant	Foetus
Carbon-14 ^a	0.64	0.18	0.09	0.88	1.3	0.35	0.17	1.7	0.53	0.15	0.07	0.73	0.55	0.15	0.08	0.76
Cobalt-60	-	-	-	-	-	-	-	-	-	-	-	-	0.006	0.004	0.002	0.003
Strontium-90	-	-	-	-	-	-	-	-	-	-	-	-	0.02	0.01	0.004	0.04
Technetium-99	0.003	0.001	0.001	0.002	0.05	0.02	0.02	0.04	0.86	0.35	0.32	0.62	0.03	0.01	0.01	0.02
Ruthenium-106	0.03	0.01	0.01	0.002	0.05	0.02	0.02	0.003	-	-	-	-	0.11	0.05	0.04	0.006
Antimony-125	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Iodine-129	-	-	-	-	-	-	-	-	0.80	0.28	0.08	0.32	-	-	-	-
Caesium-137	0.86	0.13	0.04	0.38	0.88	0.14	0.04	0.39	0.17	0.03	0.008	0.08	0.08	0.01	0.004	0.04
Neptunium-237	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Plutonium-alpha	0.01	0.003	0.001	0.0005	0.07	0.01	0.006	0.003	0.41	0.09	0.03	0.02	0.59	0.13	0.05	0.02
Plutonium-241	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Americium-241	0.01	0.003	0.001	0.0002	0.08	0.02	0.007	0.001	2.3	0.51	0.21	0.03	1.8	0.40	0.17	0.02
Curium-alpha	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	1.6	0.33	0.14	1.3	2.4	0.56	0.27	2.2	5.1	1.4	0.73	1.8	3.2	0.76	0.35	0.91

Radionuclide	Nephrops				Winkles				Mussels			
	Adult	Child	Infant	Foetus	Adult	Child	Infant	Foetus	Adult	Child	Infant	Foetus
Carbon-14 ^a	0.53	0.15	0.07	0.74	0.27	0.07	0.04	0.37	0.23	0.06	0.03	0.32
Cobalt-60	-	-	-	-	0.02	0.02	0.01	0.01	0.007	0.005	0.003	0.004
Strontium-90	-	-	-	-	0.48	0.21	0.07	0.72	0.07	0.03	0.01	0.11
Technetium-99	0.42	0.17	0.16	0.30	0.27	0.11	0.10	0.20	0.19	0.08	0.07	0.14
Ruthenium-106	-	-	-	-	0.26	0.11	0.09	0.01	0.09	0.04	0.03	0.005
Antimony-125	-	-	-	-	0.005	0.002	0.001	0.002	0.002	0.0007	0.0005	0.0008
Iodine-129	-	-	-	-	0.11	0.04	0.01	0.04	0.04	0.02	0.004	0.02
Caesium-137	0.24	0.04	0.01	0.11	0.57	0.09	0.03	0.25	0.10	0.02	0.005	0.05
Neptunium-237	-	-	-	-	0.009	0.002	0.0008	0.0003	0.004	0.0009	0.0004	0.0001
Plutonium-alpha	2.1	0.45	0.18	0.08	7.6	1.6	0.64	0.29	4.4	0.95	0.37	0.17
Plutonium-241	-	-	-	-	0.66	0.14	0.04	0.02	0.46	0.10	0.03	0.01
Americium-241	7.8	1.7	0.72	0.10	11	2.3	0.98	0.15	6.8	1.5	0.63	0.09
Curium-alpha	-	-	-	-	0.12	0.02	0.01	0.12	0.03	0.006	0.003	0.03
Total	11	2.5	1.1	1.3	21	4.8	2.0	2.2	12	2.8	1.2	0.94

a. Calculated using background corrected activity concentrations (see Monitoring chapter, paragraph 24).

Table B10. Summary of doses to terrestrial critical group from terrestrial foodstuffs and inhalation (μSv)^a, 2016

Radionuclide	Milk				Beef Muscle				Beef Offal				Sheep Muscle			
	Adult	Child	Infant	Foetus	Adult	Child	Infant	Foetus	Adult	Child	Infant	Foetus	Adult	Child	Infant	Foetus
Total tritium	0.01	0.02	0.06	0.02	0.008	0.01	0.004	0.01	<0.001	<0.001	<0.001	<0.001	0.002	0.002	<0.001	0.004
Carbon-14 ^b	0.03	0.05	0.12	0.05	-	-	-	-	-	-	-	-	-	-	-	-
Cobalt-60	-	-	-	-	0.003	0.01	0.005	0.002	<0.001	<0.001	<0.001	<0.001	0.002	0.003	0.001	<0.001
Strontium-90	0.09	0.22	0.36	0.13	0.02	0.04	0.01	0.03	0.004	0.005	0.002	0.006	0.01	0.01	0.003	0.01
Technetium-99	-	-	-	-	<0.001	0.002	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Ruthenium-106 ^c	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Antimony-125	0.01	0.02	0.08	0.004	0.002	0.004	0.003	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	0.001	<0.001	<0.001
Iodine-129	0.10	0.21	0.29	0.04	0.03	0.06	0.01	0.01	0.006	0.006	0.002	0.002	0.02	0.02	0.004	0.007
Iodine-131	0.001	0.004	0.02	0.001	-	-	-	-	-	-	-	-	-	-	-	-
Caesium-134	-	-	-	-	0.02	0.01	0.003	0.009	0.002	<0.001	<0.001	<0.001	0.01	0.004	<0.001	0.005
Caesium-137	0.10	0.09	0.12	0.04	0.04	0.03	0.006	0.02	0.003	0.001	<0.001	0.001	0.23	0.09	0.02	0.10
Plutonium-alpha	-	-	-	-	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Plutonium-241	-	-	-	-	0.02	0.02	0.004	<0.001	0.003	0.002	<0.001	<0.001	0.008	0.004	0.001	<0.001
Americium-241	-	-	-	-	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Total	0.34	0.62	1.1	0.29	0.15	0.19	0.05	0.09	0.03	0.02	0.01	0.02	0.29	0.14	0.04	0.13

Radionuclide	Sheep Offal				Poultry				Eggs				Game			
	Adult	Child	Infant	Foetus	Adult	Child	Infant	Foetus	Adult	Child	Infant	Foetus	Adult	Child	Infant	Foetus
Total tritium	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	0.001	0.002	0.002	0.004	0.004	0.003	0.002	0.001	0.004
Carbon-14 ^b	0.009	0.006	0.004	0.01	-	-	-	-	-	-	-	-	0.01	0.01	0.004	0.01
Cobalt-60	<0.001	<0.001	<0.001	<0.001	0.002	0.004	0.004	0.001	0.001	0.003	0.005	<0.001	0.002	0.003	0.002	<0.001
Strontium-90	0.004	0.005	0.002	0.006	0.02	0.02	0.009	0.02	0.01	0.02	0.02	0.02	0.009	0.01	0.004	0.01
Technetium-99	<0.001	<0.001	<0.001	<0.001	0.001	0.002	0.002	<0.001	-	-	-	-	<0.001	<0.001	<0.001	<0.001
Ruthenium-106 ^c	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Antimony-125	<0.001	<0.001	<0.001	<0.001	0.001	0.002	0.002	<0.001	<0.001	0.001	0.003	<0.001	<0.001	0.001	<0.001	<0.001
Iodine-129	0.006	0.006	0.002	0.002	0.07	0.06	0.03	0.03	0.03	0.04	0.03	0.01	0.02	0.03	0.006	0.009
Iodine-131	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Caesium-134	0.003	0.001	<0.001	0.001	0.01	0.004	0.002	0.004	0.008	0.005	0.004	0.004	0.009	0.004	0.001	0.004
Caesium-137	0.03	0.01	0.004	0.01	0.01	0.005	0.002	0.005	0.004	0.003	0.002	0.002	0.21	0.11	0.03	0.09
Plutonium-alpha	0.005	0.003	0.002	<0.001	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Plutonium-241	0.004	0.002	<0.001	<0.001	0.02	0.01	0.004	<0.001	0.009	0.007	0.006	<0.001	0.009	0.006	0.001	<0.001
Americium-241	0.004	0.003	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Total	0.07	0.04	0.02	0.04	0.14	0.11	0.06	0.07	0.07	0.08	0.08	0.05	0.28	0.18	0.05	0.13

Radionuclide	Honey				Mushroom				Potato				Root Vegetables			
	Adult	Child	Infant	Foetus	Adult	Child	Infant	Foetus	Adult	Child	Infant	Foetus	Adult	Child	Infant	Foetus
Total tritium	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.01	0.01	0.01	0.02	0.001	0.001	0.002	0.002
Carbon-14 ^b	0.01	0.01	0.03	0.02	0.01	0.008	0.007	0.02	0.05	0.04	0.04	0.06	0.04	0.04	0.06	0.06
Cobalt-60	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.02	0.04	0.04	0.009	0.002	0.004	0.008	0.001
Strontium-90	0.003	0.005	0.007	0.005	0.005	0.005	0.003	0.007	0.11	0.17	0.10	0.17	0.04	0.05	0.06	0.06
Technetium-99	-	-	-	-	-	-	-	-	-	-	-	-	<0.001	<0.001	0.002	<0.001
Ruthenium-106 ^c	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Antimony-125	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.02	0.02	0.03	0.007	0.001	0.002	0.004	<0.001
Iodine-129	0.006	0.008	0.009	0.002	0.007	0.006	0.003	0.003	0.26	0.32	0.15	0.11	0.03	0.03	0.03	0.01
Iodine-131	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Caesium-134	0.001	<0.001	<0.001	<0.001	0.002	<0.001	<0.001	0.001	0.14	0.07	0.03	0.06	0.01	0.006	0.006	0.006
Caesium-137	0.002	0.001	0.001	<0.01	0.02	0.006	0.003	0.007	0.14	0.08	0.04	0.06	0.01	0.005	0.005	0.005
Plutonium-alpha	<0.001	<0.001	<0.001	<0.001	0.02	0.009	0.006	<0.001	0.02	0.02	0.01	<0.001	-	-	-	-
Plutonium-241	0.003	0.003	0.003	<0.001	0.003	0.002	<0.001	<0.001	0.21	0.16	0.07	0.005	-	-	-	-
Americium-241	<0.001	<0.001	<0.001	<0.001	0.02	0.01	0.009	<0.001	0.01	0.01	0.008	<0.001	-	-	-	-
Total	0.03	0.03	0.06	0.04	0.09	0.05	0.04	0.05	0.99	0.94	0.53	0.50	0.14	0.14	0.18	0.15

Radionuclide	Green Vegetables				Domestic Fruit				Wild Fruit				Legumes			
	Adult	Child	Infant	Foetus	Adult	Child	Infant	Foetus	Adult	Child	Infant	Foetus	Adult	Child	Infant	Foetus
Total tritium	0.001	<0.001	<0.001	0.002	0.009	0.008	0.01	0.01	0.001	<0.001	<0.001	0.002	0.002	<0.001	<0.001	0.003
Carbon-14 ^b	0.05	0.03	0.03	0.07	0.33	0.31	0.43	0.46	0.05	0.03	0.02	0.07	-	-	-	-
Cobalt-60	0.004	0.006	0.008	0.002	0.03	0.06	0.10	0.02	0.002	0.003	0.002	0.001	0.004	0.005	0.005	0.002
Strontium-90	0.04	0.03	0.03	0.06	0.20	0.29	0.28	0.30	0.03	0.03	0.01	0.05	0.20	0.17	0.09	0.30
Technetium-99	-	-	-	-	-	-	-	-	<0.001	<0.001	<0.001	<0.001	-	-	-	-
Ruthenium-106 ^c	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Antimony-125	0.002	0.002	0.003	<0.001	0.02	0.02	0.04	0.007	0.001	0.001	0.001	<0.001	0.002	0.002	0.002	0.001
Iodine-129	0.04	0.03	0.02	0.02	0.33	0.38	0.31	0.13	0.05	0.03	0.01	0.02	0.13	0.09	0.04	0.05
Iodine-131	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Caesium-134	0.02	0.006	0.004	0.009	0.10	0.05	0.04	0.05	0.01	0.004	0.001	0.005	0.02	0.007	0.003	0.01
Caesium-137	0.01	0.004	0.003	0.005	0.08	0.04	0.04	0.04	0.01	0.004	0.002	0.006	0.02	0.005	0.002	0.007
Plutonium-alpha	<0.001	<0.001	<0.001	<0.001	0.01	0.007	0.008	<0.001	0.005	0.002	0.001	<0.001	0.002	<0.001	<0.001	<0.001
Plutonium-241	0.01	0.006	0.004	<0.001	0.03	0.02	0.02	<0.001	0.007	0.003	0.001	<0.001	-	-	-	-
Americium-241	<0.001	<0.001	<0.001	<0.001	0.02	0.01	0.01	<0.001	0.006	0.003	0.002	<0.001	0.003	0.001	<0.001	<0.001
Total	0.18	0.12	0.11	0.17	1.2	1.2	1.3	1.0	0.17	0.11	0.05	0.16	0.38	0.28	0.15	0.38

Radionuclide	Drinking water				Inhalation			
	Adult	Child	Infant	Foetus	Adult	Child	Infant	Foetus
Total tritium	0.09	0.08	0.12	0.14	-	-	-	-
Carbon-14 ^b	-	-	-	-	-	-	-	-
Cobalt-60	-	-	-	-	-	-	-	-
Strontium-90	0.04	0.05	0.05	0.06	0.003	0.002	0.002	<0.001
Technetium-99	-	-	-	-	-	-	-	-
Ruthenium-106 ^c	-	-	-	-	0.009	0.008	0.007	<0.001
Antimony-125	-	-	-	-	0.001	<0.001	<0.001	<0.001
Iodine-129	-	-	-	-	-	-	-	-
Iodine-131	-	-	-	-	-	-	-	-
Caesium-134	-	-	-	-	<0.001	<0.001	<0.001	<0.001
Caesium-137	0.04	0.02	0.01	0.02	<0.001	<0.001	<0.001	<0.001
Plutonium-alpha	0.05	0.03	0.03	0.002	0.41	0.22	0.12	0.008
Plutonium-241	-	-	-	-	0.24	0.12	0.05	0.003
Americium-241	0.16	0.10	0.13	0.002	0.35	0.19	0.11	0.002
Total	0.38	0.28	0.34	0.22	1.0	0.54	0.29	0.02

a. Values in pale blue boxes have been calculated using FSA monitoring data.

b. Calculated using background corrected activity concentrations (see Monitoring chapter, paragraph 24).

c. Derived from standard modelling techniques.

Table B11. Summary of radionuclide doses to the terrestrial critical group from terrestrial pathways and inhalation, 2016

Radionuclide	Total dose per radionuclide (µSv)			
	Adult	Child	Infant	Foetus
Total tritium	0.14	0.14	0.22	0.23
Carbon-14 ^a	0.59	0.53	0.75	0.83
Cobalt-60	0.08	0.15	0.18	0.05
Strontium-90	0.84	1.1	1.0	1.2
Technetium-99	0.008	0.01	0.01	0.008
Ruthenium-106 ^b	0.03	0.02	0.02	0.02
Antimony-125	0.07	0.08	0.18	0.03
Iodine-129	1.1	1.3	0.95	0.46
Iodine-131	0.001	0.004	0.02	0.001
Caesium-134	0.37	0.18	0.10	0.17
Caesium-137	0.96	0.51	0.29	0.42
Plutonium-alpha	0.53	0.30	0.19	0.02
Plutonium-241	0.58	0.37	0.17	0.02
Americium-241	0.58	0.34	0.28	0.02
Total	5.9	5.1	4.4	3.5

a. Calculated using background corrected activity concentrations

b. Derived from standard modelling techniques.

Table B12. Summary of doses to the terrestrial critical group from seafood consumption (µSv) in 2016

Radionuclide	Adult	Child	Infant	Foetus
Carbon-14 ^a	0.47	0.13	0.07	0.65
Technetium-99	0.01	0.005	0.004	0.008
Ruthenium-106	0.02	0.01	0.009	0.001
Caesium-137	0.55	0.08	0.03	0.24
Plutonium-alpha	0.03	0.006	0.003	0.001
Americium-241	0.05	0.01	0.004	0.0006
Total	1.1	0.25	0.11	0.90

a. Calculated using background corrected activity concentrations.

Figure B1. Technetium-99 in *Fucus vesiculosus* at Nethertown

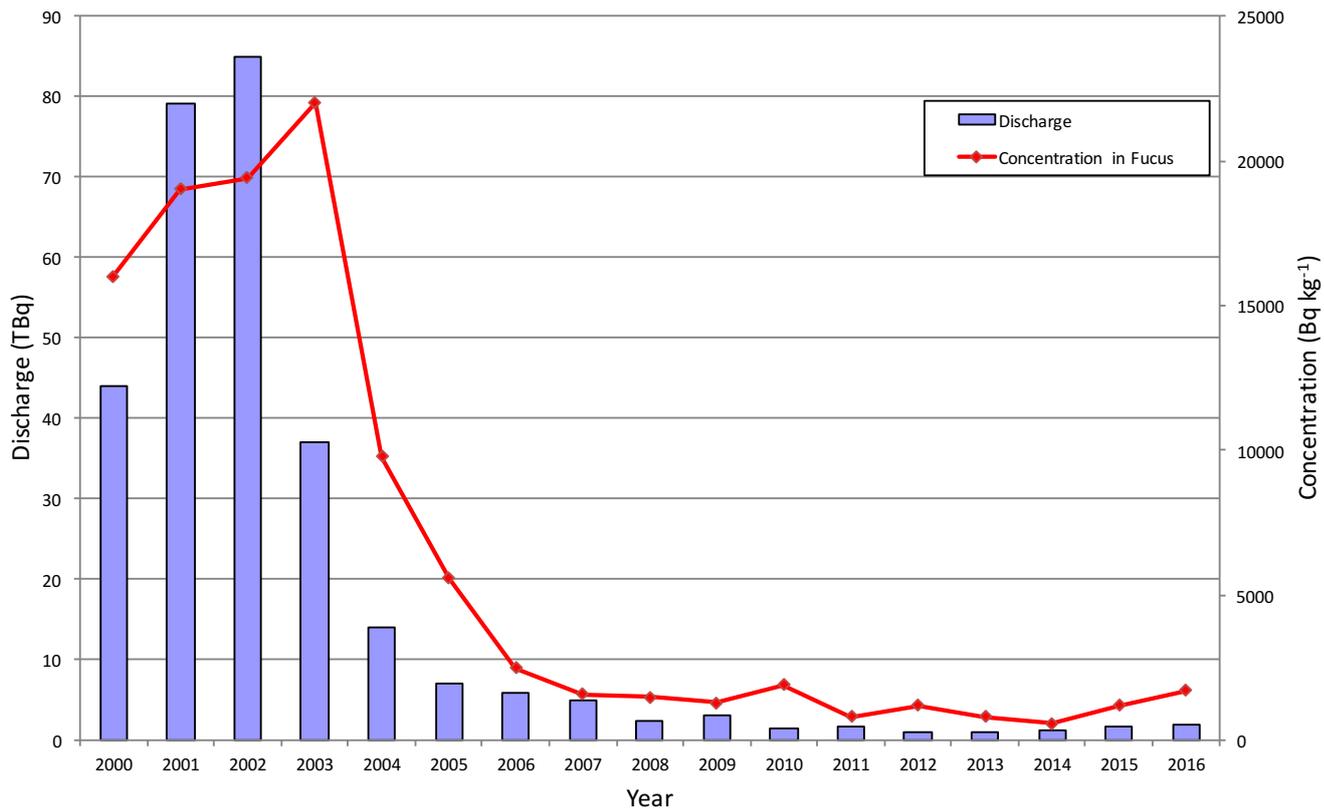


Figure B2. Caesium-137 in seawater filtrate at Sellafeld beach

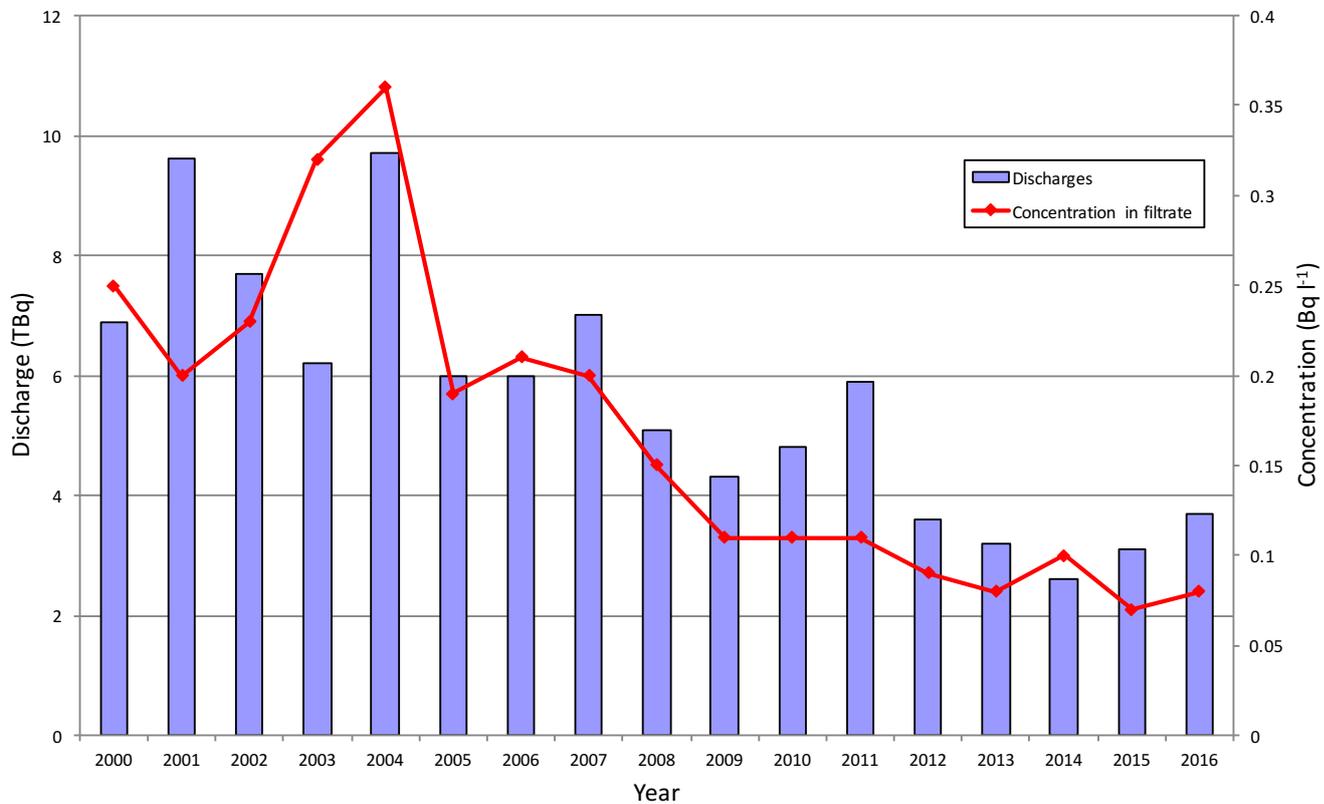


Figure B3. Plutonium-alpha in seawater filtrate at Sellafield beach

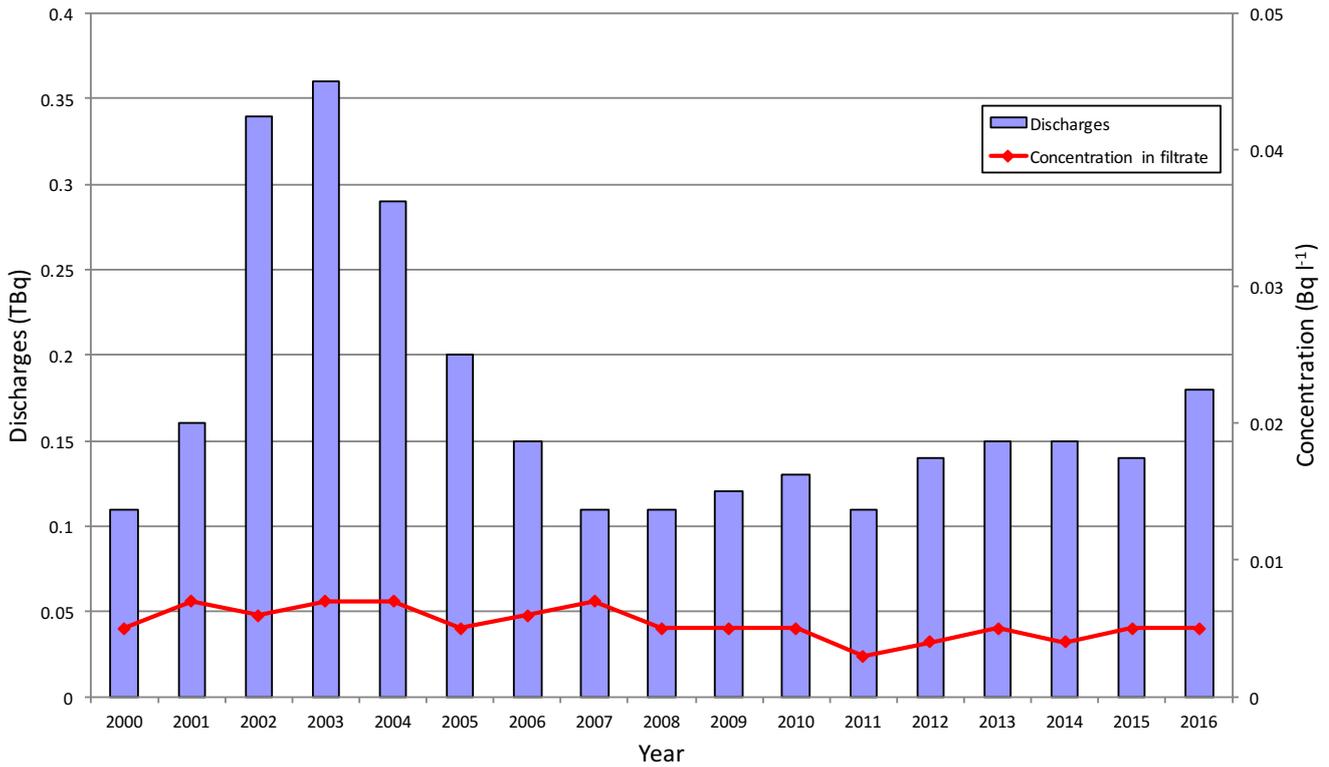
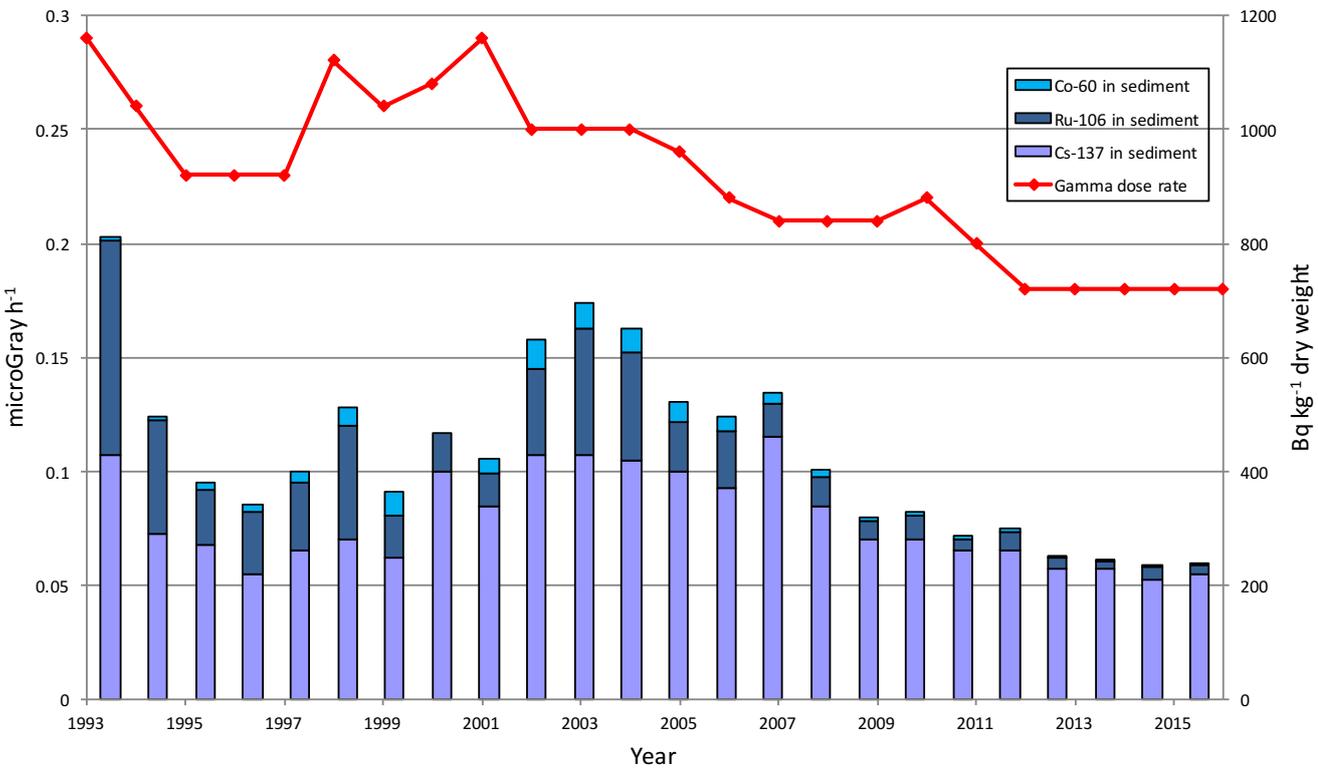


Figure B4. External gamma dose rates at Newbiggin compared to sediment concentrations



Appendix C

Discharges and Environmental Monitoring Annual Report 2016

Representative person dose calculations

Representative person dose calculations

- 1 A Representative Person is defined as an individual receiving a dose that is representative of the more highly exposed individuals in the population¹. This term is the equivalent of, and replaces, 'average member of the critical group' described in previous ICRP Recommendations.
- 2 The Representative Person approach is applied in the Radioactivity in Food and the Environment (RIFE) series of publications. This approach applies habit data, collected by CEFAS through surveys of the local population, to identify realistic profiles of foodstuff consumption and occupancy habits (e.g. time spent over sediment) for groups of individuals in the local population. The profiles are deliberately aligned to the habits and locations where groups of individuals may be expected to receive the highest radiological doses². It should be noted that the dose profiles for 2012 are based on the 2008 comprehensive habit survey³, incorporating annual updates on the consumption of marine foodstuffs and occupancy on intertidal areas. Dose profiles for 2013 onwards are based on the 2013 comprehensive habit survey⁴, again incorporating annual updates. Differences between these baseline habit surveys explain the variability between the results for 2012 and those of subsequent years
- 3 An assessment was conducted for this report applying the RIFE dose profiling methodology using the CEFAS habit data for 2012 - 2016 (as applied in RIFE 18⁵ - RIFE 22⁶). The data for concentrations in foodstuffs, external dose rates and direct shine were taken from the relevant Sellafield Limited Discharges and Environmental Monitoring reports. This assessment of dose profiles therefore differs from that presented in RIFE as it more closely represents the doses attributed to the Sellafield site as it does not include the contributions from naturally occurring radioactivity or from anthropogenic radionuclides released from other industries. The results from the dose profiling can therefore be directly compared with those obtained from the calculations of doses to members of the critical group used in the Sellafield Limited reports.
- 4 It should be noted that, in line with dose calculations applied elsewhere in this report, the representative persons dose calculations assumed that concentrations at the limit of detection (e.g. < 10 Bq kg⁻¹, indicating the range 0 - 10 Bq kg⁻¹) were at the upper limit of this range (i.e. 10 Bq kg⁻¹). The doses therefore represent an upper bound to those that would actually be received by the more highly exposed individuals in the population.
- 5 Doses to adults are shown in Figure C1 and demonstrate that the two highest dose profiles overall were Occupants over Sediment and Mollusc Consumers. Doses in 2016 for Occupants over Sediment were 40 µSv with 87% of this dose being from exposure to external gamma irradiation whilst on sediments and the remainder being mostly from the consumption of marine foodstuffs. Doses to the Mollusc Consumers in 2016 were 83 µSv with 33% of this dose being from external gamma irradiation whilst on sediments. The consumption of molluscs accounted for 40% of the total. The Radiological Impact of Operations at Sellafield section of this report presents the dose to adult members of the marine Critical Group as 57 µSv through marine foodstuff consumption, and a total dose, including exposure on sediments, terrestrial pathways and direct shine as 110 µSv. This demonstrates that the dose assessment methodology applied in the Radiological Impact of Operations at Sellafield section of this report provides a conservative estimate by compounding the impacts of all habits at the highest rates.
- 6 Doses from terrestrial exposure pathways in 2016 to adult representative persons were highest for the profile Local Inhabitants (0-0.25 km). This group received a dose of 9 µSv in total, including 0.4 µSv from marine exposure pathways. The dose that was received was dominated by direct shine from the site (60%), the consumption of locally grown potatoes (15%) and exposure to airborne radioactivity (13%) with other terrestrial foodstuff pathways and exposure to marine sediments accounting for the remainder. The estimated dose to adults in the terrestrial critical group, presented in the Radiological Impact of Operations at Sellafield section of this report, was 16 µSv which is higher than the estimates for the Representative Person and demonstrates that the methodology in the Radiological Impact of Operations at Sellafield section provides conservative results.
- 7 Figure C2 presents the doses to children using the Representative Persons methodology. As found for adults the two highest groups overall were Occupants over Sediment and Mollusc Consumers. The doses received by Representative Persons in the child age group were approximately half those estimated for adults (20 µSv being received by Occupants over Sediment and 30 µSv received by Mollusc Consumers in 2016). Doses to children where terrestrial pathways dominated were highest for Local Inhabitants (0-0.25 km), with a total dose of 9 µSv being estimated for 2016 with 62% due to direct shine. It should be noted that the Representative Persons methodology assumes that adults, children and infants have the same direct shine exposure. The dose to a child member of the terrestrial critical group, detailed in the Radiological Impact of Operations at Sellafield section of this report, was 7 µSv. Although the CEFAS habit data⁴ did not identify any children living close to the site for the sake of completeness an additional 4 µSv due to direct shine from the site could be determined based on infant habit data. The total dose of 11 µSv is in close agreement with that estimated for the representative person (9 µSv), noting the differences in the assumption regarding direct shine exposure, and demonstrates that the methodology in the Radiological Impact of Operations at Sellafield section provides conservative results.
- 8 Figure C3 presents the doses to infants using the Representative Persons methodology. The two highest groups overall were Other Domestic Vegetable Consumers and Local Inhabitants (0-0.25 km). The doses to infants were less than 10 µSv and therefore considerably lower than the doses to adult or child representative persons. Terrestrial pathways dominated for Other Domestic Vegetable Consumers and Local Inhabitants

(0-0.25 km) with total doses of 7 μ Sv and 8 μ Sv, respectively, being received in 2016. The dose assessment in the Radiological Impact of Operations at Sellafield section of this report calculated a dose to infant members of the terrestrial critical group of 5 μ Sv with an additional 4 μ Sv being calculated from direct shine from the site based on CEFAS habit data⁴. The doses from the different methodologies are in close agreement, noting the differences in the assumption regarding direct shine exposure, although demonstrate that the methodology in the Radiological Impact of Operations at Sellafield section provides conservative results.

9 In conclusion, the Representative Persons methodology, as applied in the RIFE series of reports, provides realistic estimates of peak doses to the most exposed individuals in the population and the Critical Group approach applied by Sellafield Ltd is more conservative. There is therefore no requirement to modify the Critical Group methodology applied in this report for determining radiological doses to the public.

References

1. International Commission on Radiological Protection (2006). **Assessing dose of the representative person for the purpose of radiation protection of the public and the optimisation of radiological protection: Broadening the process**. ICRP Publication 101. Ann. ICRP 36 (3).
2. Garrod C.J. and Clyne F.J (2017). **Radiological Habits Survey: Sellafield Review**. RL 03/17. Cefas Lowestoft.
3. Clyne F.J., Tipple J.R., Garrod C.J. and Jeffs T.M.(2009). **Radiological Habits Survey: Sellafield, 2008**. RL 02/09. Cefas Lowestoft.
4. Clyne F.J., Garrod C.J. and Papworth G.P.(2014). **Radiological Habits Survey: Sellafield, 2013**. RL 02/14. Cefas Lowestoft.
5. Environment Agency, Food Standards Agency, Food Standards Scotland, Natural Resources Wales, Northern Ireland Environment Agency and Scottish Environment Protection Agency (2013). **Radioactivity in food and the environment, 2012**. RIFE-18. EA, FSA, FSS, NRW, NIEA and SEPA; Preston, London, Aberdeen, Cardiff, Belfast and Stirling.
6. Environment Agency, Food Standards Agency, Food Standards Scotland, Natural Resources Wales, Northern Ireland Environment Agency and Scottish Environment Protection Agency (2017). **Radioactivity in food and the environment, 2016**. RIFE-22. EA, FSA, FSS, NRW, NIEA and SEPA; Preston, London, Aberdeen, Cardiff, Belfast and Stirling.

Figure C1: Radiological doses to adult representative persons (2012-2016).

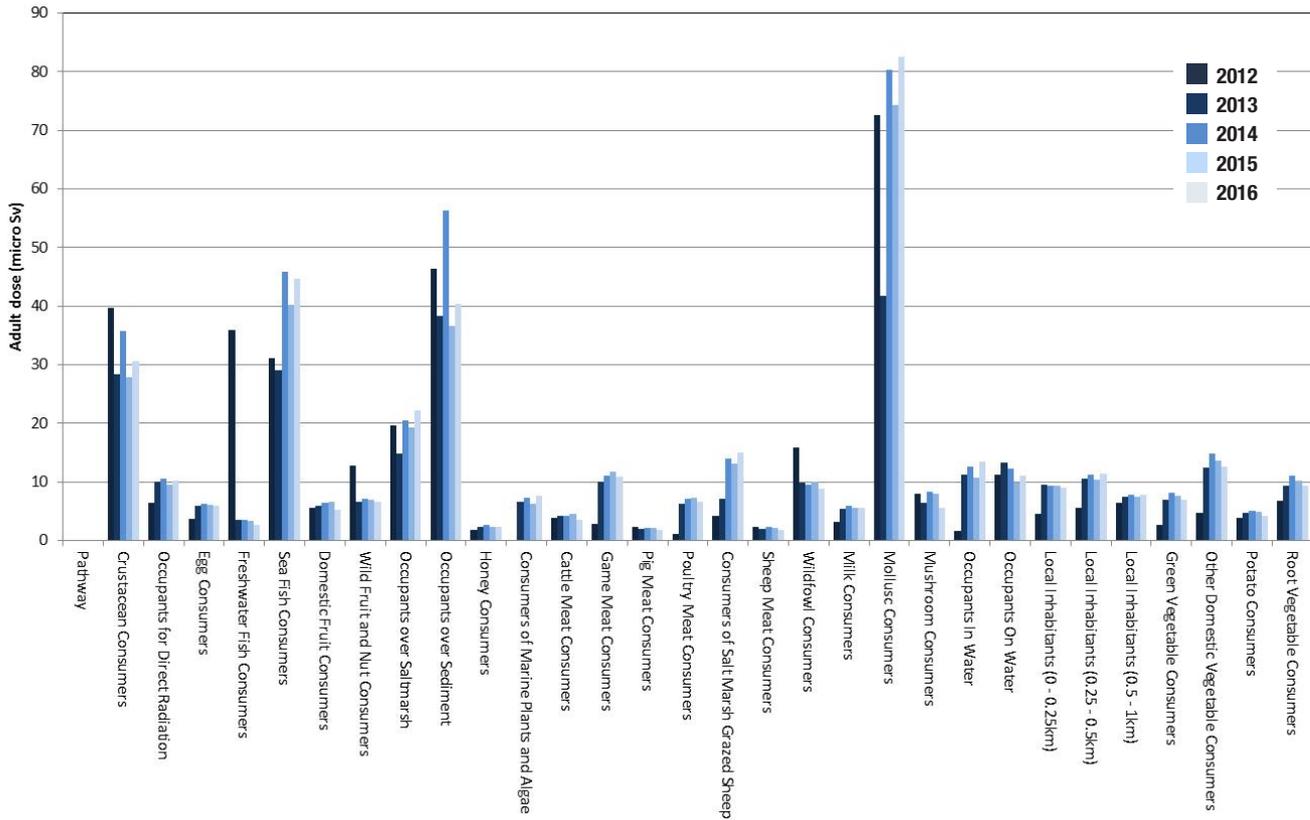


Figure C2: Radiological doses to child representative persons (2012-2016).

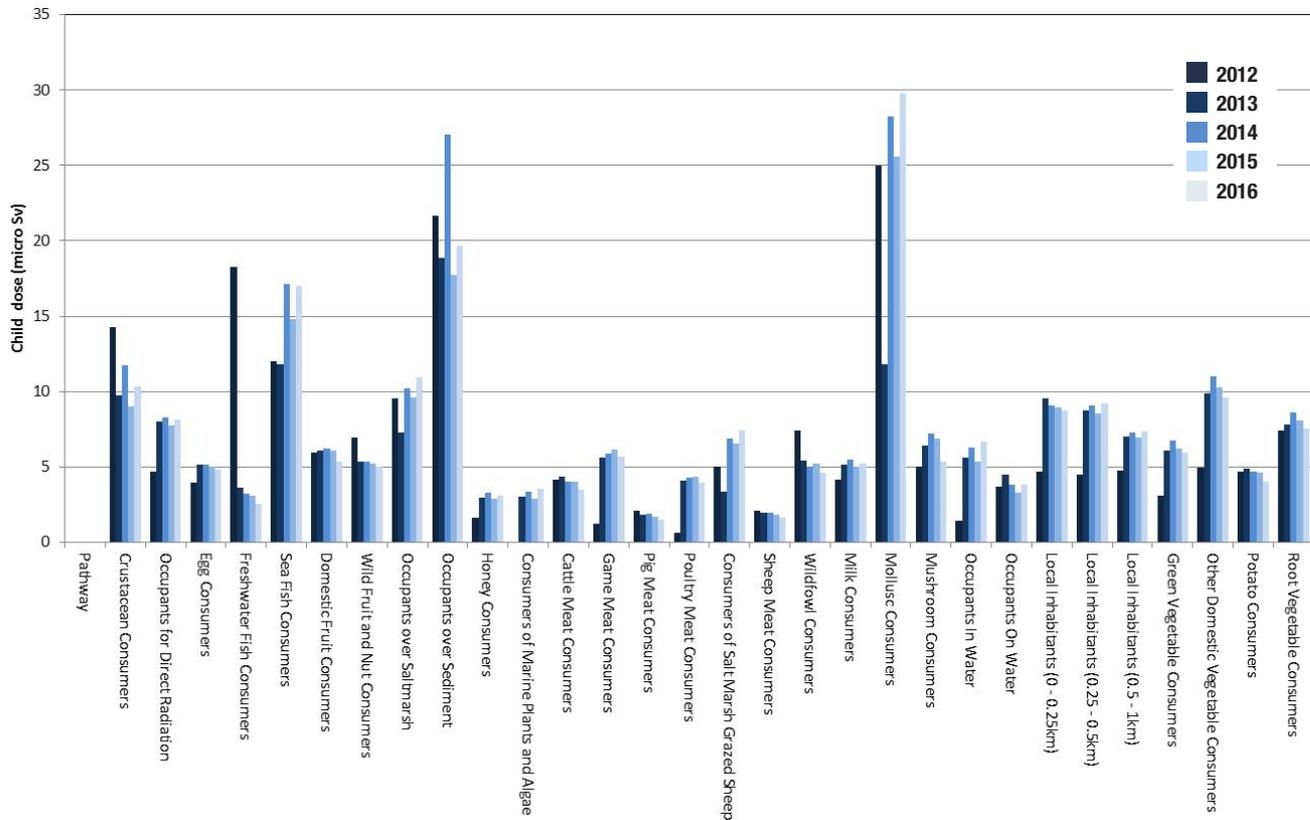
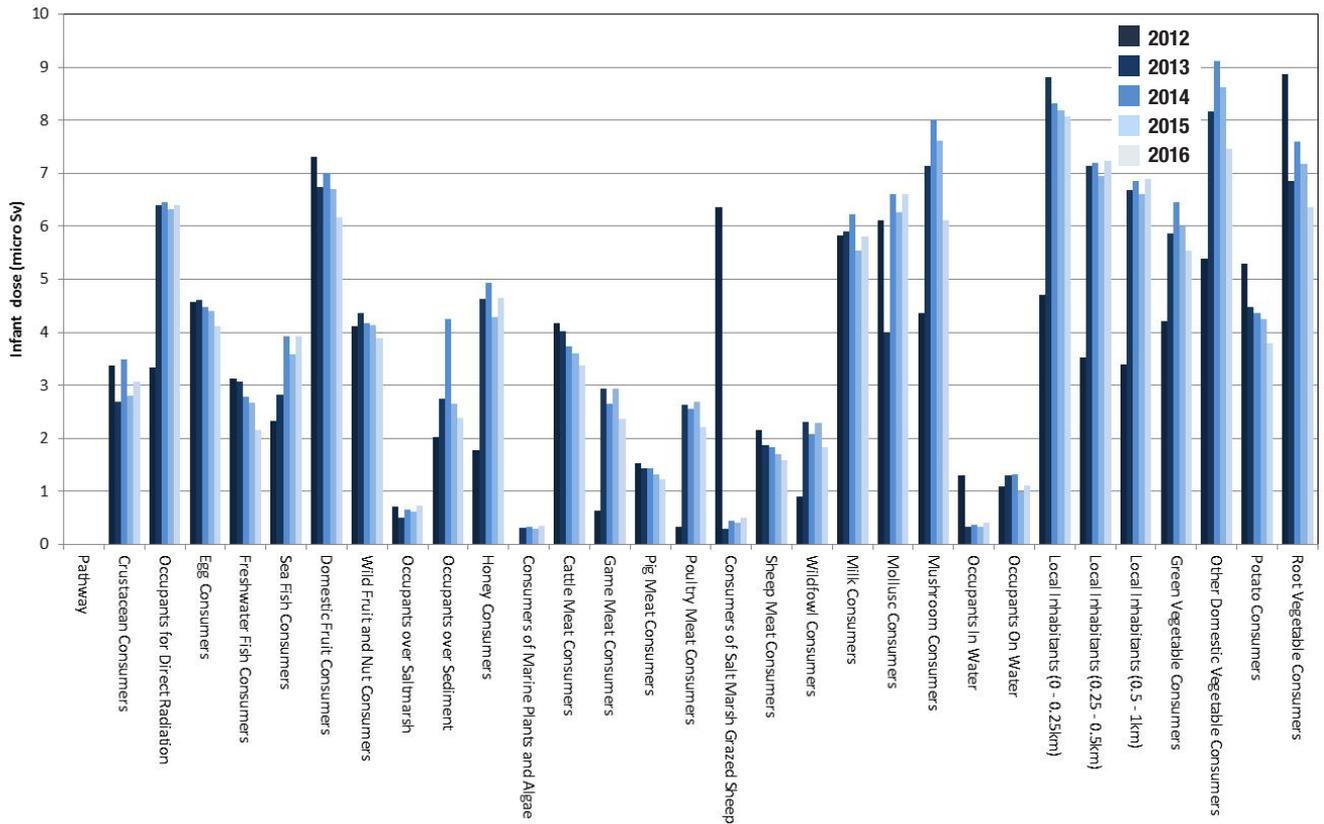


Figure C3: Radiological doses to infant representative persons (2012-2016).



Glossary

Discharges and Environmental Monitoring
Annual Report 2016

Glossary of terms and abbreviations

Absorbed radiation dose Quantity of energy imparted by ionising radiation to unit mass of matter such as tissue. The unit is the Gray (Gy). 1 Gy = 1 joule per kilogram.

Activation products Radionuclides produced by the interaction of neutrons with stable nuclides.

Activity See *radioactivity*.

Alpha activity Radionuclides that decay by emitting an alpha particle. The latter consists of two protons and two neutrons.

ALARA (As Low as Reasonably Achievable) Radiation doses from a source of exposure are ALARA when they are consistent with the relevant dose or target standard and have been reduced to a level that represents a balance between radiological and other factors, including social and economic. The level of protection may then be said to be optimised.

Authorisation Permission given by regulatory authority under the *Radioactive Substances Act* or *Environmental Protection Act* to dispose of respectively radioactive and non-radioactive waste, subject to conditions.

Basic Safety Standards Directive (BSS) European Community Directive 80/836/Euratom, Basic Safety Standards for the Health Protection of the General Public and Workers against the Dangers of Ionising Radiation. These standards were adopted as European Law in 1980. A revised Directive 96/29/Euratom was adopted in May 1996 for implementation in Member States by May 2000. The Radioactive Substances (Basic Safety Standards) Direction 2000 is the means by which the BSS Directive has been implemented in England and Wales, and in Scotland, with respect to the *Radioactive Substances Act 1993*. Other provisions of the BSS Directive were implemented through the *Ionising Radiation Regulations 1999*.

Becquerel The SI unit of *radioactivity* equal to one transformation per second.

BAT (Best Available Technique) “*Best*” – means the most effective techniques for achieving a high level of protection of the environment as a whole. “*Available*” – means techniques developed on a scale which allows them to be used in the relevant industrial sector, under economically and technically viable conditions, taking into account of the costs and advantages. “*Techniques*” – includes both the technology and the way the installation is designed, built, maintained, operated and decommissioned. Application of BAT is central to PPC compliance and guidance on what constitutes BAT is provided by the EA.

Beta activity Radionuclides that decay by emitting a beta particle (an electron with high energy).

Cefas The Centre for Environment, Fisheries and Aquaculture Science is a scientific research and advisory centre for fisheries management and environmental protection. It is an Agency of the UK Government’s *Department for Environment, Food and Rural Affairs (Defra)*. It was formed in 1997 from the Fisheries Research Laboratory of MAFF and its Lowestoft laboratory carries out habit surveys and monitoring of radioactivity in the environment on behalf of the *Food Standards Agency*.

Collective dose See *dose*.

Committed effective dose See *dose*.

Critical group A group of members of the public whose radiation exposure is reasonably homogeneous and is typical of the people receiving the highest dose from a radiation source. The critical group dose is calculated as the mean effective dose to members of the group. The average member of the critical group is equivalent to the ‘representative person’.

Defra (Department for Environment, Food and Rural Affairs) Formed in 2001 from *MAFF* and is the environmental section of the Department of Environment, Transport and the Regions (DETR). It is the sponsoring department for the EA, and is responsible inter alia for environmental policy in England, including that for the management and disposal of radioactive wastes.

Direct radiation Term used to refer to radiation direct from a nuclear site as distinct from the radiation emitted from discharged radioactive wastes.

Dose A measure of radiation received, which may be quantified in several different ways. The dose quantities most commonly referred to are defined below. In this document it is used primarily to mean the ‘effective dose’ received by members of critical groups.

Absorbed dose The mean energy imparted by ionising radiation to matter in a given volume divided by the mass of the matter. Normally used in the context of the dose averaged over an organ or tissue. The unit is the Gray (Gy) (see inside front cover).

Equivalent dose The **absorbed dose** in a tissue or organ weighted by the radiation weighting factor (e.g. alpha particles = 20, beta particles = 1, gamma rays = 1) which allows for the different effectiveness of various types of ionising radiations in causing harm to tissues. The unit is the Sievert (Sv) (see inside front cover).

Effective dose The sum of the **equivalent doses** in all tissues and organs of the body from internal and external radiation multiplied by the tissue weighting factor (e.g. skin = 0.01, thyroid = 0.05, red bone marrow = 0.12, gonads = 0.20). It allows the various equivalent doses in the body to be represented by a single number giving a broad indication of the detriment to the health of an individual from exposure to ionising radiation, regardless of the energy and type of radiation. For comparison with dose limits, the term takes on a specific meaning (see below).

Committed effective dose The time integral of the **effective dose** from ingested and inhaled radioactivity delivered over 50 years (adults, who are cautiously assumed to be 20 years old at the time of intake) or to age 70 years (children). For a particular radionuclide, it is a function of the distribution within and clearance from the body and also the radioactive **half-life**. For radionuclides which are cleared quickly from the body (e.g. caesium-137) or which have a short **half-life** (e.g. sulphur-35), most of the committed effective dose is delivered in the year in which the intake of **activity** took place. For others, such as plutonium, the committed dose is delivered over the remaining lifetime of the individual and so the dose in the year of intake is much lower than the committed dose.

Effective dose (definition used for calculation of critical group doses and for comparison with dose limits)

The overall annual effective dose is the sum of **committed effective doses** from intakes of radionuclides in a given year and the effective dose from external irradiation in that year. It is this quantity that should be compared with the annual limit on effective dose (**dose limit**).

Collective dose The summation of individual effective doses received by the population of a defined geographical area over a defined period of time. A 500 year integration period is used in this report (see paragraph 20 of Appendix A). The unit is the man sievert (man Sv).

Dose constraint A restriction on annual dose to an individual from a single source, applied at the design and planning stage of any activity in order to ensure that when aggregated with doses from all sources, excluding natural background and medical procedures, the dose limit is not exceeded.

Dose limit For the purpose of discharge authorisations, since 1986 the UK has applied a dose limit of 1 mSv (1000 µSv) per annum to members of the public from all man-made sources of radiation (other than medical exposure). This limit is now incorporated into UK law (see **Basic Safety Standards Directive**).

EA (Environment Agency) The leading public body for protecting and improving the environment in England and Wales (see **Defra**).

Effective dose See **dose**.

Environment Act 1995 The legislation giving the EA its powers, aims and objectives.

Environmental Permitting (England and Wales) Regulations (2016) The Environmental Permitting (England and Wales) Regulations 2016 extend the permitting regime introduced in 2010 which included water discharge consents, groundwater permits and radioactive substances regulations.

Equivalent dose See **dose**.

Fission products Nuclear fission is the splitting of a heavy atomic nucleus such as uranium into (usually) two nuclei, either spontaneously or under the impact of another particle, with resulting increase of energy. The two nuclei are called fission products.

Fluorinated Greenhouse Gases Fluorinated greenhouse gases are powerful greenhouse gases that trap heat in the atmosphere and contribute to global warming. The most commonly used fluorinated greenhouse gases belong to a class of chemicals known as hydrofluorocarbons (HFCs) and are being used to replace ozone depleting substances, an example being refrigeration and air conditioning equipment.

Food Standards Agency Formed in April 2000 from parts of **MAFF** and the Department of Health. It is responsible for food safety issues in the UK. Although it is a Government agency it does not report to a specific minister and is free to publish any advice it issues. It is accountable to Parliament through Health Ministers and to the devolved administrations in Scotland, Wales and Northern Ireland for its activities within their respective areas.

Gray The SI unit of absorbed **dose**.

Half-life (radioactive) The time taken for the radioactivity of a radionuclide to decrease to one half of its initial value by radioactive decay. Half-lives range from fractions of a second to millions of years.

Half-life (biological) The effective half-life in the human body of a quantity of ingested radioactivity is a function of the radioactive half-life and biokinetic behaviour.

High Level Waste (HLW) Waste that is sufficiently radioactive that the generation of heat needs to be taken into account in the design of disposal or storage facilities.

HPA (Health Protection Agency) A non-departmental public body established in 2003 to provide an integrated approach to protecting UK public health. Merged with the NRPB on 1 April 2005 to form the HPA Radiation Protection Division. Became part of **Public Health England** on 1 April 2013.

Intermediate Level Waste (ILW) Waste with radioactivity levels exceeding the upper boundaries for low level waste but which does not require heat generation by the waste to be accounted for in the design of disposal or storage facilities.

ICRP International Commission on Radiological Protection. An independent group of experts founded in 1928 which provides guidance on principles and criteria in the field of radiological protection. The recommendations are not legally binding but are accepted as the basis for national legislation in most countries including the UK.

Ionising Radiation Regulations 1999 (IRRs 1999) These regulations under the Health and Safety at Work Act 1974 in part implement the European **Basic Safety Standards Directive of 1996**.

Low level waste (LLW) Waste containing levels of radioactivity greater than those acceptable for dustbin disposal but not exceeding 4 GBq per tonne of alpha-emitting radionuclides or 12 GBq per tonne of beta-emitting radionuclides.

LLWR The UK's national low level radioactive waste facility, located close to the West Cumbrian coastline in the north-west of England.

MAFF (Ministry of Agriculture, Fisheries and Food) Superseded by **Defra**. MAFF's statutory responsibilities for food safety issues in the UK have been passed to the **Food Standards Agency**.

Magnox A magnesium/aluminium alloy that is used in the manufacture of the canister for uranium fuel metal ('Magnox fuel') used in a type of nuclear reactor ('Magnox reactor').

National Dose Assessment Working Group (NDAWG) Publishes guidance on the assessment of public dose from past, present and future discharges and direct radiation from the nuclear industry and minor users of radioactivity. Membership comprises UK Government agency, nuclear industry and independent experts.

NDA (Nuclear Decommissioning Authority) The public body set up in 2005, tasked by Her Majesty's Government with taking strategic responsibility for the decommissioning of civil public sector nuclear sites in the UK. The NDA owns the 20 nuclear legacy sites in the UK including the operating and decommissioning plants at Sellafield in West Cumbria. The NDA does not carry out the operations or clean-up work itself but places contracts with Sellafield Ltd who are responsible for operations on site.

NIEA Northern Ireland Environment Agency

NNL National Nuclear Laboratory

NRPB (National Radiological Protection Board)

Merged with the **Health Protection Agency** on 1 April 2005 forming its new Radiation Protection Division. An independent statutory body set up by the Radiological Protection Act 1970 to advance the acquisition of knowledge about the protection of mankind from radiation hazards and to provide information and advice on matters relating to radiological protection and radiation hazards, including the interpretation of **ICRP** recommendations.

NRW Natural Resources Wales

ONR (Office for Nuclear Regulation) Part of the Health and Safety Executive. It is responsible for enforcing legislation relating to nuclear safety under the Nuclear Installations Act 1965.

OSPAR Convention The Oslo Paris Convention. Contracting parties (including the UK) have signed up to deliver the North-East Atlantic Environment Strategy which includes the OSPAR Radioactive Substances Strategy. This includes a strategic objective, with regard to radioactive substances, to prevent pollution of the OSPAR maritime area from ionising radiation. The Radioactive Substances strategy includes numerous different elements, relating to discharges, concentrations and application of BAT.

Ozone Depleting Substances (ODS) Substances that, if allowed to escape, damage the ozone layer in the upper atmosphere. Ozone depleting substances include chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs). Many ODS are banned or are being phased out by the **Fluorinated Greenhouse Gases Regulations 2009**.

PHE (Public Health England) An executive agency of the Department of Health established 1 April 2013 to bring together public health specialists, including those in the **Health Protection Agency**, to form a single organisation tasked with public health protection. PHE's Centre for Radiation, Chemical and Environmental Hazards provides expert advice on all aspects of radiological protection.

PPC Pollution Prevention and Control Regulations 2000.

Quarterly Notification Level (QNL) Quarterly discharge or disposal levels that the **EA** may specify in **RSA** authorisations. They enable the application of **BAT** to be monitored by the EA. Exceeding a QNL requires the operator to submit a written justification of the BPM used to limit discharges.

Radioactive Substances Act (RSA) 1960, 1993

Statutory legislation to control the keeping and use of radioactive substances and the accumulation discharge or disposal of **radioactive waste**.

Radioactive waste Material that contains radioactivity above the appropriate levels specified in the **Radioactive Substances Act 1993** and which meets the definition of waste given in the Act.

Radioactivity The spontaneous disintegration of atomic nuclei. Radioactive substances or the radiation they emit (e.g. **alpha** particles, **beta** particles, gamma rays); the rate of radioactive decay. Measured in the standard international (SI) unit, **Becquerels** (Bq) or their multiples or sub-multiples (see inside front cover).

Radionuclide A radioactive isotope of an element.

Representative person An individual receiving a dose that is representative of the more highly exposed individuals in the population. This term is equivalent to 'average member of the critical group'.

SEMP Statutory Environmental Monitoring Programme

SEPA Scottish Environment Protection Agency.

Sievert The SI unit of **equivalent dose and effective dose**.

Thorp (Thermal Oxide Reprocessing Plant) A plant at Sellafield where oxide fuels from Advanced Gas Cooled Reactors and Light Water Reactors have been reprocessed since 1995.

UKAEA United Kingdom Atomic Energy Authority.

Waste hierarchy The waste hierarchy is a useful framework which sets out the order in which options for waste management should be considered, based on environmental impact. The framework is based on trying to avoid the creation of waste in the first instance, if this is not possible then working down the hierarchy trying to minimise, re-use/recycle as much of the waste as possible. The last resort is to dispose of the waste to landfill.

