RIFE - 22

# Radioactivity in Food and the Environment, 2016

Environment Agency

Food Standards Agency food.gov.uk

Food Standards Scotland

Cyfoeth Naturiol Cymru Natural Resources Wales

NIEA Northern Ireland Environment Agency www.daera-ni.gov.uk

SEPA Scottish Environment Protection Agency Buidheann Dìon Àrainneachd na h-Alba

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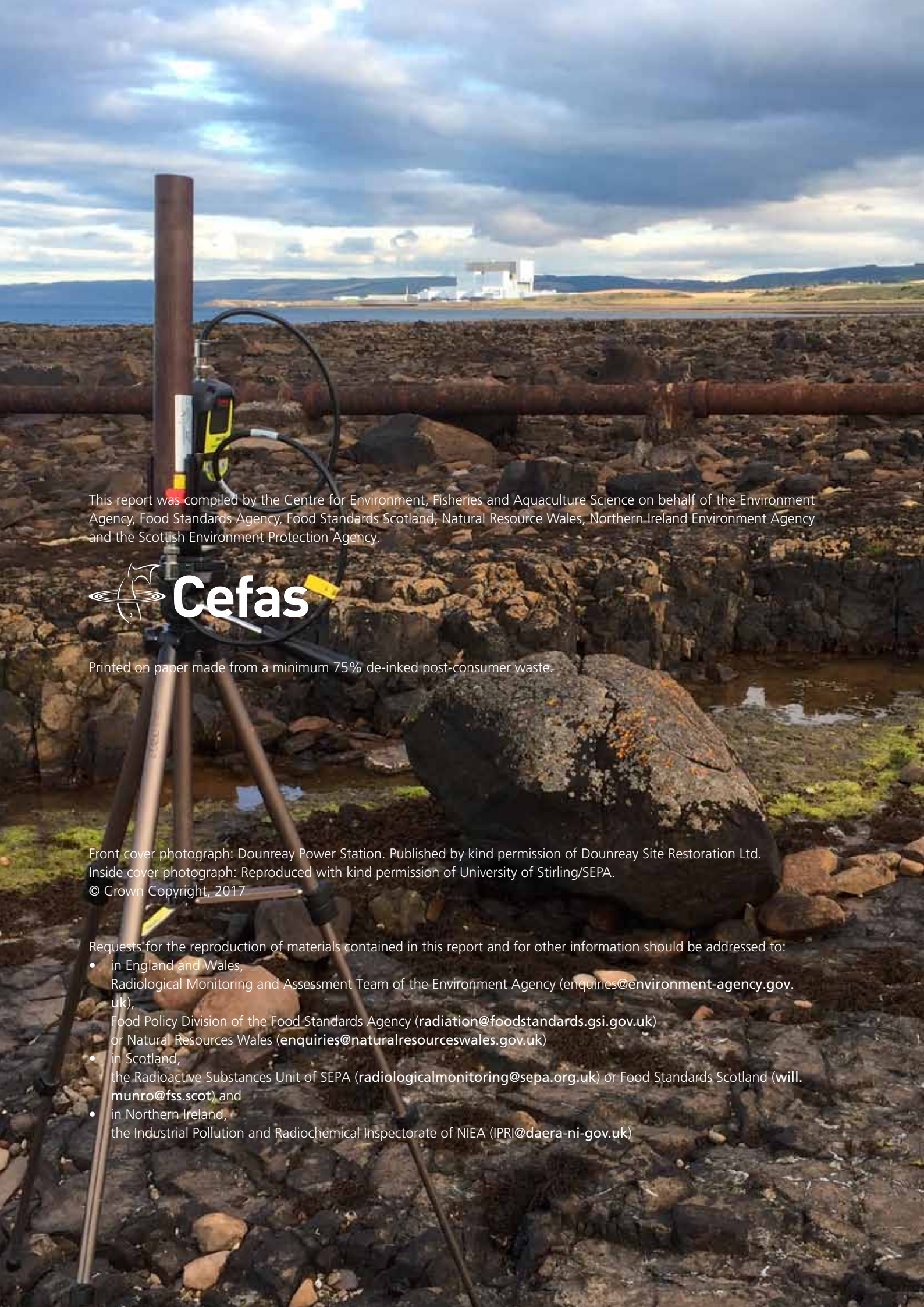
# Radioactivity in Food and the Environment, 2016

## RIFE – 22

October 2017



This report was compiled by the Centre for Environment, Fisheries and Aquaculture Science on behalf of the Environment Agency, Food Standards Agency, Food Standards Scotland, Natural Resource Wales, Northern Ireland Environment Agency and the Scottish Environment Protection Agency.

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  the Radioactive Substances Unit of SEPA (**radiologicalmonitoring@sepa.org.uk**) *or* Food Standards Scotland (**will.munro@fss.scot**) and
- in Northern Ireland,
  the Industrial Pollution and Radiochemical Inspectorate of NIEA (IPRI**@daera-ni-gov.uk**)

# Contents

Page

# List of Tables

# List of Figures

# Preface

This report covers sampling and analysis carried out in 2016 for the UK-wide monitoring programmes of the Food Standards Agency, Environment Agency, Scottish Environment Protection Agency, Food Standards Scotland, Natural Resources Wales and the Northern Ireland Environment Agency. The monitoring programmes conducted by these agencies are independent of, and are also used as a check on, the nuclear site operators' programmes.

This report includes the results of monitoring which continue to take place around Magnox sites as they undergo decommissioning as well as the Advanced Gas Cooled Reactors and Pressurised Water Reactor which continue to generate power. This report also includes monitoring at sites involved in nuclear fuel production and reprocessing, research establishments, defence establishments, radiochemical production, legacy sites and certain industrial and landfill sites.

The results of these monitoring programmes are used to assess the dose received by members of the public in the vicinity of nuclear licensed sites and industrial and landfill sites. These dose assessments utilize information on diets and occupancy habits of people living near nuclear licensed sites gathered during habit surveys. In 2016, habit surveys were carried out in Heysham, Amersham and Sellafield in England, and at Faslane and Torness in Scotland.

Food in people's general diet and sources of public drinking water were analysed across the UK. Results showed that artificial radionuclides only contributed a small proportion of the total public radiation dose in people's general diet.

During 2016 regulated radioactive waste disposal in England and Wales was carried out under the Environmental Permitting Regulations 2010 (EPR 10). At the beginning of 2017, the Environmental Permitting Regulations (EPR 16) replaced the previous EPR regulations. In Scotland and Northern Ireland, the Radioactive Substances Act 1993 remains the extant legislation.

Decommissioning of many nuclear sites in Great Britain is underway. In 2016, the environment agencies undertook a consultation process on draft guidance on the principles, requirements and regulatory process that will apply to nuclear sites in all stages of decommissioning and clean-up. The aim is to ensure that radioactive waste and contamination is managed in a way that is safe so that nuclear sites may eventually be released from regulation under radioactive substances legislation.

The RIFE report and the associated monitoring programmes conform to the requirements of the Euratom Directive laying down basic safety standards for protection against the dangers arising from exposure to ionising radiation. Specifically, it provides estimates of doses to members of the public from authorised practices and enables such results to be made available to stakeholders. BEIS has overall UK Government policy lead responsibility for the EU Basic Safety Standards Directive. The new Basic Safety Standards Directive (BSSD) consolidates and updates existing Euratom provisions for protection against the harmful effects of ionising radiation by replacing five existing Directives and a Commission Recommendation. It covers standards for public exposure as well as those for occupational and medical exposures. Euratom member states are required to transpose the revised directive into domestic law by the 6 February 2018. Most of the requirements in the new directive for the public exposure resulting from radioactive waste disposal are already implemented in UK law. However some changes to the Environmental Permitting Regulations 2016 covering England and Wales, and equivalent legislation in Scotland and Northern Ireland, may be needed and BEIS will be consulting on these in the autumn of 2017.

Following the EU Referendum result to leave the European Union, the UK Government announced its decision to withdraw its membership of the Euratom community. The Euratom Treaty applies to all EU member States and seeks to promote nuclear safety standards, investment and research within those member States. The UK Government is currently reviewing the mechanisms and arrangements needed to ensure the highest standards of nuclear safety and support for the industry are maintained to a similar degree once the UK leaves Euratom.

Radiation doses to people living around nuclear licensed sites from authorised releases of radioactivity were well below the UK national and European limit of 1 millisievert per year in 2016.

# Technical summary

This section is sub-divided into topics to highlight the scope of this report. These are:

- Radiation exposures (doses) to people living around UK nuclear licensed sites
- Radioactivity concentrations in samples collected around UK nuclear licensed sites
- External dose rates measured from around UK nuclear licensed sites
- UK nuclear licensed site incidents and non-routine surveys
- Habits surveys near UK nuclear licensed sites
- Monitoring of radioactivity at other remote locations (overseas incidents, non-nuclear sites and regional monitoring across the UK)
- The environmental radioactivity monitoring programmes

## Radiation exposure (doses) to people living around UK nuclear licensed sites

Doses to people living near nuclear licensed sites are assessed using results obtained from monitoring of radioactivity in food and the environment. Radionuclide concentrations, dose rates, and information on the habits of people living near the sites are used to estimate doses. Some environmental concentrations are derived by modelling of reported discharges, where monitoring data are not available. From year to year, doses to people can vary, mostly because of changes in radionuclide concentrations and external dose rates. Changes in habits data and information, in particular food consumption (reported in habits surveys), can also contribute to the variation in the estimation of dose between years.

The dose quantity presented in this summary is known as the *'total dose'* and is made up of contributions from all sources of radioactivity from man-made processes. Source specific dose assessments are also performed in some cases to provide additional information and as a check on the *total dose* assessment method. *Total dose* is confirmed as a robust measure of exposure.

Figure S and Table S show the assessed *total doses* in 2016 due to the combined effects of authorised/permitted waste discharges and direct radiation for those people most exposed to radiation near all major nuclear licensed sites in the UK.

In this report, the term 'representative person'* is an approach used in the assessment of radiation exposures (*total doses*) to the public. Doses to individuals are determined for those people most exposed to radiation. Using this methodology, doses to the public are estimated using environmental radionuclide concentrations, dose rates and habits data. The estimated doses are compared with dose criteria. In this report, the dose criteria are legal limits for the public. The method used to calculate doses to each hypothetical individual is based on guidance from the National Dose Assessment Working Group (NDAWG). NDAWG guidance proposes development of a series of habits profiles of food consumption and occupancy of people living near nuclear licensed sites. These are derived from the habits survey data. Each habits profile provides information on their respective food consumption and occupancy rates. Doses to each habits profile are calculated and the "representative person" is that profile that receives the highest dose.

In 2016, radiation doses from authorised/permitted releases of radioactivity, to adults and children living around nuclear licensed sites, remained well below the UK national and European† limit of 1 millisievert (mSv, a measure of dose) per year (see Appendix 3 for explanation of dose units).

The locations where the public received the highest doses in 2016 were the same as those in 2015. They were near Sellafield (0.41 mSv), Capenhurst (0.17 mSv) and Amersham (0.15 mSv). The doses received near Capenhurst and Amersham were dominated by direct radiation from sources on the sites.

In 2016, the representative person in the vicinity of the Sellafield site was a high-rate mollusc consumer (who also consumed significant quantities of other seafood). Their dose of 0.41 mSv includes a contribution of 0.34 mSv from the past discharges from the former phosphate

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* *ICRP (2007) recommendations use the term 'representative person' for assessing doses to members of the public. It is defined as 'an individual receiving a dose that is representative of the more highly exposed individuals in the population'. Published RIFE reports (prior to the one for 2013) referred to an average dose to individuals in a group of people 'critical group' rather than to a single person. The 'representative person' concept is considered equivalent to the previously used 'critical group'.*

† *On 23 June 2016, the EU referendum took place and the people of the UK voted to leave the European Union. Until exit negotiations are concluded, the UK remains a full member of the European Union and all the rights and obligations of EU membership remain in force. During this period, the Government will continue to negotiate, implement and apply EU legislation.*

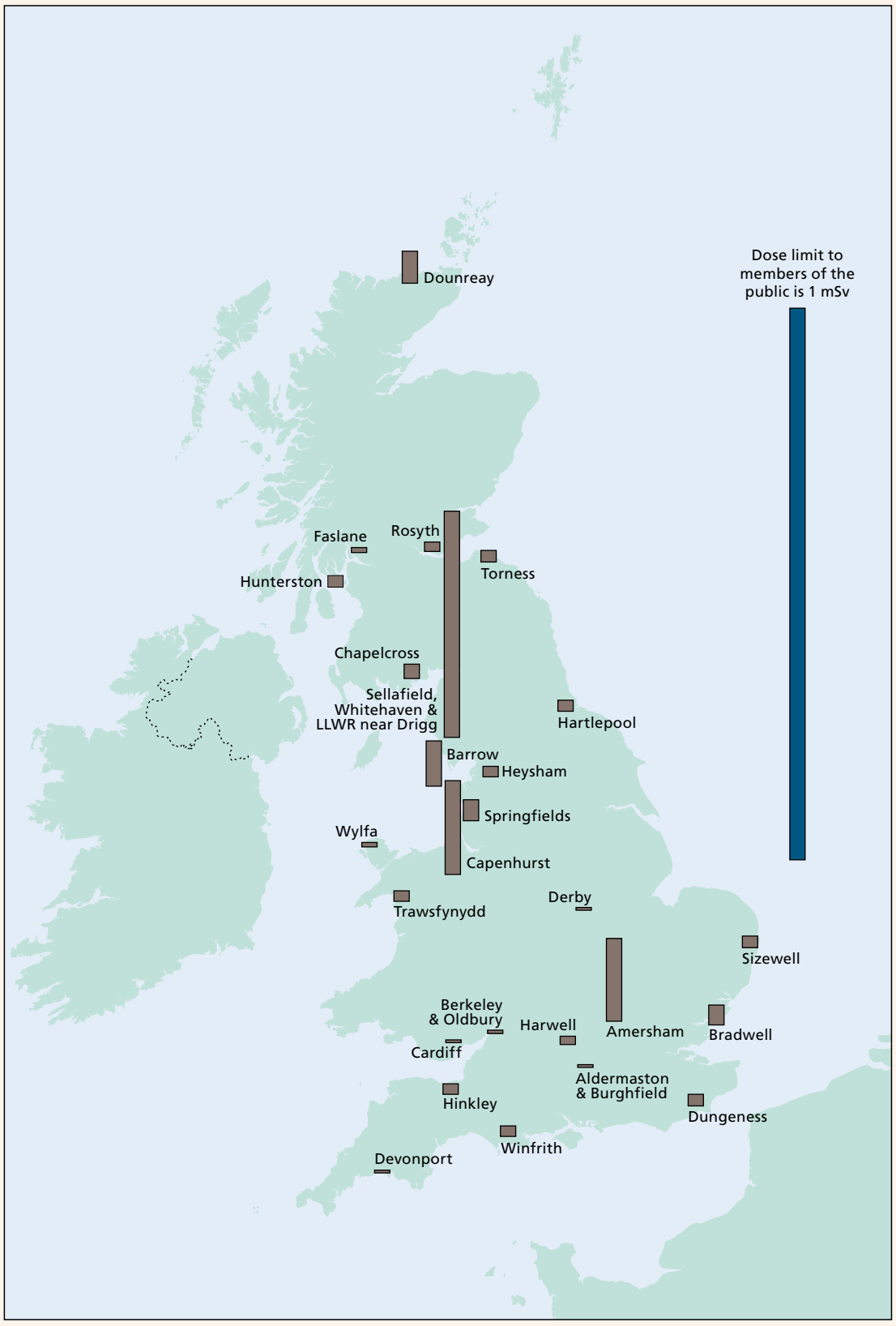



**Figure S.** *Total doses* in the UK due to radioactive waste discharges and direct radiation, 2016
(Exposures at Sellafield, Whitehaven and Drigg receive a significant contribution to the dose from technologically enhanced naturally occurring radionuclides from previous non-nuclear industrial operations)

**Summary Table S** ***Total doses*** **due to all sources at major UK sites, 2016**[a]

| Establishment | Exposure, mSv[b] per year | Contributors[c] |
|---|---|---|
| **Nuclear fuel production and processing** | | |
| Capenhurst | 0.17 | Direct radiation |
| Springfields | 0.038 | Gamma dose rate over sediment |
| Sellafield[e] | 0.41 | Crustaceans, $^{210}$Po |
| **Research establishments** | | |
| Dounreay | 0.058 | Meat – game, $^{137}$Cs |
| Harwell | 0.015 | Direct radiation |
| Winfrith | 0.019 | Direct radiation |
| **Nuclear power stations** | | |
| Berkeley and Oldbury | 0.006 | Milk, $^{14}$C |
| Bradwell | 0.036 | Direct radiation |
| Chapelcross | 0.026 | Milk, $^{14}$C, $^{90}$Sr, $^{241}$Am[d] |
| Dungeness | 0.021 | Direct radiation |
| Hartlepool | 0.020 | Direct radiation, gamma dose rate over sediment |
| Heysham | 0.019 | Gamma dose rate over sediment |
| Hinkley Point | 0.013 | Gamma dose rate over sediment |
| Hunterston | 0.021 | Direct radiation |
| Sizewell | 0.021 | Direct radiation |
| Torness | 0.021 | Direct radiation |
| Trawsfynydd | 0.019 | Direct radiation, milk, $^{14}$C, $^{241}$Am |
| Wylfa | 0.008 | Direct radiation, milk, $^{14}$C |
| **Defence establishment** | | |
| Aldermaston and Burghfield | <0.005 | Milk, $^{3}$H[d], $^{137}$Cs[d] |
| Barrow | 0.082 | Gamma dose rate over sediment |
| Derby | <0.005 | Water, $^{60}$Co[d] |
| Devonport | <0.005 | Fish, $^{14}$C, $^{131}$I[d], $^{241}$Am[d] |
| Faslane | 0.009 | Fish, gamma dose rate over sediment, $^{137}$Cs, $^{241}$Am |
| Rosyth | 0.017 | Gamma dose rate over sediment |
| **Radiochemical production** | | |
| Amersham | 0.15 | Direct radiation |
| Cardiff | <0.005 | Milk, $^{14}$C, $^{32}$P[d], $^{35}$S |
| **Industrial and landfill** | | |
| LLWR near Drigg[e] | 0.41 | Crustaceans, $^{210}$Po |
| Whitehaven[e] | 0.41 | Crustaceans, $^{210}$Po |

[a] *Includes the effects of waste discharges and direct radiation from the site. May also include the far-field effects of discharges of liquid waste from Sellafield*

[b] *Committed effective dose calculated using methodology of ICRP-60 to be compared with the dose limit of 1 mSv*

[c] *Pathways and radionuclides that contribute more than 10% of the* total dose. *Some radionuclides are reported as being at the limits of detection*

[d] *The assessed contribution is based on data at limits of detection*

[e] *The doses from man-made and naturally occurring radionuclides were 0.074 and 0.34 mSv respectively. The source of man-made radionuclides was Sellafield; naturally occurring ones were from the phosphate processing works near Sellafield at Whitehaven. Minor discharges of radionuclides were also made from the LLWR near Drigg site into the same area*

processing plant at Whitehaven and 0.074 mSv related to the discharges of artificial radionuclides by the nuclear industry. The equivalent local seafood consumer in 2015 received a dose of 0.42 mSv (including a contribution of 0.35 mSv and 0.078 mSv related to the former phosphate processing plant and the nuclear industry, respectively). The decrease in dose near Sellafield was mostly attributable to the revision of the habits information; from a decrease in the consumption rate (and a change in the mix of species) of crustaceans in 2016, in comparison to values in 2015. Polonium-210 concentrations in lobster and crab samples continued to be within or close to the expected range due to natural sources in 2016. The largest contribution to dose to seafood consumers in the vicinity of Sellafield was from polonium-210, from the former phosphate processing plant at Whitehaven. From a radiological assessment perspective, the effects from the Sellafield and Whitehaven sites both influence the same area and therefore the contributions to doses are both considered in Section 2.3.1.

The highest dose near Sellafield was mostly due to historical liquid discharges. The maximum dose for the representative person most affected by pathways related to gaseous discharge and direct radiation sources at Sellafield was 0.008 mSv in 2016, and unchanged from 2015. The most exposed age group in 2016 was children (10 year-old) and the dominant contribution to their dose was direct radiation from the site.

In Scotland, the representative person who received the highest dose from authorised releases of radioactivity consumed fish, shellfish and wildfowl on the Dumfries and Galloway coast. The dose in 2016 was 0.044 mSv. Most of this was due to the effects of past discharges from the Sellafield site.

In Wales, the representative person who received the highest dose from permitted releases of radioactivity consumed locally grown food at Trawsfynydd. The dose was 0.025 mSv in 2016.

## Radioactivity concentrations in samples collected around UK nuclear licensed sites

This topic summarises any changes in concentrations of radioactivity in food or the environment, given in becquerels per kilogramme (Bq $kg^{-1}$) or becquerels per litre (Bq $l^{-1}$).

There were no major variations in environmental concentrations of radioactivity in 2016 compared to those in 2015. The mean concentrations of caesium-137, plutonium-239+240 and americium-241 in lobster, and caesium-137 in fish, near Sellafield in 2016 are the lowest reported values in comparison to previous years.

Marine sediment samples are a useful indicator of trends in the environment. People who spend time on beaches can be exposed to radiation through the radionuclide content of the sediments. Near Sellafield, the environmental concentrations of most radionuclides have declined substantially over the last 25 years. Small increases in plutonium isotopes and americium-241 have been observed in mud samples from the Ravenglass estuary near Sellafield. However, these have had little or no effect on radiation exposures. Lower concentrations of plutonium radionuclides and americium-241 were measured from the River Mite estuary and Ravenglass in 2016, in comparison to those in 2015.

On occasion, the effects of non-nuclear sites discharge are detected at low levels by the routine monitoring programme for nuclear licensed sites. In 2016, iodine-131 was detected in samples at nuclear licensed sites. The source of the iodine-131 is not known with certainty but a likely cause was the therapeutic use of this radionuclide in local hospitals. The concentrations were of low radiological significance.

The Environment Agency has carried out a review of their environmental monitoring programme for Sellafield. The Environment Agency's review of the monitoring programme for Sellafield has been summarised (Environment Agency, 2016) and changed in 2016 to reflect the review outcomes.

A revised UK Radioactive Discharge Strategy was published in 2009. This describes how the UK will implement the commitments in the OSPAR Radioactive Substances Strategy (RSS) on radioactive discharges to the marine environment of the North-East Atlantic. The UK Strategy has resulted in substantial reductions in radioactive discharges and in nuclear licensed sites producing action plans to further reduce discharges. From a regulatory perspective, the Environment Agency, Natural Resources Wales and the Scottish Environment Protection Agency (SEPA) have continued to support the Strategy. In 2016, SEPA issued new authorisations, or varied existing ones, at three sites, Hunterston A, Rosyth and Vulcan NRTE, resulting in one or more of: strengthened conditions, reduced limits or new routes for disposing of radioactive waste.

## External dose rates measured from around UK nuclear licensed sites

Sediments in intertidal areas can make a significant contribution to the total radiation exposure of members of the public. For this reason, external doses are recorded by measuring dose rates (gamma and beta). These 'external doses' are included in the assessment of doses to the public where they are higher than background levels. Background levels are subtracted in dose assessments.

There were no major changes in external dose rates in intertidal areas in 2016 compared with 2015. At most locations, the external dose rates were close to background levels. Levels were higher in some estuaries near Sellafield (up to twice the background rate) and in the Ribble Estuary.

## UK nuclear licensed site incidents and non-routine surveys

During 2016, as a result of an ongoing programme of monitoring by the operator, radioactive items (particles*, including contaminated pebbles/stones) from Sellafield were detected on Cumbrian coastline beaches and removed (254 in financial year 2016/17). Public Health England (PHE) has provided advice that the overall health risks for beach users from radioactive objects on beaches near Sellafield are very low and significantly lower than other risks that people accept when using the beaches. A programme of work is in place to address the remaining uncertainties in the origins, fate and effects of the particles with the aim of returning the work to a routine monitoring programme only by about 2018.

The enhanced monitoring programme at Bradwell continued in 2016. This commenced in 2015, in response to local views, whilst treatment of Intermediate Level Waste was being undertaken on-site. No change in levels of radioactivity were detected in the environment at Bradwell in 2016.

At Dounreay, the comprehensive beach monitoring programme continued for fragments of irradiated nuclear fuel (particles) and further particles were recovered from local beaches (fewer in 2016, but similar in activity ranges observed in recent years). Fishing restrictions under the Food and Environment Protection Act (FEPA) 1985 are still in force.

'Special' (or *ad hoc*) sampling related to nuclear licensed site operation is undertaken at sites when the need arises, for example when increases in discharges are reported. No such need arose in 2016.

## Habits surveys near UK nuclear licensed sites

For *total dose* assessments, habits data are used to define the exposure pathways for members of the public. Habits data are used to generate one or more †hypothetical individuals (for each pathway). The doses to each hypothetical individual are calculated and the individual with the highest dose is the representative person. The dose calculated in this way is considered representative of the dose to the most highly exposed individuals in the population. Since the habits data used in this report (Appendix 1, Table X2.2) originate from published habits reports from surveys undertaken around individual nuclear sites, the hypothetical individuals are close to real individuals recently observed in the population.

In 2016, the regular programmes of habits surveys continued and these give site-specific information on diets and occupancy habits of people near nuclear licensed sites. Surveys were carried out at Amersham, Heysham and Sellafield in England and at Faslane and Torness in Scotland. The findings were used to confirm the adequacy of current monitoring programmes or strengthen and update them with a better representation of relevant pathways, and to improve the assessment of doses to members of the public near nuclear licensed sites.

## Monitoring of radioactivity at other locations remote from UK nuclear licensed sites

Additional monitoring was undertaken in the UK and surrounding seas to study the effects of (i) overseas incidents, (ii) non-nuclear sites and (iii) regional monitoring of radioactivity across the UK.

### (i) Overseas incidents

The accident at Fukushima Dai-ichi nuclear power station in Japan in March 2011 resulted in significant quantities of radioactivity being released to air and sea. Safeguard controls on imported food and feed products from Japan continued in 2016. The European Commission (EC) has implemented controls on the import of food and feed originating in or consigned from Japan. From January 2016, only certain foods specified in the controls continue to require certification by the Japanese authorities. In addition, a percentage of Japanese imports into the European Union (EU) were monitored at ports of entry. None of the imports to the UK have contained activity exceeding the maximum permissible levels in 2016. The public doses received due to the imports were of negligible radiological significance.

Food imported into the UK may contain radioactive contamination from the 1986 Chernobyl accident and other known or unknown sources. A monitoring system is in place to detect radioactivity in consignments. In 2016,

* *"Particle" is a term used in this report which encompasses discrete radioactive items which can range in radioactivity concentration, size and origin. "Particles" include radioactive scale, fragments of irradiated nuclear fuel, incinerated waste materials, typically less than 2 mm in diameter, and larger radioactive artefacts (e.g. dials) and stones which have radioactive contamination on their surface. Particles are not physically the same at each of the sites mentioned, but can be compared according to the hazard posed.*

† *A hypothetical individual is used because an actual individual (or group of individuals) cannot be defined that represents exposure from all pathways.*

no significant radioactivity was detected at entry points and there was no need to introduce food safety controls on any consignments.

## (ii) Non-nuclear sites

In the past, liquid slurry containing thorium and uranium was discharged from a phosphate processing plant near Whitehaven (Cumbria) into the Irish Sea. The plant ceased operations in 1992, decommissioned in 2002, and the plant was subsequently demolished. Past discharges generated what is sometimes known as 'Technologically enhanced Naturally Occurring Radioactive Material' (TNORM). Discharges of TNORM can lead to an increase in the concentrations of naturally occurring radionuclides in the environment. Concentrations of naturally occurring radionuclides in fish and shellfish near Whitehaven have been found to be higher than the maximum expected ranges due to natural sources. Concentrations of natural radionuclides have declined in the last 10 years, so that in recent years the concentrations were very close to natural background, making any increase due to the past discharges difficult to distinguish. Estimates of the concentrations of naturally occurring radionuclides in seafood caused by past discharges from the site have been made by subtracting the expected natural concentration of these radionuclides in UK seafood from the measured levels. Polonium-210, which is naturally occurring, is present in some seafood samples at slightly above background levels. Polonium-210 (and lead-210) are important radionuclides in that small changes in levels above background significantly influence the dose contribution from these radionuclides and similarly the value of the estimated dose. The representative person in the area who consumed large amounts of seafood was estimated to receive a dose of 0.41 mSv, with about 80 per cent from polonium-210. The dose is mostly from the effects of historical discharges of natural radionuclides from the plant near Whitehaven but also includes a contribution from the effects of discharges from the adjacent sites at Sellafield and, to a much lesser extent, at the Low Level Waste Repository (LLWR) near Drigg.

Concentrations of tritium were found in leachate from some landfill sites, at levels that were of very low radiological significance. There are several disposal routes for radioactive waste to landfill that could contain tritium, for example, from hospitals and industrial sites, and due to disposals of gaseous tritium light devices (such as fire exit signs).

Work to address the radioactive contamination at Dalgety Bay is ongoing. Public protection measures have been established and these were maintained during 2016 and into 2017. A continuing monthly beach monitoring and particle recovery programme began in 2012 by a contractor working on behalf of the Ministry of Defence (MoD). The fence demarcating the area where the highest activity particles were discovered remains in place, as well as the information signs advising the public of the contamination and precautions to be taken. In addition, the FEPA Order issued by the FSA in Scotland (now FSS) prohibiting the collection of seafood from the Dalgety Bay area remains in force. Following the publication of the risk assessment together with the appropriate persons report in 2013, COMARE recommended that effective remediation of the affected area is undertaken as soon as is possible. The MoD has progressed with addressing the contamination by initially publishing its Outline Management Options Appraisal Report in January 2014 followed by the publication in July 2014 of its broad management strategy and timescale for implementation of its preferred management option. PHE, at the request of SEPA, has provided advice on target levels of radioactive contamination for Dalgety Bay following any remediation of the affected area. The Environmental Impact Assessment (EIA) in support of the Planning Application for the remediation works has been recently submitted to Fife Council for consideration.

Further details can be found in Section 7.6 of this report and on the Radioactive Substances pages of SEPA's website (**www.sepa.org.uk**). As work in this area is ongoing, an update will be provided in next year's RIFE report.

## (iii) Regional monitoring of radioactivity across the UK

Regional monitoring in areas remote from nuclear licensed sites has continued in 2016 (i) to establish long distance transport of radioactivity from UK and other nuclear licensed sites, (ii) to indicate general contamination of the food supply and the environment and (iii) to provide data under UK obligations under Article 36 of the Euratom Treaty and the OSPAR Convention.

Monitoring artificial radioactivity in Northern Ireland showed that consumer doses were approximately 1 per cent (or less) of the annual limit of 1 mSv for members of the public. A survey on the Channel Islands confirmed that doses due to discharges from the French reprocessing plant at La Hague and other local sources were less than 1 per cent of the limit.

Food in people's general diet and sources of public drinking water were analysed across the UK. Results showed that artificial radionuclides only contributed a small proportion of the total public radiation dose in people's general diet.

The distribution of radionuclides in coastal seas away from nuclear licensed sites continues to be monitored. This supports the UK's marine environmental policies and international treaty commitments. Government research vessels are used in the sampling programme and the results have been used to show trends in the quality of the UK's coastal seas. These surveys, together with the results of monitoring at nuclear licensed sites, contribute to the UK data submitted to the OSPAR Commission. These data also

help to measure progress towards the UK Government and Devolved Administrations' objectives for improving the state of the marine environment.

## The environmental radioactivity monitoring programmes

The environmental monitoring programmes in this report were organised by the environment agencies, FSA and FSS and are independent of the industries discharging radioactive wastes. The programmes include monitoring on behalf of the Scottish Government, Channel Island States, the Department of Agriculture Environment and Rural Affairs (DAERA), the Department of Business, Energy and Industrial Strategy (BEIS), Department for Environment, Food and Rural Affairs (Defra), Natural Resources Wales (NRW) and the Welsh Government. The monitoring programmes involved four specialist laboratories working together, each with rigorous quality assurance procedures, and a wide range of sample collectors throughout the UK. Overall, around 10,000 analyses and dose rate measurements were completed in 2016.

The results of our monitoring are reported in tables in the relevant sections (Sections 2 – 8, inclusive). In order to identify the most relevant analytical data, to make the information more manageable and to minimise the presentation of redundant data (e.g. data analysed but reported as less than values by the specialist laboratories), the results reported in RIFE are prioritised in the following ways:

(i) For any radionuclide that is specified in a relevant permit/authorisation, all analytical data are reported (regardless of being positively detected or not);
(ii) All activity concentration data are reported that have been analysed by radiochemistry (e.g. plutonium radionuclides);
(iii) For any radionuclide that is reported as positively detected in the previous 5 years of annual reporting, all activity concentration data of that radionuclide are reported (i.e. only excluded from the Table after 5 continuous years of reporting less than values);
(iv) For any radionuclide that is reported as positively detected in one of the samples, all activity concentration data of that radionuclide are reported for other samples presented in the Table (terrestrial and marine) in that year;
(v) Naturally occurring radionuclides measured by gamma-ray spectrometry are not usually reported unless the intention is to establish whether there is any enhancement above the expected background levels;
(vi) Reporting of detection limits (where the results are an average of more than one data) is described in Appendix 1 (Section 2.4)

More information about all programmes described in this report is available from the sponsoring agencies. Their contact details can be found on the inside front and back covers of this report. The results of the analysis of food samples collected near nuclear licensed sites in England and Wales are published on FSA's website (**www.food.gov.uk**).

# 1. Introduction

This section (i) describes the purpose and scope of the UK monitoring programmes for radioactivity in food and the environment, (ii) provides a summary of the key results in terms of radiation exposures at each major industrial site in 2016 and (iii) gives an overview of the main sources of radiation in a regulatory context.

## Overview

- The Radioactivity in Food and the Environment (RIFE) report represents collaboration by the environment agencies, FSA and FSS across the UK, independent of industry
- RIFE provides an open check on food safety and the public's exposure to radiation in conformity with the EU Basic Safety Standards Directive
- The monitoring programme results support the UK meeting its international treaty obligations
- Dose results are summarised for major industrial sites; all doses were below the legal limit in 2016

## 1.1 Purpose and scope of the monitoring programmes

In England and Wales, FSA conducts food monitoring, whilst the Environment Agency carries out environmental and dose rate monitoring*. In Scotland, SEPA carries out food, environmental and dose rate monitoring, working closely with FSS on its programme. In Northern Ireland, this is carried out by the Northern Ireland Environment Agency (NIEA). Surveillance of imports through points of entry continued in 2016. The regular programme of monitoring of drinking water, air and rain continued on behalf of BEIS, NIEA and the Scottish Government. The FSA and SEPA (as part of the joint SEPA/FSS monitoring programme) also carry out UK monitoring of milk and canteen meals that are collected remotely from nuclear licensed sites. Annual surveys of seas around the UK (including locations away from nuclear licensed sites) is monitored on behalf of BEIS.

FSA has responsibility for food safety in England, Northern Ireland and Wales under the Food Standards Act 1999. Following the Food (Scotland) Act 2015, responsibility for food safety in Scotland was transferred to FSS. The Environment Agency, NRW, NIEA and SEPA, referred to together as the environment agencies in this report, are responsible for environmental protection in England, Wales, Northern Ireland and Scotland, respectively. Since 6 April 2010, the Environment Agency and NRW regulated radioactive waste disposal under the Environmental Permitting (England and Wales) Regulations 2010 (EPR 10), (United Kingdom - Parliament, 2010a). On 1 January 2017, the new Environmental Permitting (England and Wales) Regulations 2016 came into force (United Kingdom - Parliament, 2016), revoking the previous Regulations. Whilst there are no major changes, the new regulations provide a consolidated system of environmental permitting in England and Wales and transpose provisions of fifteen EU Directives which impose obligations requiring delivery through permits or which are capable of being delivered through permits. In Scotland and Northern Ireland, SEPA and NIEA regulate radioactive waste disposal under the Radioactive Substances Act 1993 (RSA 93) (United Kingdom - Parliament, 1993). The Environment Agency and SEPA also have broader responsibilities under the Environment Act 1995 (United Kingdom - Parliament, 1995a) for environmental protection and determining general concentrations of pollution in the environment.

The monitoring programmes have several purposes. Ongoing monitoring helps to establish the long-term trends in concentrations of radioactivity over time within the vicinity of, and at distance from, nuclear licensed sites. The results are also used to confirm the safety of the food chain. Monitoring the environment provides indicators of radionuclide dispersion around each nuclear site. Environmental and food results are used to assess dose to the public to confirm that the controls and conditions placed in the authorisations/permits provide the necessary protection and to ensure compliance with statutory dose limits. Most of the monitoring carried out and presented in this report concerns the local effects of discharges from nuclear licensed sites in the UK. Monitoring of food and the environment remote from nuclear licensed sites is also carried out, giving information on background concentrations of radionuclides; these data are reported to the EC. Guidance on planning and implementing routine environmental programmes has been published (Environment Agency, FSA and SEPA, 2010).

The RIFE report and the associated monitoring programmes conform to the requirements in Article 36 of the Euratom Directive laying down basic safety standards for protection against the dangers arising from exposure to ionising radiation (EC, 2014). Specifically, it provides estimates of doses to members of the public from authorised

* *The Environment Agency has an agreement with NRW to undertake some specific activities on its behalf in Wales including some environmental monitoring and aspects of radioactive substances regulation.*

practices and enables such results to be made available to stakeholders. BEIS has overall UK Government policy lead responsibility for the EU Basic Safety Standards Directive. In order to transpose the requirements of the directive which relates to occupational health and safety, the Health and Safety Executive (HSE) is proposing to repeal and replace the Ionising Radiation Regulations 1999 (United Kingdom - Parliament, 1999). The new Basic Safety Standards Directive consolidates and updates existing Euratom provisions for protection against the harmful effects of ionising radiation by replacing five existing Directives and a Commission Recommendation. It covers occupational, medical and public exposure. HSE is consulting on changes to the Ionising Radiation Regulations 1999 (HSE, 2017). The UK Government is required to implement the Euratom Directive into UK law by the 6 February 2018.

In recent years, FSA, SEPA and EA have all completed reviews of their environmental radioactivity monitoring programmes. Further information is available in earlier RIFE reports (e.g. Environment Agency, FSA, FSS, NIEA, NRW and SEPA, 2016).

The Environment Agency has carried out a review of their environmental monitoring programme for Sellafield, as part of a process to review their monitoring at all nuclear sites in England and Wales (on behalf of Natural Resources Wales). The majority of the review at other nuclear sites (in England and Wales) was completed during 2015. The reviews were to ensure the programmes are appropriate and are consistent with advice in the joint Agency technical guidance (Environment Agency, FSA and SEPA, 2010), resulting in an adjustment and consolidation of the monitoring around some sites. The Environment Agency's review of the monitoring programme for Sellafield has been summarised (Environment Agency, 2016). This report provides changes to the programme, to align it more closely with the ranges of sampling types and location numbers and to identify several recommendations largely aimed at informing future revisions to the programme. The Environment Agency's monitoring programme was changed in 2016 to reflect the review outcomes.

The analytical science for the monitoring programmes was carried out by numerous UK laboratories, including those listed below. These laboratories also carried out most of the sample collection for the programmes.

- Centre for Environment, Fisheries & Aquaculture Science (Cefas)
- Environmental Scientifics Group (ESG)
- Public Health England (PHE)
- LGC Limited (LGC)

Appendix 1 is in a file that accompanies the main report. It gives details of methods of sampling and analysis and explains how results are interpreted in terms of public radiation exposures. A summary of the assessment approach and current trends in doses are given in the following section (Section 1.2).

## 1.2 Summary of doses

### 1.2.1 The assessment process

The majority of the monitoring was carried out to check the effects of discharges from nuclear and non-nuclear operators on people's food and their environment. The results are used to assess doses to the public that can then be compared with the relevant dose limits. The dose assessments are retrospective in that they apply to 2016, using monitoring results for that year. The radioactivity concentrations and dose rates reported include the combined radiological impact of all discharges made up to the time of sampling.

In this report, two main types of retrospective doses are assessed (see Figure 1.1). The first type of assessment is more complete in considering the combined effects of direct radiation exposure, gaseous and liquid radioactive discharges from nuclear licensed sites. This assessment gives an estimate of the *total dose* to people around the nuclear licensed sites and *total dose* is presented as the primary dose quantity. Exposure from direct radiation can be a significant contributor to dose close to operating power stations and/or close to site storage of radioactive materials. The regulation of direct radiation is the responsibility of the ONR. Operators of nuclear licensed sites provide estimates of direct radiation doses to ONR (Table 1.1); annual exposure data are then made available for use in *total dose* assessments. These *dose* assessments use recent habit survey data which has been profiled using an agreed method (Camplin *et al.*, 2005).

The second type of assessment estimates dose from specific sources and associated exposure pathways. These dose assessments check on the adequacy of the *total dose* method and offer additional information for key pathways. The sum of the doses from specific sources does not give the same result as the assessment of *total dose* from all sources. This is because the assessment methods use different ways of defining the most exposed people.

Both types of assessment consider those people in the population most exposed to radiation. These results are for comparison with legal limits. The method of calculation involves an assessment for the 'representative person'.

The calculated doses are compared with the dose limit for members of the public of 1 mSv per year. Dose assessments for exposure to skin are also determined at some sites and compared with the relevant skin dose limit. The approaches used are for relatively widespread contamination in food and the environment where the probability of encounter/consumption is certain. These methods are not appropriate for exposure to small radioactive particles where the chance of encounter is a relevant factor to be considered (Dale *et al.,* 2008). All dose limits are based on recommendations made by the ICRP (ICRP, 1991) and are consistent with EU legislation (EC, 2014).

| Primary purpose | Assess dose from main sources of exposure at each site for comparison with 1 mSv limit | | | |
|---|---|---|---|---|
| Types of assessment | *Total dose* | Source specific dose | | |
| Sources considered | Gaseous discharges<br>Liquid discharges<br>Direct radiation from site | Gaseous discharges | Liquid discharges | Direct radiation (dose estimates provided by ONR) |
| Habits data e.g. food consumption rates or occupancy of beaches | Define usage of pathways relating to all sources at site | Define usage of pathways relating to gaseous discharges at site | Define usage of pathways relating to liquid discharges at site | |
| Monitoring data | Collate monitoring data for relevant pathways e.g. radionuclide concentratons in food or dose rates on beaches | Collate monitoring data for relevant pathways e.g. radionuclide concentratons in food | Collate monitoring data for relevant pathways e.g. radionuclide concentrations in food or dose rates on beaches | |
| Dose calculations | Calculate dose from all sources to individuals who may represent those most exposed<br>Select the highest dose for the person representing the most exposed | Calculate dose from gaseous discharges to people representing those most exposed | Calculate dose from liquid discharges to people representing those most exposed | |
| Dose quantity | *Total dose* | Dose from gaseous discharges | Dose from liquid discharges | Dose from direct radiation |

**Figure 1.1.** The dose assessment process for major nuclear sites

An additional comparison can be made with the exposure from natural radioactivity. The estimated dose for each person (per caput) in the UK population (in 2010) from natural radiation is approximately 2.3 mSv per year (Oatway *et al.*, 2016).

Collective doses are beyond the scope of this report. They are derived using modelling techniques. The EC has published an assessment of individual and collective doses from reported discharges from nuclear power stations and reprocessing sites for the gaseous and liquid waste disposals in the years 2004 to 2008 (Jones *et al.*, 2013).

Radiation exposures to some specific groups of workers are included in the assessment of doses from nuclear licensed sites. These are workers who may be exposed incidentally, but do not work specifically with ionising radiation. These include fishermen, farmers, sewage workers, nature wardens, etc. It is appropriate to compare their doses to the dose limit for members of the public (Allott, 2005). Doses to workers who are involved with ionising radiation and receive a dose from their work should be assessed as part of their employment.

### 1.2.2 *Total dose* results for 2016

The results of the assessment for each site are summarised in Table 1.2 (see also Figure S and Table S in the Technical Summary). These data are presented in three parts. The representative person receiving the highest doses from the pathways predominantly relating to gaseous discharges and direct radiation are shown in part A and those for liquid discharges in part B. Occasionally, the people receiving the highest doses from all pathways and sources are different from those in A and B. Therefore, this case is presented in part C. The major contributions to dose are provided. The use of radionuclide concentrations reported at the limits of detection provide an upper estimate of doses calculated for pathways based on these measurements. The full output from the assessment for each site can be provided by contacting one of the agencies listed on the inside cover of the report.

In all cases, doses estimated for 2016 were less than the limit of 1 mSv for members of the public. The people most affected from gaseous discharges and direct radiation varied from site to site but the dominant pathway was often direct radiation where it was applicable. The people most affected from liquid discharges were generally adult consumers of seafood or occupants over contaminated sediments.

The representative person, who received the highest *total dose*, consumed molluscan shellfish at high-rates (and other seafood) near Sellafield. The *total dose* (from all sources) at this site is combined with the effects of all local sources, including specifically the effects of historical discharges of natural radionuclides from the former phosphate processing plant at Whitehaven and (to a lesser extent) the effects of discharges from the LLWR (near Drigg). The representative persons, receiving the next highest *total doses*, were local inhabitants living near the Capenhurst and Amersham sites; these doses were almost entirely due to direct radiation from the sites.

### 1.2.3 *Total dose* trends

A time-series of *total dose* from 2004 - 2016 is shown in Figure 1.2 (Table 1.3 gives numerical values). Many sites showed a downward trend in *total dose* over this period. Changes in direct radiation dominated the inter-annual variation at most of the power station sites, and small fluctuations in external dose rates had relatively large effects at some sites where high rates of intertidal occupancy were recorded. Following the cessation of power production by Magnox reactors at Dungeness and Sizewell, the effect has been a reduction in direct radiation at these sites. The most significant trend in *total dose* due to discharges of waste was for high-rate consumers of seafood on the Cumbrian coast near Sellafield, Whitehaven and the LLWR near Drigg. In this case, the overall downward trend in *total dose* broadly followed the general downward trend in concentrations of naturally occurring and artificial radionuclides from non-nuclear and nuclear sources, respectively. Year to year changes were also influenced by changes in consumption and occupancy characteristics of local people and the natural variability in radionuclide concentrations in food and the environment. In 2015 and 2016, doses to these people increased due to small increases in concentrations of polonium-210 in local seafood.

At Cardiff, there has been an overall downward trend in *total dose* due to reductions in discharges of tritium and carbon-14 to sea. The increase in *total dose* at this site in 2013 was due to higher carbon-14 concentrations in milk. The *total dose* observed at Dounreay in recent years has decreased from the peak value in 2008. The increase in *total dose* at Dounreay in 2016 was due to changes in caesium-137 concentrations in game meat and the type of game meat. The reductions in *total dose* at Heysham (2011), Hinkley Point (2010) and Springfields (2012) were largely due to findings from new habits surveys. At Capenhurst, any changes in *total doses* with time are attributable to changes in the estimates of direct radiation from the site. The small increases in *total dose* at Bradwell and Winfrith (both in 2015 and 2016) were mostly due to higher estimates of direct radiation from the individual sites.

### 1.2.4 Source specific dose results for 2016

The results of the source specific assessments for the main industrial sites in the UK are summarised in Table 1.4 and Figure 1.3. The focus for these assessments is the effect of gaseous or liquid waste discharges, unlike that for *total dose* which also includes all sources including the effect of direct radiation.

The most significant exposures were found at the LLWR near Drigg, and near Sellafield and Whitehaven where seafood consumption dominated, and at Barrow and at Springfields where external exposure on houseboats dominated. At the LLWR near Drigg, at Sellafield and at Whitehaven the majority of the dose was from the legacy of historical discharges from Sellafield and from non-nuclear industrial operations resulting in technologically enhanced levels of natural radionuclides. The most important pathways and radionuclides at each site were similar to those found for *total dose* if the effect of direct radiation is taken into account. At Barrow and Springfields the dose was largely due to activity in sediments beneath houseboats, also from historical discharges from Sellafield.

Although some source specific doses were estimated to be higher than *total doses,* the reasons for this are understood and relate to the different assumptions of the two assessment methodologies. The assumptions used for source specific assessments are conservative with respect to adding together the effects of consumption of different foods. The assumptions used for *total dose* assessments are more realistic, and the estimates from the source specific assessments confirm the adequacy of the *total dose* approach of assessment. Radiation doses to adults and children, calculated using the source specific method, were all found to be well below the national and European limit of 1 mSv per year.

### 1.2.5 Protecting the environment

The focus of this report is on the protection of people, but the protection of wildlife and the environment is also relevant. ICRP in its 2007 recommendations concluded that there is a need for a systematic approach for the radiological assessment of non-human species to support the management of radiation effects in the environment (ICRP, 2007). In pursuit of this aim, ICRP has considered the use of a set of Reference Animals and Plants (RAPs) (ICRP, 2008) and have published their aims in terms of environmental protection, that is (i) prevention or reduction of the frequency of deleterious radiation effects on biota to a level where they would have a negligible impact on the maintenance of biological diversity, (ii) the conservation of species and the health and status of natural habitats, communities and ecosystems (ICRP, 2014).

In the UK, the current legislative measures relevant to the protection of wildlife from radiation are the Birds and the Habitats Directives, on the conservation of wild birds (CEC, 2009) and on the conservation of natural habitats and wild flora and fauna (CEC, 1992), and are implemented through the Habitats Regulations.

Under the Habitats Regulations, the Environment Agency, NRW and SEPA have obligations to review existing authorisations/permits to ensure that no authorised activity or permission results in an adverse effect, either directly or indirectly, on the integrity of Natura 2000* habitat sites. Similarly, there is also an obligation for any new or varied

* *Natura 2000 is made up of sites designated as Special Areas of Conservation (SACs) and Special Protection Areas (SPAs)*

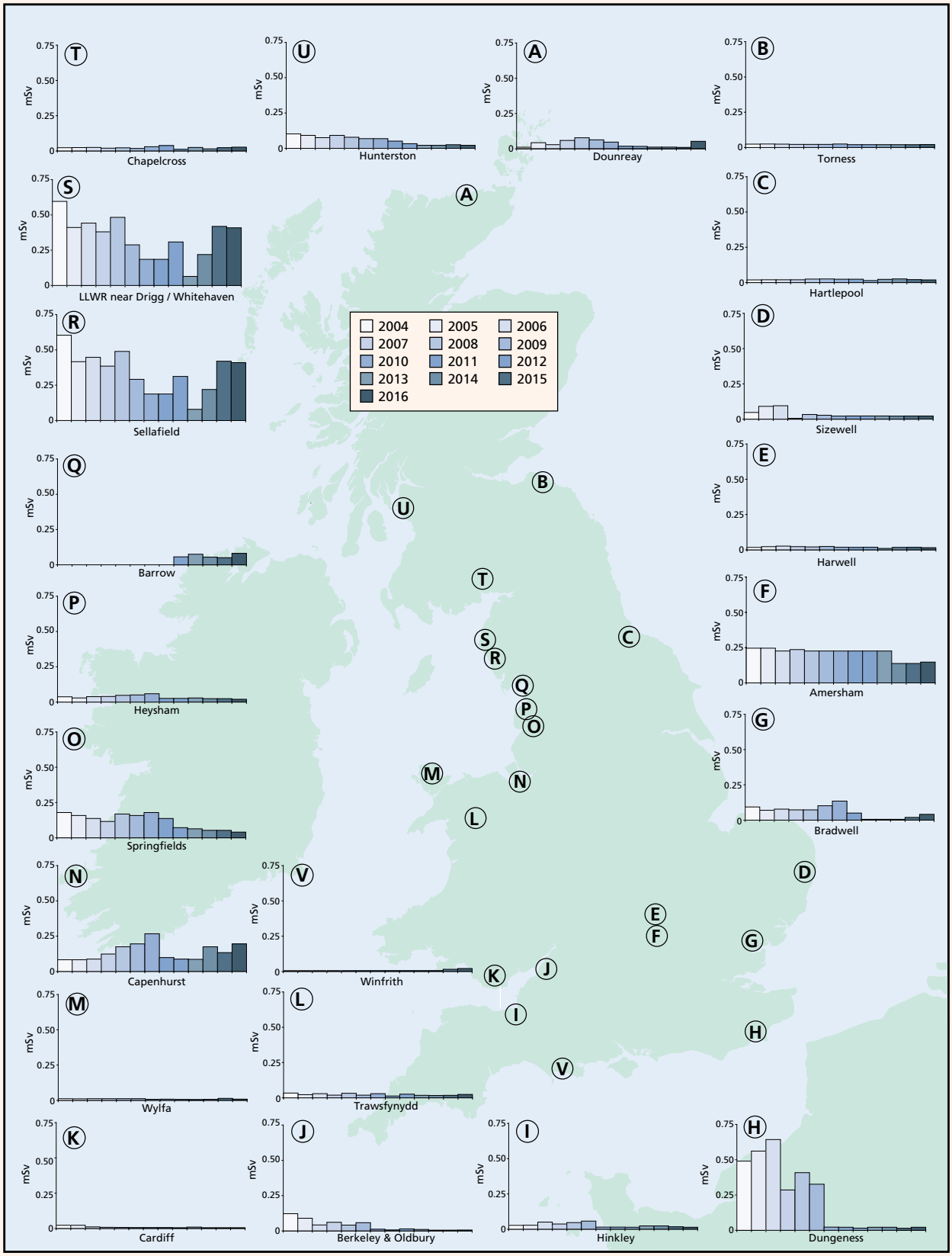



**Figure 1.2.** *Total doses* around the UK's nuclear sites due to radioactive waste discharges and direct radiation (2004-2016). (Exposures at Sellafield/Whitehaven/LLWR receive a significant contribution to the dose from technologically enhanced naturally occurring radionuclides from previous non-nuclear industrial operations)

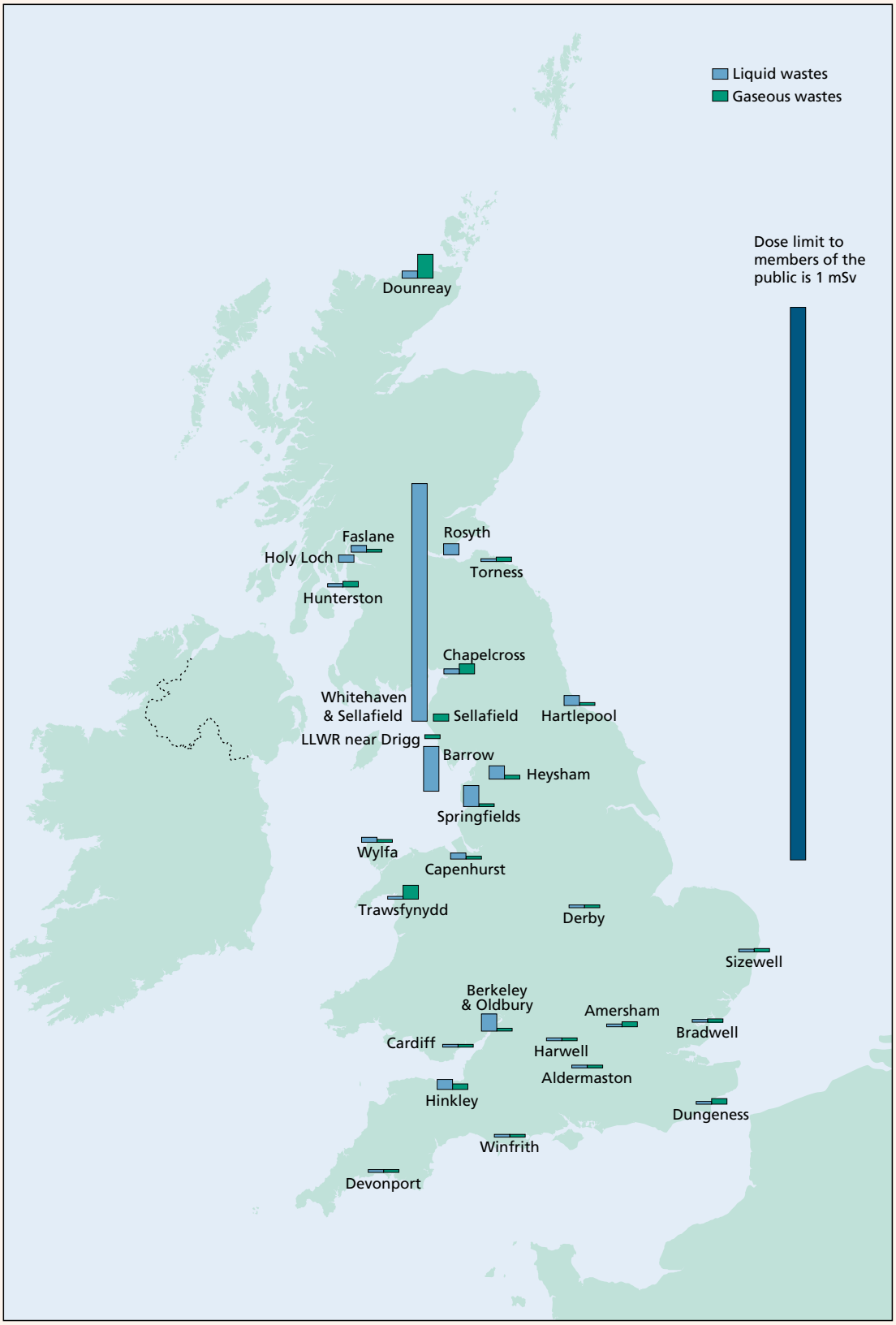



**Figure 1.3.** Source specific doses in the UK, 2016 (Exposures at Whitehaven and Sellafield receive a significant contribution to the dose from technologically enhanced naturally occurring radionuclides from previous non-nuclear industrial operations)

authorisation/permit, whereby the applicant is required to make an assessment of the potential impact of the discharges on reference organisms that represent species which may be adversely affected.

The Environment Agency has assessed the dose rates to reference organisms and feature species for authorised discharges under RSA 93 and, since April 2010, EPR10 (Environment Agency, 2009a). Environmental

concentrations were predicted using appropriate dispersion models and the data were used to calculate the dose rates. The assessment concluded that, for all but two of the habitat sites, dose rates to the worst affected organisms were less than an agreed threshold of 40 μGy $h^{-1}$. Hence, there was no significant impact on the integrity of these habitat sites. The two habitat sites, with the potential for dose rates to the worst affected organism to be greater than the agreed threshold, were the Drigg coast and the Ribble and Alt Estuaries. A detailed assessment has been carried out for the Drigg coast using monitoring data and this confirmed there was no indication of significant impact from ionising radiation on the sand dune biota (Wood *et al*., 2008). A detailed assessment was also carried out for the Ribble and Alt estuaries using monitoring data and taking into account new discharge limits for the Springfields site which came into force in 2008 (Environment Agency, 2009b). This assessment concluded that the dose rate to the worst affected organism was less than the agreed threshold and hence there was no significant impact on the integrity of this habitat site.

SEPA has carried out a Pressures and Impacts Assessment from radioactive substances on Scotland's water environment. The study concluded that there was no adverse impact on the aquatic environment as a result of authorised discharges of radioactive substances, although it recognised that there may be a need for further data to support this conclusion. The study report is available from SEPA. SEPA has included a specific habitats assessment in any new authorisation granted by the agency.

## 1.3 Sources of radiation exposure

### 1.3.1 Radioactive waste disposal from nuclear licensed sites

Nuclear licensed sites in the UK discharge liquid and/or gaseous radioactive waste as part of their operations. In addition, solid Low Level Waste (LLW) from nuclear licensed sites can be transferred to the Low Level Waste Repository (LLWR) near Drigg for disposal and solid wastes containing low levels of radioactivity can also be disposed of to approved landfill sites (see Section 7). Solid LLW from Dounreay can be transferred to the new Dounreay LLW Facility which began accepting waste for disposal in April 2015. These discharges and disposals are regulated by the environment agencies under RSA 93 or EPR 16* (formerly EPR 10).

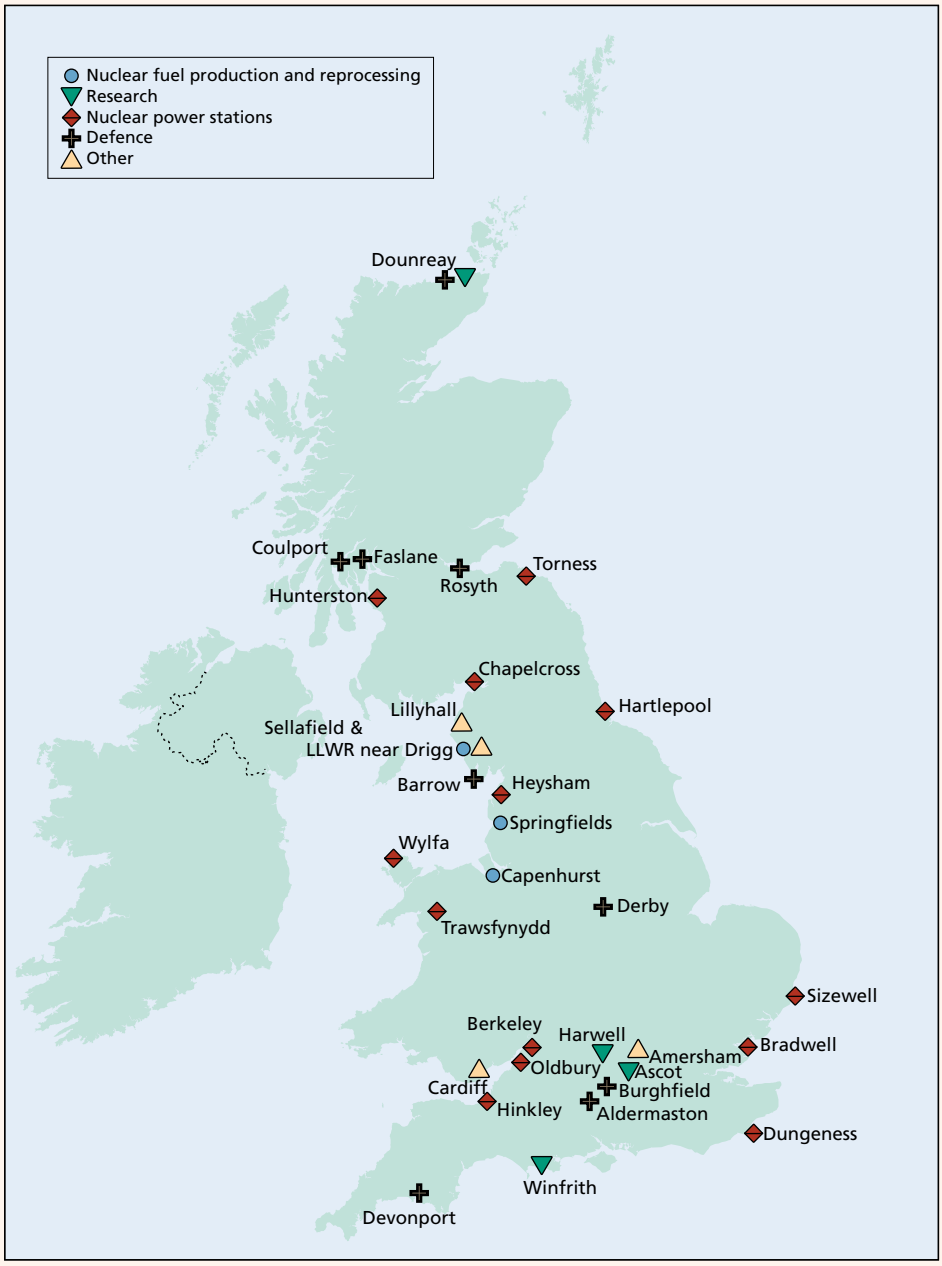
Figure 1.4 shows the nuclear licensed sites that produce waste containing artificial radionuclides. Nuclear licensed sites are authorised to dispose of radioactive waste (United Kingdom - Parliament, 1993). They are also subject to the Nuclear Installations Act (United Kingdom - Parliament, 1965). The monitoring programmes reported here include studies at each of these sites. Discharges of radioactive waste from other sites such as hospitals, industrial sites and research establishments are also regulated under RSA 93 or EPR 16 (formerly EPR 10), but are not subject to the Nuclear Installations Act. Occasionally, radioactivity is detected in the environment during monitoring programmes because of discharges from these other sites. For example, iodine-131 from hospitals is occasionally detected in some river and marine samples. Small amounts of very low level solid radioactive waste are disposed of from some non-nuclear sites to approved landfill sites (for controlled burial, incineration etc.). There is also a significant radiological impact due to the legacy of past discharges of radionuclides from non-nuclear industrial activity that also occur naturally in the environment. This includes radionuclides discharged from the former phosphate processing plant at Whitehaven, and so monitoring is carried out near this site. Discharges from other non-nuclear sites are generally considered insignificant in England and Wales and so monitoring to protect public health is not usually carried out by the environment agencies, although some routine monitoring programmes are undertaken in Lancashire, Northamptonshire and Glamorganshire (Section 7). In Scotland, SEPA undertake routine sampling in the Firth of Clyde and at landfill sites to assess the impact of the non-nuclear industry on the environment. Additionally, to ensure the doses from combined discharges to a sewer network are assessed properly, SEPA periodically undertakes intensive sampling at major sewage treatment plants to monitor the combined discharges from the non-nuclear industry.

Principal authorised/permitted discharges and disposals of radioactive wastes from nuclear establishments in 2016 are given in Appendix 2 (Tables A2.1 - A2.4, inclusive). The tables also list the main discharge and disposal limits that are specified or, in the case of the MoD, administratively agreed. In 2016, discharges and disposals were all below the limits. In 2016, solid waste transfers from nuclear establishments in Scotland are also given in Appendix 2 (Table A2.4). Section 7 gives information on discharges from non-nuclear sites.

The discharge limits are set through an assessment process, initiated either by the operator or the relevant environment agency. In support of the process, prospective assessments of doses to the public are made assuming discharges at the specified limits. Discharge limits are set so that doses to the public will be below the source and site dose constraints of 0.3 and 0.5 mSv per year respectively if discharges occurred at the limits (Environment Agency, SEPA, NIEA, HPA and FSA, 2012). The determination of discharge limits also considers the dose due to consumption of food. During the determination of the limits, the effect of the planned discharges on the environment and wildlife is

* *In England and Wales, the term 'authorisation' has been replaced by 'permit' with EPR 16 (formerly EPR 10, effective from 6th April 2010) taking effect from 1st January 2017. In this report 'permit' has been used to apply to all sites in England and Wales irrespective of whether the period considered includes activities prior to 6th April 2010. 'Authorisation' remains the relevant term for Scotland and Northern Ireland*

**Figure 1.4.** Principal nuclear site sources of radioactive waste disposal in the UK, 2016 (Showing main initial operation. Some operations are undergoing decommissioning)




also considered. In addition, the regulations require Best Available Techniques or Best Available Technology (BAT), under EPR 16 (formerly EPR 10), to be used to further minimise discharges. The principles of Best Practicable Means (BPM) are applied in Scotland (SEPA, 2012a).

The discharges and disposals made by sites are generally regular throughout the year. However, from time to time there may be unplanned events that cause unintended leakages, spillages or other emissions that are different to the normal or expected pattern of discharges. These events must be reported to the environment agencies and may lead to follow up action, including reactive monitoring by the site, the environment agencies or FSA. In cases where there has been a breach of limits, or if appropriate actions have not been undertaken to ensure discharges are as low as possible, regulatory action may be taken. Where monitoring took place because of these events, the results are presented and discussed in the relevant site text later in this report. Appendix 2 (Table A2.5) summarises the types of events that occurred in 2016.

### 1.3.2 International agreements, the UK Discharge Strategy and new nuclear power stations

This section gives information on the context of UK radioactive discharges as they relate to international agreements and the future building of new nuclear power stations. The UK is a contracting part to the Convention for the Protection of the Marine Environment of the North-East Atlantic (the 'OSPAR Convention'). This provides a framework for preventing and eliminating pollution in the north-east Atlantic, including the seas around the UK (OSPAR, 2000a).

In 1998, the Ministers of the UK Government Ministers agreed a long-term Radioactive Substances Strategy (RSS) and signed the Sintra Statement which included the following commitment (OSPAR, 1998):

"We shall ensure that discharges, emissions and losses of radioactive substances are reduced by the year 2020 to levels where the additional concentrations in the marine environment above historical levels, resulting from such discharges, emissions, losses, are close to zero."

In 2002, a UK Strategy for Radioactive Discharges was published (Defra, 2002). This described how the UK would implement the agreements reached at the 1998 and subsequent meetings of OSPAR. The aims of the Strategy related to liquid wastes from the major sources, primarily the nuclear industry, and not to gaseous or solid wastes. BEIS and the Devolved Administrations issued a revised Strategy in 2009 (DECC, Department of the Environment Northern Ireland, the Scottish Government and Welsh Assembly Government, 2009).

The revised Strategy expanded its scope to include aerial, as well as liquid discharges, from decommissioning as well as operational activities, and from the non-nuclear as well as the nuclear industry sectors. It also includes considerations of uncertainties associated with discharges from new nuclear power stations, the possible extension of the operational lives of some of the existing nuclear power reactors, and discharges arising from decommissioning activities. The objectives of this revised Strategy are:

- To implement the UK's obligations, rigorously and transparently, in respect of the OSPAR RSS intermediate objective for 2020
- To provide a clear statement of Government policy and a strategic framework for discharge reductions, sector by sector, to inform decision making by industry and regulators

The expected outcomes of the UK Strategy are:

- Progressive and substantial reductions in radioactive discharges, to the extent needed to achieve the sectoral outcomes, whilst taking uncertainties into account
- Progressive reductions in concentrations of radionuclides in the marine environment resulting from radioactive discharges, such that by 2020 they add close to zero to historical levels
- Progressive reductions in human exposures to ionising radiation resulting from radioactive discharges, from planned reductions in discharges

To support implementation of UK Government policy, the Scottish Government has issued Statutory Guidance to SEPA (Scottish Government, 2008). Similarly, BEIS and the Welsh Government issued guidance to the Environment Agency (DECC and Welsh Assembly Government, 2009). The Environment Agency has developed Radioactive Substances Regulation (RSR) Environmental Principles (RSR Environmental Principles, or REPs) to form a consistent and standardised framework for the technical assessments that will be made when regulating radioactive substances (Environment Agency, 2010a). Developed jointly with SEPA, the Environment Agency has also issued guidance for the assessment of Best Practicable Environmental Option studies at nuclear sites (Environment Agency and SEPA, 2004).

Information on work in progress within the OSPAR Convention can be found on OSPAR's website **www.ospar.org**. The basis for OSPAR's approach is the RSS whose primary objective is to prevent marine pollution (OSPAR, 2003), as amended in 2010 (OSPAR, 2010a). A recent report from the OSPAR Radioactive Substances Committee records work completed and planned, relating to reporting of discharges, environmental measurements, standards and quality assurance (OSPAR, 2017). An agreement has been reached on the basis for monitoring of relevance to OSPAR by Contracting Parties (OSPAR, 2006). The programme includes sampling in fifteen sub-divisions of the OSPAR maritime area and is supported by procedures for ensuring quality control. Inputs in the North-East Atlantic have been summarised for both nuclear and non-nuclear sectors (OSPAR, 2011a; b). The UK submission concerning the implementation of the principle of using BAT has also been published (OSPAR, 2013). Progress by Contracting Parties towards meeting the objectives in RSS has been reviewed (OSPAR, 2016), as has a quality status of the Convention area (OSPAR, 2010b). The Quality Status Report considers radioactivity in food and the environment and refers to results of the monitoring programmes published in earlier issues of this report; the overall conclusions of the review have been summarised elsewhere (Environment Agency, FSA, FSS, NIEA, NRW and SEPA, 2016). The Fourth Periodic Evaluation focusses on radioactive discharges from the nuclear and non-nuclear sectors, reporting there is clear evidence of progress towards the RSS objectives for the nuclear sector (OSPAR, 2016).

The importance of an integrated approach to stewardship of the marine environment has been recognised in the UK, and a strategy to achieve this has been published (Defra, Scottish Executive and Welsh Assembly Government, 2002). The report *"Safeguarding Our Seas"* considers conservation and sustainable development of the marine environment and sets out how the UK is addressing those issues in relation to radioactive and other substances and effects. The UK completed a fully integrated assessment of the marine environment in 2005 (Defra, 2005a, b; Defra, Department of the Environment Northern Ireland, Scottish Executive, Welsh Assembly Government, 2005) and has completed a new assessment *"Charting Progress 2"* in 2010 (Defra, 2010). The Department for Agriculture, Environment and Rural Affairs and the Scottish Government have also published individual assessments of the state of the seas around their coasts (Baxter *et al.,* 2011; Department of the Environment Northern Ireland, 2011).

The EC has considered various options for a new policy instrument concerning the protection and conservation of the marine environment and issued a Marine Strategy Framework Directive (CEC, 2008). The Directive was transposed into UK law (United Kingdom - Parliament, 2010b) and is supported by measures to improve management of the marine environment covering the UK, and latterly Scotland and Northern Ireland (United Kingdom - Parliament, 2009; Scotland - Parliament, 2010; Northern Ireland - Parliament, 2013). It requires Member States to put in place the necessary management measures to achieve Good Environmental Status (GES) in waters under their jurisdiction by 2020. The UK submitted an initial assessment (part one of the Marine Strategy) to the Commission (HM Government, 2012), followed by publication of parts two and three in 2014 and 2015, respectively (Defra, Department of the Environment Northern Ireland, Scottish Government, Welsh Government, 2014; 2015). Further details on the Marine Strategy Framework Directive are provided on the **GOV.UK** website: **http://jncc.defra.gov.uk/page-5193**

In the 2008 White Paper "Meeting the Energy Challenge", (Department for Business, Enterprise and Regulatory Reform, 2008), the UK Government set out its view that new nuclear power stations should have a role to play in this country's future energy mix alongside other low-carbon sources; that it would be in the public interest to allow energy companies the option of investing in new nuclear power stations and that the Government should take active steps to facilitate this. More information concerning subsequent national policy statements, consultations and decisions, together with details of the approach for assessing the design of potential new nuclear power stations and approvals for their proposed developments, is available in earlier RIFE reports (e.g. Environment Agency, FSA, NIEA, NRW and SEPA, 2014). The eight nuclear sites, assessed as being potentially suitable for the development of new nuclear power stations, are shown in Figure 1.5.

As regulators of the nuclear industry, ONR, the Environment Agency and NRW, are working together to ensure that any new nuclear power stations built in the UK meet high standards of safety, security, environmental protection and waste management. The assessment process, Generic Design Assessment (GDA), for the design of potential new nuclear power stations continued in 2016 for Hitachi-GE's UK Advanced Boiling Water Reactor (UK ABWR) and Westinghouse's AP1000® reactor (ONR, Environment Agency and NRW, 2017). The start of the GDA of the UK HPR1000 also commenced following a request from Government in January 2017. ONR continues to be engaged in conducting safety and security assessment for Hinkley Point C and is working with companies seeking to apply for nuclear site licenses at:

- Wylfa, Anglesey (Horizon Nuclear Power Limited, ABWR design)
- Moorside, Cumbria (NuGen Limited, AP1000® design)
- Sizewell C, Suffolk (NNB GenCo Limited, EPR design)

### 1.3.3 Managing radioactive liabilities in the UK

The UK Government has ratified the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management (IAEA, 1997). This agreement has an objective to ensure that individuals, society and the environment are protected from the harmful effects of ionising radiation from the management of spent nuclear fuel and radioactive waste. The UK is required, on a triennial basis, to submit National Reports for international peer review, to comply with the obligations with the Joint Convention (for example, DECC, 2011, 2014b). The European Council Directive 2011/70, for the implementation of management policies for spent fuel and radioactive waste, requires EU Member States to have National Programmes (EC, 2011a). The UK's national report on compliance with the Directive was published in 2015 (DECC, 2015).

The Energy Act 2004 sets out the current arrangements for managing civil sector nuclear clean-up. The Nuclear Decommissioning Authority (NDA), a non-departmental public body (created through the Energy Act 2004), was established in 2005. NDA reports to BEIS and is responsible to Scottish ministers. NDA manages the decommissioning and clean-up of the civil public sector nuclear sites, plus the associated liabilities and assets. In 2016, NDA took direct ownership of Sellafield Limited, which now operates as a wholly owned subsidiary of NDA. The role of NDA is strategic, developing and implementing an overall strategy for cleaning up the civil public sector nuclear legacy safely, securely, and in ways that protect the environment. The Energy Act 2004 requires the NDA to review and publish its strategy every 5 years. The most recent strategy was published in 2016 (NDA, 2016a) and the plan for 2017/20 is available (NDA, 2017). The health and socio-economic impacts of the strategy have been considered (NDA, 2016b). In 2016, NDA published an up-to-date inventory and forecast of radioactive wastes in the UK (as of 1 April 2016) jointly with BEIS (NDA and BEIS, 2016).

In 2007, the UK Government and Devolved Administrations issued a UK-wide policy document, setting out principles for the long-term management of LLW (Defra, DTI and the Devolved Administrations, 2007). Within the policy, NDA were required to develop a UK strategy for the management of solid low level radioactive waste in the nuclear industry. NDA developed and published the "*UK Strategy for the Management of Solid Low-Level Radioactive Waste from the Nuclear Industry*" in 2010 (NDA, 2010). Following a review process, including a public consultation on a revised version, a new strategy was published in February 2016 (DECC, Scottish Government, Welsh Government and Northern Ireland Department of Environment, 2016). The overall direction of the strategy remains unchanged. However, there have been significant changes and these are reflected in the new strategy, including:

**Figure 1.5.** Potential sites for new nuclear power stations


- The diversion of significant volumes of LLW from the Low Level Waste Repository (LLWR)
- The development and use of alternate treatment and disposal routes
- The application of the waste hierarchy by waste producers when making waste management decisions
- The identification of opportunities for improvement and the sharing of good practices for LLW management
- The engagement of a broad range of stakeholders within the process

The 2010 policy statement also acknowledged that a UK-wide strategy was needed for solid radioactive waste arising from the non-nuclear industry (NDA, 2010). More generally, consideration of the development of strategy for LLW from the non-nuclear industry resulted in the development and publication of the strategy in two parts. The first part of the joint UK strategy for the non-nuclear industry (covering anthropogenic waste, for example from hospitals and universities) was published by BEIS in 2012 (DECC, Scottish Government, Welsh Government and the Northern Ireland Department of the Environment, 2012). The second part, covers the UK strategy for all NORM waste, regardless of activity level, including liquid and gaseous Naturally Occurring Radioactive Materials (NORM) wastes as well as solid wastes. (DECC, Scottish Government, Welsh Government and the Northern Ireland Department of the Environment, 2014).

UK Government policy is that geological disposal is the best available means of managing higher activity radioactive waste in the long term.

A framework for implementing geological disposal, including a voluntaristic process for identifying a Geological Disposal Facility (GDF) site that was based on local

communities' willingness to participate in the process, was set out in the 2008 White Paper (Defra, Department for Business, Enterprise and Regulatory Reform, Welsh Assembly Government and Northern Ireland Assembly, 2008). UK Government published the 2014 White Paper that sets out the policy framework for managing higher activity radioactive waste in the long term through geological disposal (DECC, 2014a). The 2014 White Paper sets out a policy framework for the future implementation of geological disposal and explains the "Initial Actions" that will happen before formal discussions begin between interested communities and the developer of a GDF, Radioactive Waste Management Limited (a wholly owned subsidiary company of NDA). Three initial actions, National Geological Screening (NGS); Working with Communities; and Land-use Planning, underpin the work to deliver outputs. A public consultation has been undertaken on the NGS exercise to bring together information about UK geology that is relevant to the long-term safety of a GDF (Radioactive Waste Management, 2016). No specific sites have been selected or are currently under consideration (DECC, 2016a). A scoping report has considered the proposed content of an Appraisal of Sustainability for a GDF policy statement that is being prepared by BEIS (DECC, 2016b) and the NDA has developed an Industry Guidance on the interim storage of packaged higher activity waste, effective from January 2017 (NDA, 2016c).

Radioactive waste management is a devolved policy issue. Therefore, the Scottish Government, Welsh Government and Northern Ireland Executive each have responsibility for determining geological disposal policy in their respective areas.

The Scottish Government is not a sponsor of the programme for implementing geological disposal, but does remain committed to dealing responsibly with radioactive waste arising in Scotland. Scottish Government policy support a robust programme of interim storage and an ongoing programme of research and development, and that the long-term management of higher activity radioactive waste should be in near-surface facilities. Facilities should be located as near to the site as possible (Scottish Government, 2011).

The Welsh Government is committed to securing the long-term safety of radioactive wastes and to the implementation of a framework appropriate to the needs of Wales and continues to play an active part in the Managing Radioactive Waste Safely (MRWS) programme to promote the interests of the people of Wales. In 2015, the Welsh Government adopted a policy for geological disposal for the long-term management of higher activity radioactive waste (Welsh Government, 2015). The Welsh Government's policy states clearly that a GDF will only be built in Wales provided a Welsh community chooses to host the facility. Following the adoption of this policy, the Welsh Government issued a further consultation in 2015. The views of the people of Wales were sought on the processes and mechanisms by which a siting process could be carried out in Wales, should a community in Wales wish to enter and take forward discussions about potentially hosting a GDF.

The Northern Ireland Executive continues to support the implementation of geological disposal for the UK's higher activity radioactive waste, recognising that it is in the best interests of Northern Ireland that these wastes are managed in the safest and most secure manner.

Independent scrutiny of the Government's long-term management, storage and disposal of radioactive waste is continuing by the Committee on Radioactive Waste Management (CoRWM) who have published their proposed work programme for 2015-2016 (CoRWM, 2016).

Some low level radioactive waste, mostly from non-nuclear sites, and some very low level radioactive waste is currently disposed of in landfill by controlled burial (Section 7). There is still a large amount of solid low level radioactive wastes that will require disposal. Some will be sent to the LLWR near Drigg, the low level radioactive waste from Dounreay can be disposed of at the new Dounreay LLW Facility close to the site, and further alternative disposal options are also being considered. Guidance on requirements for authorisation for geological and near-surface disposal facilities has now been issued (Environment Agency and NIEA, 2009; Environment Agency, NIEA and SEPA, 2009; and Environment Agency, 2013a). In addition, SEPA has issued a policy statement which specifies how it will regulate the disposal of LLW from nuclear licensed sites. The position identified has several practical implications including simplification of the process such that individual disposal sites need no longer be named in authorisations (SEPA, 2012b).

Decommissioning of many nuclear sites in Great Britain is underway. In 2016, the environment agencies undertook a consultation process on draft guidance, "Guidance on Requirements for Release of Nuclear Sites from Radioactive Substances Regulation" (GRR), on the principles, requirements and regulatory process that will apply to nuclear sites in all stages of decommissioning and clean-up (NRW, SEPA and the Environment Agency, 2016). The aim is to ensure that radioactive waste and contamination is managed in a way that is safe so that nuclear sites may eventually be released from regulation under radioactive substances legislation. The environment agencies provided a response to the consultation comments in November 2016: **https://consultation.sepa.org.uk/operations-portfolio/grr/results/2016_12_14-grr-consultation-agencies-response.pdf**

NORM is contained in some wastes and is subject to existing regulatory systems that are designed to protect human health and the environment. However, there are improvements that can be achieved and, following a broad ranging consultation, BEIS, the Scottish and Welsh Governments and the Department for Agriculture,

Environment and Rural Affairs published the UK NORM Waste Strategy in 2014 (DECC, Scottish Government, Welsh Government and the Department of the Environment Northern Ireland, 2014). The Strategy in respect of the NORM sector is based on stimulating investment in the waste management supply chain. It will achieve this principally through (i) reforming the regulatory framework to ensure it is clear, coherent and effective, (ii) removing policy barriers to the development of a robust and efficient market for NORM waste management and (iii) supporting efforts by waste producers and the waste management supply chain to generate better data and information about current and future NORM waste arisings.

### 1.3.4 Solid radioactive waste disposal at sea

In the past, packaged solid waste of low specific activity was disposed of deep in the North Atlantic Ocean. The last disposal of this type was in 1982. The UK Government announced at the OSPAR Ministerial meeting in 1998 that it was stopping disposal of this material at sea. At that meeting, Contracting Parties agreed that there would no longer be any exception to prohibiting the dumping of radioactive substances, including waste (OSPAR, 1998). The environmental impact of the deep ocean disposals was predicted by detailed mathematical modelling and has been shown to be negligible (OECD, Nuclear Energy Agency, 1985). Disposals of small amounts of waste also took place from 1950 to 1963 in a part of the English Channel known as the Hurd Deep. The results of environmental monitoring of this area are presented in Section 8 and confirm that the radiological impact of these disposals was insignificant.

In England, the MMO administers a range of statutory controls that apply to marine works on behalf of the Secretary of State for Environment, Food and Rural Affairs; this includes issuing licences under the Marine and Coastal Access Act 2009 (United Kingdom - Parliament, 2009) for the disposal of dredged material at sea. Licences for disposals made in Scottish and Welsh waters, and around the coast of Northern Ireland, are the responsibility of the Scottish Government (Marine Scotland), NRW and the Department of Agriculture Environment and Rural Affairs, respectively.

The protection of the marine environment is considered before a licence is issued. Since dredge materials will contain varying concentrations of radioactivity from natural and artificial sources, assessments are carried out, when appropriate, to provide reassurance that there is no significant risk to the food chain or other risk from the disposal. Guidance on exemption criteria for radioactivity in relation to sea disposal is available from IAEA (1999). IAEA has published a system of assessment that can be applied to dredge spoil disposal (IAEA, 2003; 2015) and which has been adapted to reflect operational practices in England and Wales (McCubbin and Vivian, 2006). No assessments of radiological impact (on behalf of the MMO) were carried out in 2016 for the disposal of dredged material at sea.

### 1.3.5 Other sources of radioactivity

There are several other man-made sources of radioactivity that may affect the food chain and the environment. These could include disposals of material from offshore installations, transport incidents, satellite re-entry, releases from overseas nuclear installations and the operation of nuclear powered submarines. PHE has assessed incidents involving the transport of radioactive materials in the UK (Jones and Harvey, 2014). PHE have also considered the effects of discharges from the oil and gas industry into the marine environment (Harvey *et al.,* 2010). Using modelling, the highest individual (per head of population) annual doses for discharges from 2005 – 2008 were estimated to be less than 0.001 mSv. Submarine berths in the UK are monitored by the MoD (DSTL Radiological Protection Services, 2016). General monitoring of the British Isles is carried out as part of the programmes described in this report, to detect any gross effects from the sources above. No such effects were found in 2016. Low concentrations of radionuclides were detected in the marine environment around the Channel Islands (Section 8) and these may be partly due to discharges from the nuclear fuel reprocessing plant at La Hague in France.

The exploration for, and extraction of, gas from shale rock is being actively investigated in the UK with support from BEIS. Further details on fracking: developing shale gas in the UK (updated January 2017) are provided on the **GOV.UK** website: **www.gov.uk/government/publications/about-shale-gas-and-hydraulic-fracturing-fracking/developing-shale-oil-and-gas-in-the-uk**

This process, along with others for unconventional sources of gas such as coal bed methane, represents a potential source of exposure of the public and workers to naturally occurring radioactivity. The form of the radioactivity could be gaseous, liquid or solid. Examples of routes of exposure are inhalation of radon gas emissions, and ingestion of water and food where the process has enhanced levels of NORM.

Each of the environment agencies is working to ensure that appropriate regulatory regimes are in operation to control exposures of the public from unconventional gas exploration and extraction. Reports have been published to support engagement with industry, the public and other stakeholders (Environment Agency, 2013b; NIEA, 2013; SEPA, 2013) and a review of potential public health impacts of exposures to radioactivity owing to shale gas extraction has been issued by PHE (Kibble *et al*., 2014). The Environment Agency has granted permits for a number of different operators to carry out shale gas exploration at their respective sites, including in Roseacre Wood near Elswick in Lancashire, Preston New Road, near Blackpool,

in Kirby Misperton, near Pickering in North Yorkshire, and in Tinker Lane in Nottinghamshire. BEIS is currently grant-funding a research consortium (led by the British Geological Survey) to deliver a baseline environmental monitoring programme in and around sites in the Fylde (Lancashire) and Kirby Misperton (North Yorkshire). Monitoring of radioactivity from the exploration and extraction of shale gas in the environment and food is not undertaken by the environment agencies, FSA or FSS at present. However, the agencies will continue to review the position as specific proposals for development are taken forward and any results of monitoring will be reported in future issues of the RIFE report.

The Environmental Protection Act 1990 provides the basis for a regulatory regime for identifying and remediating contaminated land. This regime was extended in 2006 to provide a system for identifying and remediating land: contamination causing people to be exposed to lasting exposure to radiation resulting from the after-effects of a radiological emergency, past practice or post work activity; and where intervention is liable to be justified. In the UK, local authorities have a duty to inspect land under Part ll A of the Environmental Protection Act 1990, but there must be reasonable grounds for inspecting land for radioactivity. Reasonable grounds are defined in the statutory guidance. Once a local council has decided that an area is a special site, it is regulated by the environment agencies in their respective areas.

In England and Wales, regulations were extended in 2007 to cover land contaminated with radioactivity originating from nuclear licensed sites. A profile of industries which may have caused land contamination has been published (Defra, 2006). Dose criteria for the designation of contaminated land have been determined for England and Wales (Smith *et al*., 2006). A report giving an overview of the progress made by local authorities and the Environment Agency in identifying and remediating contaminated land was published in 2009 (Environment Agency, 2009c). BEIS issued revised guidance for radioactive contaminated land to local authorities and the Environment Agency in 2012 (DECC, 2012). The Environment Agency has issued a series of Briefing Notes that provide information on land contaminated with radioactivity in England and Wales (Environment Agency, 2012). To date, no site has been legally designated as 'contaminated land' due to radioactivity in England and Wales.

Equivalent legislation for identifying and remediating contaminated land comprising The Radioactive Contaminated Land Regulations (Northern Ireland) 2006 and subsequent amending legislation, issued in 2007 and 2010, exists as Statutory Instruments in Northern Ireland (Statutory Instruments, 2007; 2010).

In 2007, the Radioactive Contaminated Land (Scotland) Regulations came into force by amending Part ll A of the Environmental Protection Act 1990. SEPA has powers to inspect land that may be contaminated with radioactivity, to decide if land should be identified as radioactive contaminated land and require remediation if considered necessary. Revised Statutory Guidance was issued to SEPA in 2009. This guidance is broadly similar to that issued to the Environment Agency, apart from the fact that for the designation of radioactive contaminated land, clear dose criteria are set for homogeneous and heterogeneous contamination, and whether or not the probability of receiving the dose should be taken into account. To date, no site has been designated as 'contaminated land' due to radioactivity in Scotland.

The contribution of aerial radioactive discharges from UK installations to concentrations of radionuclides in the marine environment has been studied (Defra, 2004). The main conclusion was that aerial discharges do not make a significant contribution to levels in the marine environment. On occasion, the effects of aerial discharges may be detected in the aquatic environment, and conversely the effects of aquatic discharges may be detected on land. Where this is found, appropriate comments are made in this report.

All sources of ionising radiation exposure to the UK population are reviewed, the most recent report was published in 2016 (Oatway *et al*., 2016). The predominate source was natural radiation (radon and thoron). The estimated dose for each person from exposure to all significant sources of ionising radiation was about 2.7 mSv, the same as that reported in the previous review (Watson *et al*., 2005). The dose from radiation in the environment was about 2.3 mSv, or about 84 per cent of the dose from all sources of radiation. This was dominated by exposure to naturally occurring sources of radiation although there is significant variation across the UK due to local geology and other factors. Only about 0.2 per cent of the dose was from man-made sources; the majority was from radionuclides released during historical testing of nuclear weapons in the atmosphere, with exposure to radionuclides routinely discharged by industry contributing less than 0.01 per cent to the total dose. The dose for each person in the UK population not due to exposure to radiation in the environment was about 0.4 mSv, or about 16 per cent of the dose from all sources of radiation. This was almost entirely the result of patient exposure during diagnostic medical examinations. Occupational exposure contributed significantly less than 1 per cent of the dose. These figures represent the exposure of the average person.

The RIFE report is directed at establishing the exposure of people who might receive the highest possible doses due to radioactive waste discharges, because of their age, diet, location or habits. It is the exposure of these people which forms the basis for comparisons with dose limits in EU and UK law.

## Table 1.1 Individual doses - direct radiation pathway, 2016

| Site | Exposure, mSv |
|---|---|
| **Nuclear fuel production and reprocessing** | |
| Capenhurst | 0.17 |
| Sellafield | 0.005 |
| Springfields | 0.026 |
| **Research establishments** | |
| Dounreay | 0.006 |
| Harwell | 0.015 |
| Winfrith | 0.019 |
| **Nuclear power stations** | |
| Berkeley | Bgd[a] |
| Bradwell | 0.036 |
| Chapelcross | Bgd[a] |
| Dungeness | 0.020[b] |
| Hartlepool | 0.010 |
| Heysham | 0.010 |
| Hinkley Point | 0.010[c] |
| Hunterston | 0.020[d] |
| Oldbury | Bgd[a] |
| Sizewell | 0.020[e] |
| Torness | 0.020 |
| Trawsfynydd | 0.006 |
| Wylfa | 0.006 |
| **Defence establishments** | |
| Aldermaston | Bgd[a] |
| Barrow | Bgd[a] |
| Burghfield | Bgd[a] |
| Derby | Bgd[a] |
| Devonport | Bgd[a] |
| Faslane | Bgd[a] |
| Rosyth | Bgd[a] |
| **Radiochemical production** | |
| Amersham | 0.14 |
| Cardiff | Bgd[a] |
| **Industrial and landfill sites** | |
| LLWR near Drigg | 0.032 |

[a] *Doses not significantly different from natural background*
[b] *Datum for Dungeness B. Dungeness A (0.013) not used*
[c] *Datum for Hinkley B. Hinkley A (Bgd[a]) not used*
[d] *Datum for Hunterston B. Hunterston A (0.002) not used*
[e] *Datum for Sizewell B. Sizewell A (Bgd[a]) not used*

**Table 1.2 *Total doses* integrated across pathways, 2016**

| Site | Representative person[a] | Exposure, mSv | |
|---|---|---|---|
| | | Total | Dominant contributions[b] |
| **A Gaseous releases and direct radiation from the site** | | | |
| Aldermaston & Burghfield | Infant milk consumers | <0.005[g] | Milk, $^{3}H$[c], $^{137}Cs$[c] |
| Amersham | Local adult inhabitants (0–0.25km) | 0.15[g] | Direct radiation |
| Barrow | Adult potato consumers | <0.005 | Gamma dose rate over sediment, potatoes, $^{137}Cs$ |
| Berkeley & Oldbury | Infant milk consumers | 0.006 | Milk, $^{14}C$ |
| Bradwell | Prenatal children of local inhabitants (0–0.25km) | 0.036 | Direct radiation |
| Capenhurst | Infant local inhabitants (0.25–0.5km) | 0.17[g] | Direct radiation |
| Cardiff | Infant milk consumers | <0.005 | Milk, $^{14}C$, $^{32}P$[c], $^{35}S$ |
| Chapelcross | Infant milk consumers | 0.026 | Milk, $^{14}C$, $^{90}Sr$, $^{241}Am$[c] |
| Derby | Children potato consumers | <0.005[g] | Potatoes, $^{234}U$, $^{238}U$ |
| Devonport | Prenatal children of milk consumers | <0.005 | Potatoes, $^{3}H$[c] |
| Dounreay | Adult game meat consumers | 0.058 | Meat – game, $^{137}Cs$ |
| Dungeness | Local adult inhabitants (0–0.25km) | 0.021 | Direct radiation |
| Faslane | Adult honey consumers | <0.005 | Gamma dose rate over sediment, honey, $^{137}Cs$ |
| Hartlepool | Local adult inhabitants (0–0.25km) | 0.020 | Direct radiation, gamma dose rate over sediment |
| Harwell | Local adult inhabitants (0–0.25km) | 0.015 | Direct radiation |
| Heysham | Local adult inhabitants (0–0.25km) | 0.014 | Direct radiation, gamma dose rate over sediment, external and inhalation near site, $^{14}C$ |
| Hinkley Point | Prenatal children of occupants for direct radiation | 0.012 | Direct radiation, gamma dose rate over sediment |
| Hunterston | Prenatal children of local inhabitants (0.25–0.5km) | 0.021 | Direct radiation |
| LLWR near Drigg | Infant local inhabitants (0.5–1km) | 0.034 | Direct radiation |
| Rosyth[d] | – | – | |
| Sellafield | Local child inhabitants (0–0.25km) | 0.008[g] | Direct radiation, potatoes |
| Sizewell | Local adult inhabitants (0–0.25km) | 0.021 | Direct radiation |
| Springfields | Local adult inhabitants (0.5–1km) | 0.026[g] | Direct radiation |
| Torness | Prenatal children of local inhabitants (0.5–1km) | 0.021 | Direct radiation |
| Trawsfynydd | Infant local inhabitants (0.25–0.5km) | 0.019 | Direct radiation, milk, $^{14}C$, $^{241}Am$ |
| Winfrith | Prenatal children of local inhabitants (0.5–1km) | 0.019 | Direct radiation |
| Wylfa | Infant local inhabitants (0.25–0.5km) | 0.008 | Direct radiation, milk, $^{14}C$ |
| **B Liquid releases from the site** | | | |
| Aldermaston & Burghfield | Adult occupants over riverbank | <0.005 | Exposure over riverbank |
| Amersham | Adult occupants over riverbank | <0.005 | Gamma dose rate over riverbank |
| Barrow | Adult occupants on houseboats | 0.082 | Gamma dose rate over sediment |
| Berkeley & Oldbury | Adult occupants over sediment | <0.005 | Gamma dose rate over sediment |
| Bradwell | Infant consumers of marine plants and algae | <0.005 | Direct radiation |
| Capenhurst | Occupants over riverbank aged 10y | 0.009 | Gamma dose rate over sediment |
| Cardiff | Prenatal children of occupants over sediment | <0.005 | Gamma dose rate over sediment |
| Chapelcross | Adult wildfowl consumers | 0.006 | Gamma dose rate over sediment, molluscs, wildfowl, $^{239/240}Pu$, $^{241}Am$ |
| Derby | Adult consumers of locally sourced water | <0.005 | Water, $^{60}Co$[c] |
| Devonport | Adult fish consumers | <0.005 | Fish, $^{14}C$, $^{131}I$[c], $^{241}Am$[c] |
| Dounreay | Adult occupants over sediment | 0.013 | Gamma dose rate over sediment |
| Dungeness | Adult fish consumers | <0.005 | Crustaceans, fish, $^{137}Cs$[c], $^{241}Am$ |
| Faslane | Adult fish consumers | 0.009 | Fish, gamma dose rate over sediment, $^{137}Cs$, $^{241}Am$ |
| Hartlepool | Adult occupants over sediment | 0.019 | Direct radiation, gamma dose rate over sediment |
| Harwell | Adult occupants over sediment | <0.005 | Gamma dose rate over riverbank |
| Heysham | Adult occupants over sediment | 0.019 | Gamma dose rate over sediment |
| Hinkley Point | Adult occupants over sediment | 0.013 | Gamma dose rate over sediment |
| Hunterston | Adult occupants over sediment | <0.005 | Gamma dose rate over sediment |
| LLWR near Drigg[e] | Adult mollusc consumers | 0.41[f] | Crustaceans, $^{210}Po$ |

**Table 1.2 continued**

| Site | Representative person[a] | Exposure, mSv | |
|---|---|---|---|
| | | Total | Dominant contributions[b] |
| Rosyth | Adult occupants over sediment | 0.017 | Gamma dose rate over sediment |
| Sellafield[e] | Adult mollusc consumers | 0.41[f] | Crustaceans, $^{210}$Po |
| Sizewell | Adult occupants over sediment | 0.007 | Direct radiation, gamma dose rate over sediment |
| Springfields | Adult occupants on houseboats | 0.038 | Gamma dose rate over sediment |
| Torness | Adult fish consumers | <0.005 | Fish, $^{241}$Am |
| Trawsfynydd | Prenatal children of fish consumers | <0.005 | Exposure over sediment, fish, $^{14}$C, $^{90}$Sr |
| Whitehaven[e] | Adult mollusc consumers | 0.41[f] | Crustaceans, $^{210}$Po |
| Winfrith | Adult occupants over sediment | 0.007 | Direct radiation, gamma dose rate over sediment |
| Wylfa | Adult occupants over sediment | 0.007 | Gamma dose rate over sediment |
| | | | |
| **C All sources** | | | |
| Aldermaston & Burghfield | Infant milk consumers | <0.005[g] | Milk, $^{3}$H[c], $^{137}$Cs[c] |
| Amersham | Local adult inhabitants (0–0.25km) | 0.15[g] | Direct radiation |
| Barrow | Adult occupants on houseboats | 0.082 | Gamma dose rate over sediment |
| Berkeley & Oldbury | Infant milk consumers | 0.006 | Milk, $^{14}$C |
| Bradwell | Prenatal children of local inhabitants (0–0.25km) | 0.036 | Direct radiation |
| Capenhurst | Infant local inhabitants (0.25–0.5km) | 0.17[g] | Direct radiation |
| Cardiff | Infant milk consumers | <0.005 | Milk, $^{14}$C, $^{32}$P[c], $^{35}$S |
| Chapelcross | Infant milk consumers | 0.026 | Milk, $^{14}$C, $^{90}$Sr, $^{241}$Am[c] |
| Derby | Adult consumers of locally sourced water | <0.005 | Water, $^{60}$Co[c] |
| Devonport | Adult fish consumers | <0.005 | Fish, $^{14}$C, $^{131}$I[c], $^{241}$Am[c] |
| Dounreay | Adult game meat consumers | 0.058 | Meat - game, $^{137}$Cs |
| Dungeness | Local adult inhabitants (0–0.25km) | 0.021 | Direct radiation |
| Faslane | Adult fish consumers | 0.009 | Fish, gamma dose rate over sediment, $^{137}$Cs, $^{241}$Am |
| Hartlepool | Local adult inhabitants (0–0.25km) | 0.020 | Direct radiation, gamma dose rate over sediment |
| Harwell | Local adult inhabitants (0–0.25km) | 0.015 | Direct radiation |
| Heysham | Adult occupants over sediment | 0.019 | Gamma dose rate over sediment |
| Hinkley Point | Adult occupants over sediment | 0.013 | Gamma dose rate over sediment |
| Hunterston | Prenatal children of local inhabitants (0.25–0.5km) | 0.021 | Direct radiation |
| LLWR near Drigg[e] | Adult mollusc consumers | 0.41[f] | Crustaceans, $^{210}$Po |
| Rosyth | Adult occupants over sediment | 0.017 | Gamma dose rate over sediment |
| Sellafield[e] | Adult mollusc consumers | 0.41[f] | Crustaceans, $^{210}$Po |
| Sizewell | Local adult inhabitants (0–0.25km) | 0.021 | Direct radiation |
| Springfields | Adult occupants on houseboats | 0.038 | Gamma dose rate over sediment |
| Torness | Prenatal children of local inhabitants (0.5–1km) | 0.021 | Direct radiation |
| Trawsfynydd | Infant local inhabitants (0.25–0.5km) | 0.019 | Direct radiation, milk, $^{14}$C, $^{241}$Am |
| Whitehaven[e] | Adult mollusc consumers | 0.41[f] | Crustaceans, $^{210}$Po |
| Winfrith | Local adult inhabitants (0.5–1km) | 0.019 | Direct radiation |
| Wylfa | Infant local inhabitants (0.25–0.5km) | 0.008 | Direct radiation, milk, $^{14}$C |

[a] *Selected on the basis of providing the highest dose from the pathways associated with the sources as defined in A, B or C*

[b] *Pathways and radionuclides that contribute more than 10% of the* total dose. *Some radionuclides are reported as being at the limits of detection and based on these measurements, an upper estimate of dose is calculated*

[c] *The assessed contribution is based on data at limits of detection*

[d] *The effects of gaseous discharges and direct radiation are not assessed as there are no sources for this site*

[e] *The effects of liquid discharges from Sellafield, Whitehaven and LLWR near Drigg are considered together when assessing exposures at these sites because their effects are manifested in a common area of the Cumbrian coast*

[f] *The doses from man-made and naturally occurring radionuclides were 0.074 and 0.34 mSv respectively. The source of naturally occurring radionuclides was a phosphate processing works near Sellafield at Whitehaven. Minor discharges of radionuclides were also made from the LLWR near Drigg into the same area*

[g] *Includes a component due to natural sources of radionuclides*

**Table 1.3 Trends in *total doses* (mSv) from all sources[a]**

| Site | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Aldermaston & Burghfield | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 |
| Amersham | | 0.24 | 0.24 | 0.22 | 0.23 | 0.22 | 0.22 | 0.22 | 0.22 | 0.22 | 0.22 | 0.14 | 0.14 | 0.15 |
| Barrow | | | | | | | | | | 0.057 | 0.076 | 0.055 | 0.051 | 0.082 |
| Berkeley & Oldbury | | *0.12* | *0.090* | *0.042* | 0.061 | 0.041 | 0.058 | 0.011 | 0.006 | 0.014 | 0.010 | <0.005 | <0.005 | 0.006 |
| Bradwell | | *0.090* | *0.067* | *0.075* | 0.070 | 0.070 | 0.098 | 0.13 | 0.048 | <0.005 | <0.005 | <0.005 | 0.017 | 0.036 |
| Capenhurst | | *0.080* | *0.080* | *0.085* | *0.12* | 0.17 | 0.19 | 0.26 | 0.095 | 0.085 | 0.080 | 0.17 | 0.13 | 0.17 |
| Cardiff | 0.038 | 0.023 | 0.023 | 0.011 | 0.008 | 0.007 | 0.006 | 0.006 | 0.006 | 0.005 | 0.010 | <0.005 | <0.005 | <0.005 |
| Chapelcross | | *0.022* | 0.023 | 0.024 | 0.019 | 0.021 | 0.017 | 0.029 | 0.037 | 0.011 | 0.024 | 0.014 | 0.022 | 0.026 |
| Derby | | | | | | | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 |
| Devonport | | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 |
| Dounreay | 0.012 | 0.011 | 0.043 | 0.029 | 0.059 | 0.078 | 0.063 | 0.047 | 0.018 | 0.017 | 0.012 | 0.012 | 0.010 | 0.058 |
| Dungeness | | *0.48* | 0.55 | 0.63 | 0.28 | 0.40 | 0.32 | 0.022 | 0.021 | 0.015 | 0.021 | 0.021 | 0.014 | 0.021 |
| Faslane | | *<0.005* | *<0.005* | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | 0.009 |
| Hartlepool | 0.021 | 0.020 | 0.021 | 0.021 | 0.021 | 0.026 | 0.027 | 0.025 | 0.025 | 0.015 | 0.024 | 0.027 | 0.022 | 0.020 |
| Harwell | | *0.017* | *0.022* | *0.026* | 0.022 | 0.020 | 0.023 | 0.018 | 0.017 | 0.018 | 0.010 | 0.016 | 0.017 | 0.015 |
| Heysham | | *0.036* | *0.028* | 0.037 | 0.038 | 0.046 | 0.049 | 0.057 | 0.025 | 0.025 | 0.028 | 0.023 | 0.023 | 0.019 |
| Hinkley Point | | *0.026* | *0.027* | 0.048 | 0.035 | 0.045 | 0.055 | 0.014 | 0.014 | 0.013 | 0.022 | 0.022 | 0.016 | 0.013 |
| Hunterston | | 0.10 | 0.090 | 0.074 | 0.090 | 0.077 | 0.067 | 0.067 | 0.050 | 0.032 | 0.021 | 0.021 | 0.025 | 0.021 |
| LLWR near Drigg[b] | 0.66 | 0.58 | 0.40 | 0.43 | 0.37 | 0.47 | 0.28 | 0.18 | 0.18 | 0.30 | 0.061 | 0.22 | 0.42 | 0.41 |
| Rosyth | | *<0.005* | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | 0.006 | 0.017 |
| Sellafield[b] | 0.66 | 0.58 | 0.40 | 0.43 | 0.37 | 0.47 | 0.28 | 0.18 | 0.18 | 0.30 | 0.076[c] | 0.22 | 0.42 | 0.41 |
| Sizewell | | *0.045* | 0.086 | 0.090 | <0.005 | 0.031 | 0.026 | 0.020 | 0.021 | 0.021 | 0.021 | 0.020 | 0.021 | 0.021 |
| Springfields | | *0.17* | *0.15* | 0.13 | 0.11 | 0.16 | 0.15 | 0.17 | 0.13 | 0.068 | 0.060 | 0.050 | 0.050 | 0.038 |
| Torness | | *0.024* | *0.025* | 0.024 | 0.022 | 0.022 | 0.022 | 0.025 | 0.020 | 0.020 | 0.020 | 0.020 | 0.020 | 0.021 |
| Trawsfynydd | | *0.032* | 0.021 | 0.028 | 0.018 | 0.031 | 0.018 | 0.028 | 0.012 | 0.025 | 0.017 | 0.013 | 0.014 | 0.019 |
| Whitehaven[b] | 0.66 | 0.58 | 0.40 | 0.43 | 0.37 | 0.47 | 0.28 | 0.18 | 0.18 | 0.30 | 0.061 | 0.22 | 0.42 | 0.41 |
| Winfrith | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | 0.014 | 0.019 |
| Wylfa | | 0.011 | 0.010 | 0.011 | 0.011 | 0.011 | 0.011 | 0.007 | 0.008 | 0.006 | <0.005 | 0.007 | 0.013 | 0.008 |

[a] *Where no data are given, no assessment was undertaken due to a lack of suitable habits data at the time. Data in italics signify assessments performed to show trends in* total dose *over the five-year period from 2004–2008, using subsequently obtained habits data*

[b] *The effects of liquid discharges from Sellafield, Whitehaven and LLWR near Drigg are considered together when assessing exposures at these sites*

[c] *The highest exposure due to operations at Sellafield was to people living in houseboats near Barrow*

## Table 1.4 Source specific doses due to discharges of radioactive waste in the United Kingdom, 2016

| Establishment | Radiation exposure pathways | Gaseous or liquid source[e] | Exposure, mSv[b] per year | Contributors[c] |
|---|---|---|---|---|
| **Nuclear fuel production and processing** | | | | |
| Capenhurst | Inadvertent ingestion of water and sediment and external[h] | L | 0.011 | Ext |
| | Terrestrial foods, external and inhalation near site[j] | G | <0.005[i] | $^{3}H^{d}$, $^{99}Tc^{d}$, $^{234}U$, $^{238}U$ |
| Springfields | Fish and shellfish consumption and external in intertidal areas | L | 0.019 | Ext |
| | Terrestrial foods, external and inhalation near site | G | <0.005[i] | $^{14}C$, $^{129}I^{d}$, $^{232}Th^{d}$ |
| | External in intertidal areas (children playing)[a,h] | L | <0.005 | Ext |
| | Occupancy of houseboats | L | 0.038 | Ext |
| | External in intertidal areas (farmers) | L | 0.033 | Ext |
| | External (skin) to fishermen | L | 0.022[j] | Beta |
| | Wildfowl consumers | L | 0.005 | Ext |
| Sellafield[f] | Fish and shellfish consumption and external in intertidal areas (2012-2016 surveys) (excluding naturally occurring radionuclides)[l] | L | 0.083 | Ext, $^{239/240}Pu$, $^{241}Am$ |
| | Fish and shellfish consumption and external in intertidal areas (2012-2016 surveys) (including naturally occurring radionuclides)[m] | L | 0.43 | $^{210}Po$ |
| | Fish and shellfish consumption and external in intertidal areas (2016 surveys) (excluding naturally occurring radionuclides)[l] | L | 0.084 | Ext, $^{239/240}Pu$, $^{241}Am$ |
| | Terrestrial foods, external and inhalation near Sellafield[j] | G | 0.013 | $^{14}C$, $^{90}Sr$, $^{106}Ru^{d}$ |
| | Terrestrial foods at Ravenglass[j] | G/L | 0.019 | $^{106}Ru^{d}$, $^{144}Ce^{d}$ |
| | External in intertidal areas (Ravenglass)[a] | L | 0.011 | Ext |
| | Occupancy of houseboats (Ribble estuary) | L | 0.038 | Ext |
| | Occupancy of houseboats (Barrow) | L | 0.081 | Ext |
| | External (skin) to bait diggers | L | 0.064[g] | Beta |
| | Handling of fishing gear | L | 0.087 | Beta |
| | | | | |
| **Research establishments** | | | | |
| Culham | Water consumption[o] | L | <0.005 | $^{137}Cs^{d}$ |
| Dounreay | Fish and shellfish consumption and external in intertidal areas | L | 0.013 | Ext |
| | Terrestrial foods, external and inhalation near site | G | 0.043 | $^{137}Cs$ |
| Harwell | Fish consumption and external to anglers | L | <0.005 | Ext |
| | Terrestrial foods, external and inhalation near site[j] | G | <0.005 | $^{222}Rn$ |
| Winfrith | Fish and shellfish consumption and external in intertidal areas | L | <0.005 | Ext, $^{241}Am$ |
| | Terrestrial foods, external and inhalation near site[j] | G | <0.005 | $^{14}C$ |
| | | | | |
| **Nuclear power production** | | | | |
| Berkeley & Oldbury | Fish and shellfish consumption and external in intertidal areas | L | <0.005 | Ext |
| | Occupancy of houseboats | L | 0.031 | Ext |
| | Terrestrial foods, external and inhalation near site[j] | G | 0.006 | $^{14}C$ |
| Bradwell | Fish and shellfish consumption and external in intertidal areas | L | <0.005 | Ext |
| | Terrestrial foods, external and inhalation near site[j] | G | 0.006 | $^{14}C$ |
| Chapelcross | Wildfowl, fish and mollusc consumption and external in intertidal areas | L | 0.009 | Ext, $^{239/240}Pu$ $^{241}Am$ |
| | Crustacean consumption | L | <0.005 | $^{137}Cs$, $^{241}Am$ |
| | Terrestrial foods, external and inhalation near site[j] | G | 0.018 | $^{14}C$, $^{90}Sr$, $^{241}Am^{d}$ |
| Dungeness | Fish and shellfish consumption and external in intertidal areas | L | <0.005 | $^{241}Am$ |
| | Occupancy of houseboats | L | 0.009 | Ext |
| | Terrestrial foods, external and inhalation near site[j] | G | 0.010 | $^{14}C$ |
| Hartlepool | Fish and shellfish consumption and external in intertidal areas | L | 0.018 | Ext, $^{241}Am$ |
| | Terrestrial foods, external and inhalation near site[j] | G | <0.005 | $^{14}C$, $^{35}S^{d}$, $^{60}Co^{d}$ |
| Heysham | Fish and shellfish consumption and external in intertidal areas | L | 0.024 | Ext |
| | External in intertidal areas (turf cutters) | L | 0.010 | Ext |
| | Terrestrial foods, external and inhalation near site[j] | G | 0.007 | $^{14}C$ |
| Hinkley Point | Fish and shellfish consumption and external in intertidal areas | L | 0.018 | Ext |
| | Terrestrial foods, external and inhalation near site[j] | G | 0.011 | $^{14}C$ |
| Hunterston | Fish and shellfish consumption and external in intertidal areas | L | 0.006 | Ext, $^{241}Am$ |
| | Terrestrial foods, external and inhalation near site[j] | G | 0.010 | $^{14}C$, $^{35}S$, $^{90}Sr$ |
| Sizewell | Fish and shellfish consumption and external in intertidal areas | L | <0.005 | Ext, $^{241}Am$ |
| | Occupancy of houseboats | L | <0.005 | Ext |
| | Terrestrial foods, external and inhalation near site[j] | G | 0.006 | $^{14}C$, $^{35}S^{d}$ |

**Table 1.4 continued**

| Establishment | Radiation exposure pathways | Gaseous or liquid source[e] | Exposure, mSv[b] per year | Contributors[c] |
|---|---|---|---|---|
| Torness | Fish and shellfish consumption and external in intertidal areas | L | <0.005 | $^{241}$Am |
| | Terrestrial foods, external and inhalation near site[j] | G | 0.008 | $^{14}$C, $^{35}$S[d], $^{90}$Sr |
| Trawsfynydd | Fish consumption and external to anglers | L | <0.005 | Ext, $^{14}$C, $^{90}$Sr, $^{137}$Cs |
| | Terrestrial foods, external and inhalation near site[j] | G | 0.025 | $^{14}$C, $^{241}$Am |
| Wylfa | Fish and shellfish consumption and external in intertidal areas | L | 0.009 | Ext, $^{241}$Am |
| | Terrestrial foods, external and inhalation near site[j] | G | 0.005 | $^{14}$C, $^{35}$S |
| **Defence establishments** | | | | |
| Aldermaston | Fish consumption and external to anglers | L | <0.005[i] | Ext |
| | Terrestrial foods, external and inhalation near site[j] | G | <0.005[i] | $^{3}$H[d], $^{137}$Cs[d], $^{234}$U |
| Barrow | Occupancy of houseboats | L | 0.081 | Ext |
| | Terrestrial food consumption | G | <0.005 | $^{137}$Cs |
| Derby | Water consumption, fish consumption and external to anglers[o] | L | <0.005 | $^{60}$Co[d] |
| | Terrestrial foods, external and inhalation near site[h] | G | <0.005 | $^{234}$U, $^{238}$U |
| Devonport | Fish and shellfish consumption and external in intertidal areas | L | <0.005 | $^{14}$C, $^{131}$I[d], $^{241}$Am[d] |
| | Occupancy of houseboats | L | <0.005 | Ext |
| | Terrestrial foods, external and inhalation near site[p] | G | <0.005 | $^{3}$H[d] |
| Faslane | Fish and shellfish consumption and external in intertidal areas | L | 0.012 | Ext, $^{137}$Cs, $^{241}$Am |
| | Terrestrial food consumption | G | <0.005 | $^{137}$Cs |
| Holy Loch | External in intertidal areas | L | 0.013 | Ext |
| Rosyth | Fish and shellfish consumption and external in intertidal areas | L | 0.020 | Ext, $^{241}$Am[d] |
| **Radiochemical production** | | | | |
| Amersham | Fish consumption and external to anglers | L | <0.005 | Ext, $^{137}$Cs |
| | Terrestrial foods, external and inhalation near site[j] | G | 0.009 | $^{222}$Rn |
| Cardiff | Fish and shellfish consumption and external in intertidal areas[p] | L | <0.005 | Ext |
| | Terrestrial foods, external and inhalation near site[j] | G | <0.005 | $^{14}$C, $^{32}$P[d], $^{35}$S |
| | Inadvertent ingestion and riverbank occupancy (River Taff) | L | <0.005 | $^{14}$C |
| **Industrial and landfill** | | | | |
| LLWR near Drigg | Terrestrial foods[j] | G | 0.007 | $^{90}$Sr, $^{106}$Ru[d], $^{137}$Cs, $^{144}$Ce[d] |
| | Fish and shellfish consumption and external in intertidal areas (2012-2016 surveys) (including naturally occurring radionuclides)[f,m] | L | 0.43 | $^{210}$Po |
| | Water consumption[o] | L | <0.005 | $^{134}$Cs[d], $^{137}$Cs[d], $^{210}$Po[d] |
| Whitehaven | Fish and shellfish consumption and external in intertidal areas (2012-2016 surveys) (excluding artificial radionuclides)[f,k] | L | 0.35 | $^{210}$Po |
| | Fish and shellfish consumption and external in intertidal areas (2012-2016 surveys) (including artificial radionuclides)[f,n] | L | 0.43 | $^{210}$Po |

* *Source specific dose assessments are performed to provide additional information and as a check on the* total dose *assessment method*

[a] *Includes a component due to inadvertent ingestion of water or sediment or inhalation of resuspended sediment where appropriate*

[b] *Unless otherwise stated represents committed effective dose calculated using methodology of ICRP-60 to be compared with the dose limit of 1 mSv (see Appendix 1). Exposures due to marine pathways include the far-field effects of discharges of liquid waste from Sellafield. Unless stated otherwise, the critical group is represented by adults*

[c] *The contributors that give rise to more than 10% to the dose; either 'ext' to represent the whole body external exposure from beta or gamma radiation, 'beta' for beta radiation of skin or a radionuclide name to represent a contribution from internal exposure. The source of the radiation listed as contributing to the dose may not be discharged from the site specified, but may be from those of an adjacent site or other sources in the environment such as weapons fallout*

[d] *The assessed contribution is based on data at limits of detection.*

[e] *Dominant source of exposure. G for gaseous wastes. L for liquid wastes or surface water near solid waste sites. See also footnote 'c'*

[f] *The estimates for marine pathways include the effects of liquid discharges from LLWR. The contribution due to LLWR is negligible*

[g] *Exposure to skin including a component due to natural sources of beta radiation, to be compared with the dose limit of 50 mSv (see Appendix 1)*

[h] *10 year-old*

[i] *Includes a component due to natural sources of radionuclides*

[j] *1 year-old*

[k] *Excluding the effects of artificial radionuclides from Sellafield*

[l] *Excluding the effects of enhanced concentrations due to the legacy of discharges of naturally occurring radionuclides from a phosphate processing works, Whitehaven*

[m] *Including the effects of enhanced concentrations due to the legacy of discharges of naturally occurring radionuclides from a phosphate processing works, Whitehaven*

[n] *Including the effects of artificial radionuclides from Sellafield*

[o] *Water is from rivers and streams and not tap water*

[p] *Prenatal children*

# 2. Nuclear fuel production and reprocessing

This section considers the results of monitoring, by the Environment Agency, FSA, NIEA and SEPA, of three sites in the UK associated with civil nuclear fuel production and reprocessing. These sites are at:

Capenhurst, a site where uranium enrichment is carried out and management of uranic materials and decommissioning activities are undertaken; Springfields, a site where fuel for nuclear power stations is fabricated; Sellafield, a site where irradiated fuel from nuclear power stations is reprocessed.

The Capenhurst site is owned partly by Urenco UK Limited (UUK) and partly by NDA. UUK holds the Site Licence, and their main commercial business is production of enriched uranium for nuclear power stations. NDA's legacy storage and decommissioning activities are managed by an Urenco Group company, Capenhurst Nuclear Services Limited (CNS). Another Urenco Group company, Urenco ChemPlants Limited (UCP), is currently building a new facility (Tails Management Facility, planned to be commissioned in late 2017/early 2018) on a separate part of the site.

Both the Springfields and Sellafield sites are owned by NDA. The Springfields site is leased long-term to Springfields Fuels Limited, and used to carry out nuclear fuel manufacture and other commercial activities and have a contract with NDA to decommission legacy facilities on the site. The main operations on the Sellafield site are fuel reprocessing, decommissioning and clean-up of redundant nuclear facilities, and waste treatment and storage. On 1 April 2016, NDA became the owner of Sellafield Limited, the Site Licence Company responsible for managing and operating Sellafield on behalf of the NDA, replacing the previous management model of ownership (Parent Body Organisation (PBO) concept) by the private sector.

The Windscale site, also owned by NDA, is located on the Sellafield site and in 2008 the site licence for Windscale was transferred to Sellafield Limited, integrating the Windscale and Sellafield sites. Windscale is discussed in Section 2.4. Note that the LLWR site near Drigg is separate from Sellafield and is discussed in Section 7.1.

Gaseous and liquid discharges from each of these sites are regulated by the Environment Agency. In 2016, gaseous and liquid discharges were below permit limits for each of the sites (see Appendix 2).

## Key points

- *Total doses* for the representative person were 41 per cent (or less) of the dose limit for all assessed sites and decreased in 2016

### Capenhurst, Cheshire

- *Total dose* for the representative person was 17 per cent of the public dose limit and increased in 2016
- Gaseous discharges of uranium (from UUK) and alpha radioactivity (from CNS), and liquid discharges of non-uranic alpha radioactivity (from UUK), decreased in 2016

### Springfields, Lancashire

- *Total dose* for the representative person was less than 4 per cent of the public dose limit and decreased in 2016.
- Gaseous discharges of tritium (National Nuclear Laboratory) and liquid discharges of uranium and alpha emitting radionuclides decreased, liquid discharges of technetium-99, neptunium-237 and "other transuranic radionuclide" increased, in 2016

### Sellafield, Cumbria

- *Total doses* for the representative person were 41 per cent (or less) of the public dose limit in 2016
- The highest *total doses* were from seafood affected by past phosphate processing at Whitehaven. Historical discharges from Sellafield made a lesser contribution
- Radiation dose from natural radionuclides was slightly lower in 2016, mostly due to revision of habits information. The contribution to *total dose* from Sellafield discharges also decreased in 2016
- The mean concentrations of caesium-137, plutonium-239+240 and americium-241 in lobster, and caesium-137 in fish, (near Sellafield) in 2016 are the lowest reported values in comparison to previous years

## 2.1 Capenhurst, Cheshire


The Capenhurst site is located near Ellesmere Port and is home to a uranium enrichment plant and associated facilities; the major operators at the site are UUK, CNS and UCP. UUK operates three plants producing enriched uranium for nuclear power stations. CNS manages assets owned by NDA, comprising uranic material storage facilities and activities associated with decommissioning.

UCP are currently constructing a new facility, to allow safer long-term storage of depleted uranium, on a separate part of the site. This facility, the Tails Management Facility, will de-convert Uranium Hexafluoride ($UF_6$), or "Tails" to Uranium Oxide ($U_3O_8$) to allow the uranium to be stored in a more chemically stable oxide form for potential future reuse in the nuclear fuel cycle and will recover hydrofluoric acid for reuse in the chemical industry. It is anticipated that this facility will be commissioned in late 2017/early 2018. The plant is permitted and, when commissioned, will discharge gaseous waste to the environment, aqueous waste to UUK's effluent disposal system and will dispose of solid waste by off-site transfer.

The most recent collaborative habits survey undertaken on behalf of the Environment Agency, the FSA and the Health and Safety Executive (HSE) (including all exposure pathways from liquid discharges, gaseous discharges and direct radiation) was conducted in 2008 (Tipple *et al*., 2009). However, in 2013, an independent habits survey was carried out by Cefas on behalf of UUK. The main aim of the UUK survey was to collect occupancy data for people exposed to direct radiation from the site (living or spending time within 1 km of the site boundary). The UUK survey showed an increase in occupancy in comparison to an equivalent direct radiation survey conducted in 2004.

### Doses to the public

The *total dose* from all pathways and sources is assessed to have been 0.17 mSv (Table 2.1) in 2016, or 17 per cent of the dose limit, and up from 0.13 mSv in 2015. This dose was almost entirely due to direct radiation from the Capenhurst site. The dose assessment identifies local infants (1 year-old) living near to the site as the representative person, and was a change from that in 2015 (local adults). The increase in *total dose*, and change in the representative person (from 2015) was mostly attributed to a higher estimate of direct radiation from the site in 2016. The trend in *total dose* over the period 2004 – 2016 is given in Figures 1.2 and 2.1. Any changes in *total doses* with time are attributable to changes in the estimates of direct radiation from the site.

Source specific assessments give exposures for high-rate consumers of locally grown foods, and for children playing in and around Rivacre Brook, were less than the *total dose* in 2016 (Table 2.1). The dose for children (10 year-old), who play near the brook and may inadvertently ingest water and sediment, was 0.011 mSv in 2016 and similar to those in recent years. The dose is estimated using cautious assumptions for occupancy of the bank of the brook, inadvertent ingestion rates of water and sediment and gamma dose rates.

### Gaseous discharges and terrestrial monitoring

Uranium is the main radioactive constituent of gaseous discharges from Capenhurst, with small amounts of other radionuclides present in discharges by CNS Limited (previously Sellafield Limited). UUK discharges of uranium decreased, in comparison to releases in 2015. The apparent decrease in 2016 was due to larger than usual emissions in 2015 (see Table A2.4, RIFE 21, for further information). CNS Limited discharges of alpha radioactivity decreased, in comparison to releases in 2015, due to the closure of a processing plant. The focus for terrestrial sampling was on the content of technetium-99 and uranium in food (including milk), grass and soil. Results for 2016 are given in Table 2.2(a). Concentrations of radionuclides in milk and food samples around the site were very low and similar to previous years. Uranium concentrations in soils were also low, whilst technetium-99 concentrations in all samples are reported as less than values, in 2016. Figure 2.2 shows the trend of technetium-99 concentrations in grass from 2004. The overall trend reflects the reductions in discharges of technetium-99 from recycled uranium. The most recently observed variability (from year to year) in the technetium-99 concentrations is largely based on data reported as less than values. In future, the enrichment of reprocessed uranium is anticipated to increase, which may lead to increases in discharges of technetium-99 and neptunium-237, if recycled uranium is processed. However, no increase is expected in the discharge limits.

### Liquid waste discharges and aquatic monitoring

The UUK permit for the Capenhurst site allows liquid waste discharges to the Rivacre Brook for uranium and uranium daughters, technetium-99 and non-uranium alpha (mainly neptunium-237). UUK discharges of non-uranic alpha radioactivity decreased, in comparison to releases in 2015; other discharges from Capenhurst were similar to those in recent years.


**Figure 2.1.** *Total dose* at nuclear fuel production and reprocessing sites, 2004-2016
(Exposures at Sellafield/Whitehaven/LLWR receive a significant contribution to the dose from technologically enhanced naturally occurring radionuclides from previous non-nuclear industrial operations)

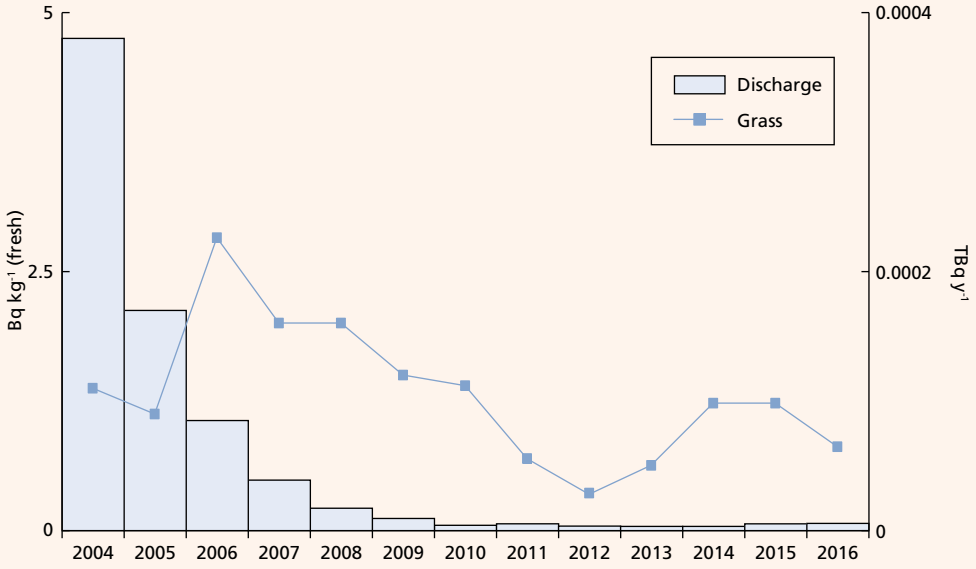
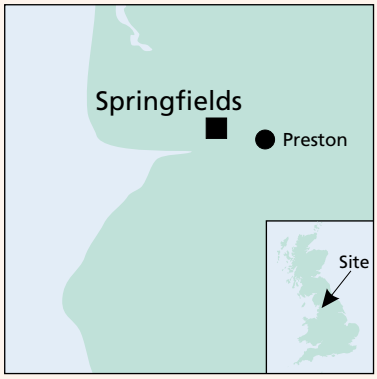



**Figure 2.2.** Technetium-99 annual discharges from and concentrations in grass at Capenhurst, 2004-2016

Monitoring included the collection of samples of fish and shellfish from the local aquatic and downstream marine environment (for analysis of a range of radionuclides) and of freshwater and sediments for the analysis of tritium, technetium-99, gamma emitting radionuclides, uranium, neptunium-237, and gross alpha and beta. Dose rate measurements were taken on the banks of the Rivacre Brook and surrounding area in 2016. Results for 2016

are given in Tables 2.2(a) and (b). Concentrations of radionuclides in foods from the marine environment were very low and generally similar to those in previous years. Thorium-234 in cockles was detected in 2016, reported just above the less than value. The low concentrations in fish and shellfish reflect the distant effects of discharges from Sellafield. Tritium was measured just above the detection limit in one sample (flounder) in 2016. As in previous years, sediment samples collected downstream from the Rivacre Brook contained very low but measurable concentrations of uranium (enhanced above natural levels) and technetium-99. In previous years, the largest enhancement of these radionuclides was measured close to the discharge point, although sediment samples were not collected from this location in 2016. Variations in concentrations in sediment from the brook are to be expected due to differences in the size distribution of the sedimentary particles. Concentrations of radionuclides in freshwaters were also very low. As in recent years, measured dose rates were higher, relative to natural background, near to the discharge point. Downstream of the Rivacre Brook, at the location where children play, dose rates (where comparisons can be made) were generally similar to those in 2015.

## 2.2 Springfields, Lancashire




The Springfields site at Salwick, near Preston, is operated by Springfields Fuels Limited (SFL) under the management of Westinghouse Electric UK Limited, on behalf of NDA. The main commercial activity is the manufacture of fuel elements for nuclear reactors and the production of uranium hexafluoride. Other important activities include recovery of uranium from residues and decommissioning redundant plant, under contract to NDA, who retain responsibility for the historical nuclear liabilities on the site. Research and development, carried out by the National Nuclear Laboratory, produces small amounts of other gaseous radionuclides that are also discharged under permit (see Appendix 2, Table A2.1).

Monitoring around the site is carried out to check not only for uranium concentrations, but also for other radionuclides discharged in the past (such as actinide daughter products from past discharges when uranium ore concentrate (UOC) was the main feed material) and for radionuclides discharged from Sellafield. The monitoring locations (excluding farms) used to determine the effects of gaseous and liquid discharges are shown in Figure 2.3.

The most recent habits survey was undertaken in 2012 (Ly *et al*., 2013). In 2016, based on a five-year rolling average (2012 – 2016), the habits information was revised, resulting in a slightly lower occupancy rate for high-rate houseboat dwellers. Revised figures for consumption rates, together with occupancy and handling rates, are provided in Appendix 1 (Table X2.2).

### Doses to the public

In 2016, the *total dose* from all pathways and sources is assessed to have been 0.038 mSv (Table 2.1), or less than 4 per cent of the dose limit, and down from 0.050 mSv in 2015. The representative person was adults who were a high occupancy houseboat dweller in a boatyard, and exposed to external radiation from activity in muddy sediments. The decrease in *total dose* (from 2015) was mostly because gamma dose rates were measured on a different ground type, from one year to the next, from one of the two houseboat locations (at Freckleton). Gamma dose rate measurements were not taken aboard a houseboat in 2016. Therefore, dose rates were derived by using measurements outside the houseboat (in 2016), and then adjusting these values by the ratio of on-board and outside dose rates from results reported (and taken aboard a houseboat) in 2014. This information was directly applicable to the locations where high-rate occupancy was taking place. *Total doses* (together with dose rates) over the period 2004 – 2016 are given in Figure 2.4. Most recently, the estimated *total dose* has decreased following on from direct measurements (beneath houseboats) being available in 2014.

Source specific assessments indicated that exposures were all less than or similar to the *total dose* (Table 2.1) for;

- High-occupancy houseboat dwellers in the Ribble Estuary
- Consumers of seafood
- Wildfowlers consuming game obtained from the estuary area
- Farmers spending time on the banks of the estuary
- Consumers of locally grown food and of seafood
- Children playing on the banks of the estuary

In 2016, the source specific assessment gave an estimated dose to a high-occupancy houseboat dweller of 0.038 mSv or less than 4 per cent of the dose limit for members of the public of 1 mSv, and was lower than that in 2015 (0.054 mSv). The reason for the decrease in dose in 2016 (from 2015) is the same as that contributing to the maximum *total dose*. This value is identical to the *total dose* (with more realistic assumptions) of 0.038 mSv, assessed for the same representative person. The dose to the representative person for high-rate consumers of seafood (including a contribution from external exposure) was 0.019 mSv in 2016. Of this dose, approximately 0.018 mSv was from external exposure and the remainder was from the consumption of fish and shellfish. The dose

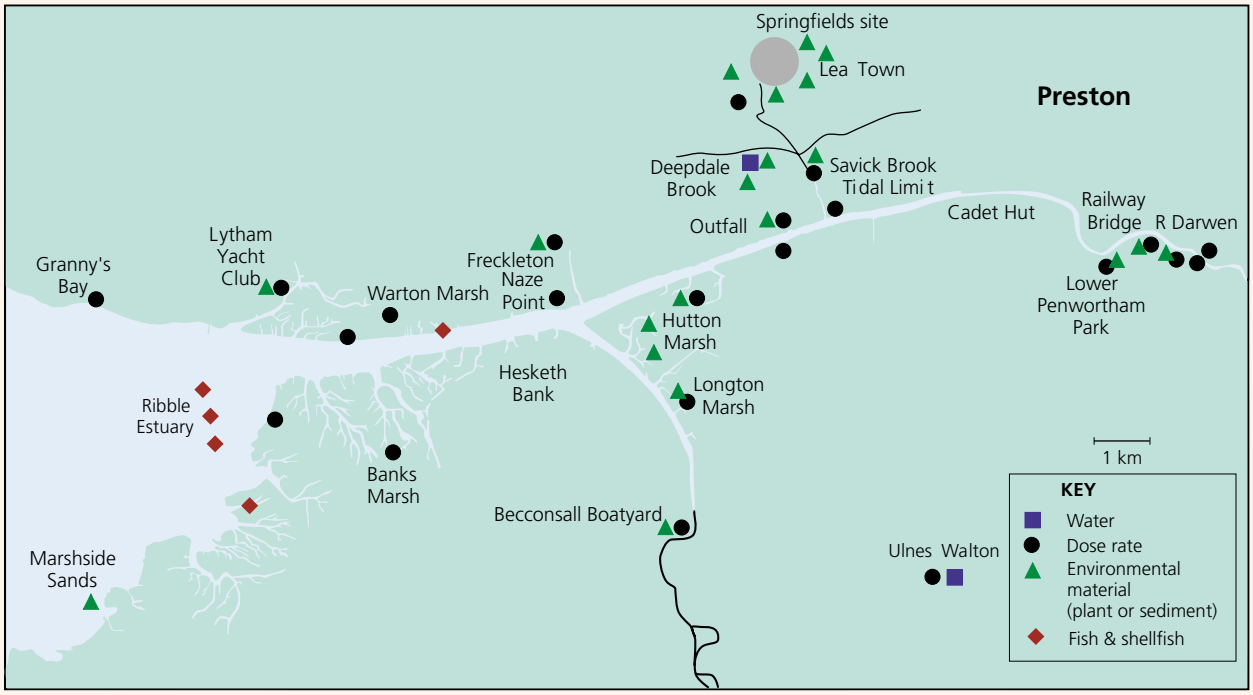



**Figure 2.3.** Monitoring locations at Springfields, 2016 (not including farms)

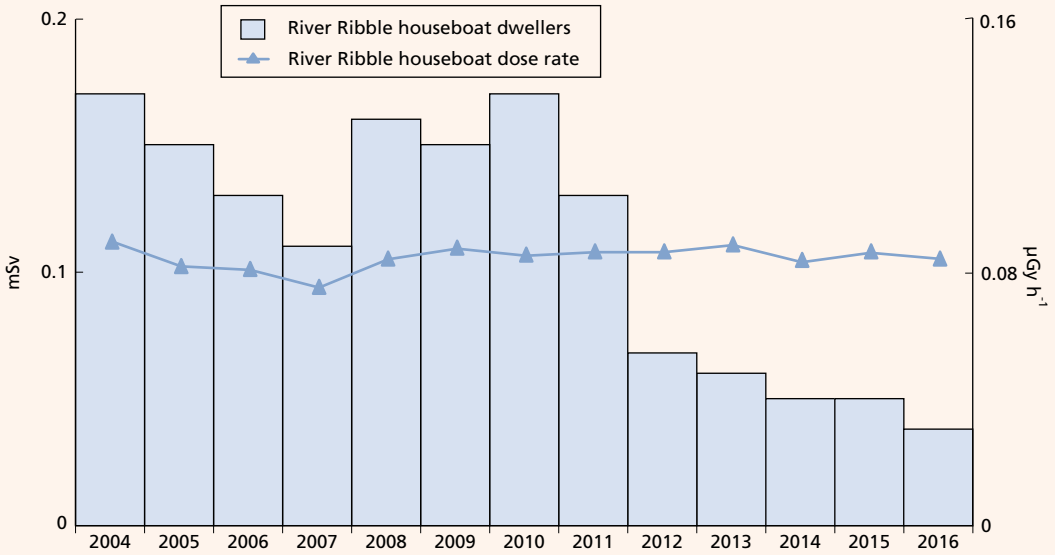



**Figure 2.4.** *Total dose* from all sources and dose rates at Springfields, 2004-2016

in 2015 was 0.020 mSv. The most important radionuclides were caesium-137 and americium-241 from past discharges from the Sellafield site. The dose to fishermen from handling their gear was 0.022 mSv in 2016, which was less than 0.5 per cent of the appropriate annual dose limit of 50 mSv specifically for skin.

As in recent years, assessments were undertaken to determine the dose to wildfowlers from external exposure over salt marsh and the consumption of game, the dose to farmers from external exposure, the dose to high-rate consumers of locally grown food and the dose to children playing on the banks of the estuary, at Springfields. The estimated doses in 2016 were 0.005 mSv, 0.033 mSv, less than 0.005 mSv and less than 0.005 mSv, respectively, for these pathways (Table 2.1).

It has been previously shown that assessed doses to the public from inhaling Ribble Estuarine sediment re-suspended in the air were much less than 0.001 mSv, and negligible in comparison with other exposure routes (Rollo *et al.*, 1994).

## Gaseous discharges and terrestrial monitoring

Uranium is the main radioactive constituent of gaseous discharges, with small amounts of other radionuclides present in discharges from the National Nuclear Laboratory's research and development facilities. Discharges of tritium (from the National Nuclear Laboratory) decreased in 2016, in comparison to releases in 2015.

The focus of the terrestrial sampling was for the content of tritium, carbon-14, strontium-90, iodine-129, and isotopes of uranium, thorium, plutonium and americium in milk, and vegetables. Grass and soil samples were collected and analysed for isotopes of uranium. Data for 2016 are given in Table 2.3(a). As in previous years, elevated concentrations of uranium isotopes were found in soils around the site, but the isotopic ratio showed they are most likely to be from natural abundance. Low concentrations of thorium were found in vegetable and grass samples. The carbon-14 concentration was above the default value used to represent the background level, and caesium-137 was detected at very low levels, in beetroot. Most other concentrations of radionuclides are reported as less than values. Results were broadly similar to those of previous years.

Figure 2.5 shows the trends over time (2004 – 2016) of uranium discharges and total uranium radionuclide concentrations in food (cabbage; 2004 – 2013: beetroot; 2014 – 2016). Over the period, concentrations of uranium were also found in soil around the site, but the isotopic ratio showed that they were naturally occurring. Total uranium was detected in cabbage and beetroot samples during the period (no data in 2006), but the concentrations were very low. The apparent peak of uranium in cabbage in 2007 was also low and significantly less than that found in soil samples.

## Liquid waste discharges and aquatic monitoring

Permitted discharges of liquid waste (including gross alpha and beta, technetium-99, thorium-230, thorium-232, neptunium-237, uranium and other transuranic radionuclides) are made from the Springfields site to the Ribble Estuary via two pipelines. Discharges of uranium and alpha emitting radionuclides decreased in 2016 (higher uranium discharges occurred in early 2015 because of higher throughput), and technetium-99, neptunium-237 and "other transuranic radionuclides" increased by small amounts (due to the processing of particular residues in 2016), in comparison to releases in 2015. Beta discharges were generally similar to those in recent years, including the short half-life beta-emitting radionuclides (mostly thorium-234) that have decreased following the end of the UOC purification process in 2006. Process improvements in the uranium hexafluoride production plants on the Springfields site have reduced the amounts of other uranium compounds needing recycling; these improvements, alongside a reduction in legacy uranic residue processing, have led to a corresponding reduction in discharges of uranium in most recent years. Discharges of technetium-99 depend almost entirely on which legacy uranic residues are being processed. Since completion of one particular residue processing campaign (around the end of 2012), technetium-99 discharges have generally decreased. The Ribble Estuary monitoring programme consisted of dose rate measurements, and mostly the analysis of sediments for uranium and thorium isotopes, and gamma emitting radionuclides.

Locally obtained fish and shellfish were analysed by gamma-ray spectrometry and for thorium and plutonium isotopes. Results for 2016 are shown in Tables 2.3(a) and (b). As in previous years, radionuclides due to discharges from both Springfields and Sellafield were detected in sediment and biota in the Ribble Estuary. Radionuclides found in the Ribble Estuary originating from Sellafield were technetium-99, caesium-137 and americium-241. Isotopes of uranium and the short half-life radionuclide thorium-234, from Springfields, were also found. Concentrations of the latter were closely linked to recent discharges from the Springfields site. In 2016, thorium-234 concentrations in sediments (over the range of sampling sites) were lower compared to those in recent years. Over a much longer timescale (2004 – 2016), these concentrations have declined due to reductions in discharges as shown by the trend of sediment concentrations at the outfall, Lower Penwortham and Becconsall (Figure 2.5). The most significant change in the discharge trends was the step reduction of short half-life beta emitting radionuclides in liquid discharges, mostly thorium-234. The reduction was because the UOC purification process ended in 2006.

Caesium-137, americium-241 and plutonium radionuclides were found in biota and sediments from the Ribble Estuary in 2016. The presence of these radionuclides was due to past liquid discharges from Sellafield, carried from west Cumbria into the Ribble Estuary by sea currents and adsorbed on fine-grained muds. The concentrations observed were generally similar to those in recent years.

Figure 2.5 also provides trend information over time (2004 – 2016) for a number of other permitted radionuclides and activity concentrations in food. Liquid discharges of uranium radionuclides steadily decreased (and other discharges to a lesser extent) over the whole period, whilst technetium-99 discharges generally decreased overall (but peaked in 2012). Caesium-137 concentrations in flounder showed variations between years and this was most likely due to natural changes in the environment, although there is some evidence that concentrations in flounder decreased overall. Concentrations of technetium-99 in shrimps generally declined over the whole period, consistent with the reduction in technetium-99 discharges from Sellafield (Figure 2.16); the apparent increases in recent years was due to the inclusion of reported less than values.

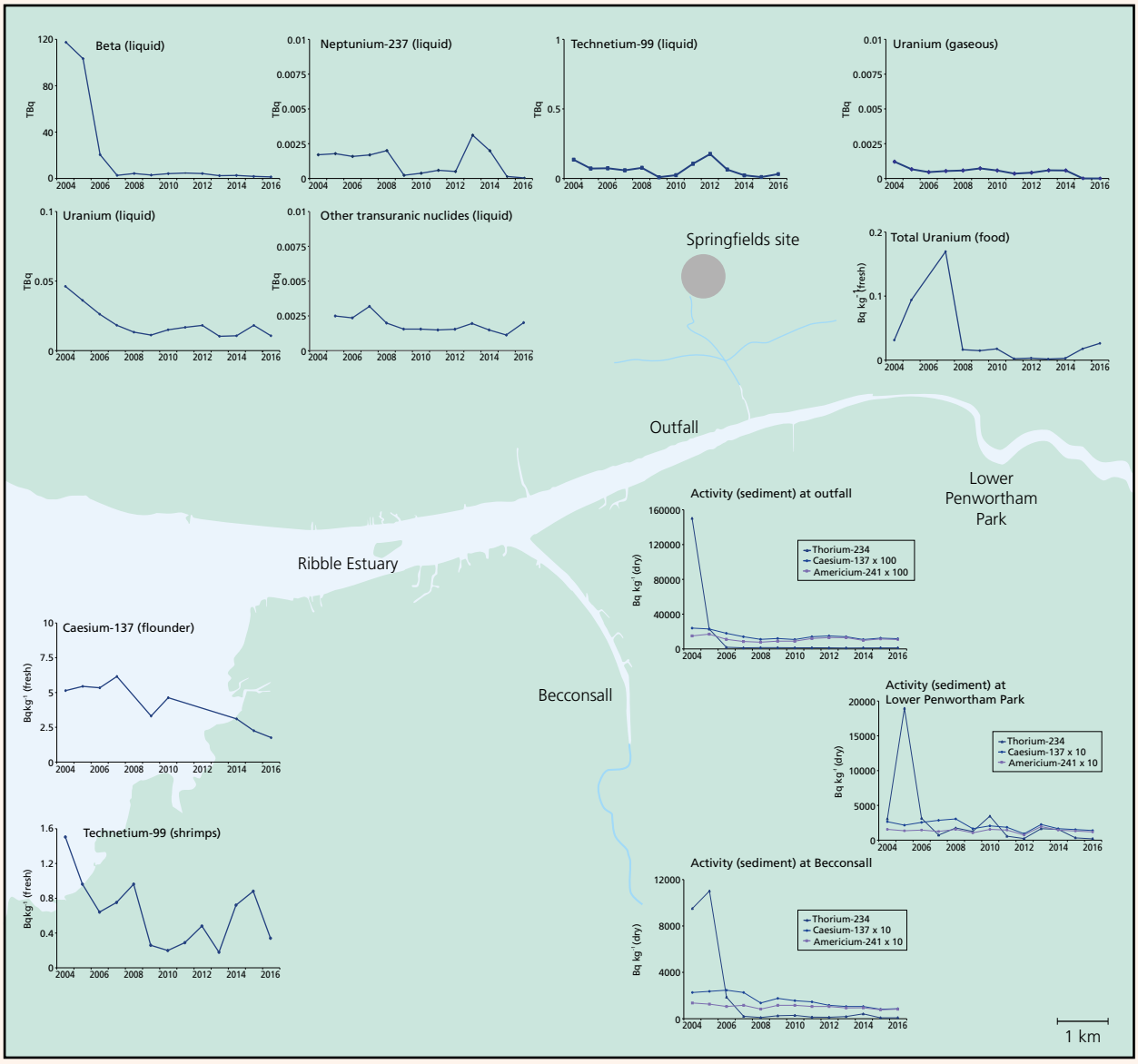
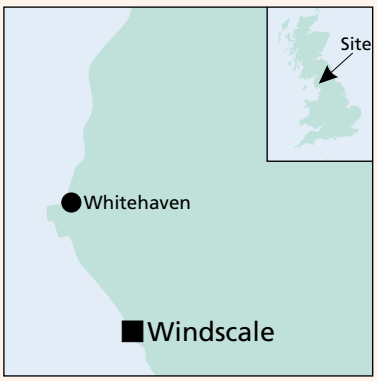



**Figure 2.5.** Discharges of gaseous and liquid radioactive wastes and monitoring of the environment, Springfields 2004–2016 (Note different scales used for discharges and activity concentrations)

Gamma dose rates in the estuary were generally higher than expected natural background levels (see Appendix 1, Section 3.7), and this is due to Sellafield-derived gamma-emitting radionuclides (caesium-137 and americium-241). In 2016, gamma dose rates in the estuary, excluding rates taken for houseboat assessments, were generally similar to those in 2015, but with some small variations at some sites. In 2016, gamma dose rates measured in the vicinity of houseboat dwellers (at Becconsall and Freckleton) were generally similar to those in 2015 (where comparisons can be made from similar ground types and locations). Beta dose rates on fishing nets (and tarpaulin) were low in 2016. Beta dose rates from sediments were mostly lower in 2016, in comparison to those in 2015.

## 2.3 Sellafield, Cumbria




Sellafield Limited is responsible for the operation of the Sellafield site and is a wholly owned subsidiary of the NDA. The main operations on the Sellafield site are: fuel reprocessing at the Magnox Reprocessing Plant and the Thermal Oxide Reprocessing Plant (THORP); decommissioning and clean-up of redundant nuclear facilities; and waste treatment and storage. Reprocessing is expected to end in 2018 and 2020 for THORP and Magnox, respectively. The

site also contains the Calder Hall Magnox nuclear power station, which ceased generating in 2003 and is undergoing decommissioning. Completion of Magnox reprocessing including de-fuelling of Calder Hall is expected in 2020 (NDA, 2017). The Windscale site is located at Sellafield, and is discussed in Section 2.4.

In 2016, the Environment Agency carried out a review of their environmental monitoring programme for the Sellafield site, as part of a process to review their monitoring at all nuclear sites in England and Wales (on behalf of Natural Resources Wales). The Environment Agency's review of the monitoring programme for Sellafield has been summarised (Environment Agency, 2016). This report identifies changes to the programme, to align it more closely with the ranges of sampling types and location numbers and to identify several recommendations largely aimed at informing future revisions to the programme. The Environment Agency's monitoring programme was changed in 2016 to reflect the review outcomes. In 2016, this resulted in an overall increase in the range of sampling and monitoring types and an overall reduction in the total number of sample and monitoring locations. There was also an overall small increase in the number of analyses from the collected samples in 2016.

In June 2017, the Environment Agency began consulting on an application for a permit variation made by Sellafield Limited. The permit variation application covers several issues relating to changes to the permitted waste types and activity limits. The application is being made to facilitate the disposal of decommissioning waste from the site, along with some other changes. The changes requested are:

- Increase in disposal limits for the Calder Landfill Extension Segregated Area (CLESA) site landfill
- Removal of the permitted limits of the Active Handling Facility stack
- Removal of limits for redundant stacks from Magnox reprocessing and Magnox Cell Vent as these major aerial discharges are now diverted to another permitted stack on the site

In 2011, Sellafield Limited and NDA published their plans for decommissioning of the Sellafield site (**www.sellafieldsites.com/wp-content/uploads/2012/08/Sellafield_Plan.pdf**). In 2014, an improved performance plan for Sellafield was accepted by NDA (**www.sellafieldsites.com/wp-content/uploads/2015/03/Performance-Plan_single.pdf**), and replaces the 2011 Sellafield Plan. In April 2017, Sellafield Limited published their first Corporate Strategy, as a wholly-owned subsidiary of the NDA, as well as a Transformation Plan (**www.sellafieldsites.com/2017/04/transformation-plan-and-corporate-strategy-connect-the-dots/**).

Sellafield Limited continued retrievals of sludge from legacy pond facilities in 2016 and continues to prepare for retrievals of intermediate level waste from legacy facilities and to reduce environmental risk. Some of these projects have the potential to impact on discharges to the environment. In 2016, a number of decommissioning projects continued including that of the Calder Hall reactors.

During the financial year 2016/17, 450 tonnes of uranium were processed through THORP (compared with 460 tonnes in 2015/2016). In respect of Magnox fuel, 465 tonnes of uranium were processed for 2016/17 (compared with 390 tonnes in 2015/2016). The reprocessing of the remaining fuel is scheduled to end in 2018 and 2020 for THORP and Magnox reprocessing, respectively (NDA, 2017).

A full habits survey is conducted every five years in the vicinity of the Sellafield site which investigates the exposure pathways relating to liquid and gaseous discharges, and direct radiation. Annual review habits surveys are undertaken between these full habits surveys. These annual surveys investigate the pathways relating to liquid discharges, review high-rate fish and shellfish consumption by local people (known as the Sellafield Fishing Community) and review their intertidal occupancy rates. The most recent full habits survey was conducted in 2013 (Clyne *et al*., 2014). In 2016, some changes were found in the amounts (and mixes) of species consumed and in handling and intertidal occupancy rates (Garrod and Clyne, 2017) from the full habits survey conducted in 2013. Further afield, the most recent habits surveys were conducted in 2012, to determine the consumption and occupancy rates by members of the public on the Dumfries and Galloway coast (Garrod *et al*., 2013a) and around Barrow and the south-west Cumbrian coast (Garrod *et al*., 2013b). The results of this survey are used to determine the potential exposure pathways relating to permitted liquid discharges from the Sellafield nuclear licensed site in Cumbria. Revised figures for consumption rates, together with occupancy rates, are provided in Appendix 1 (Table X2.2).

Habits surveys to obtain data on activities undertaken on beaches relating to potential public exposure to radioactive particles in the vicinity of the Sellafield nuclear licensed site were undertaken in 2007 and 2009 (Clyne *et al*., 2008; Clyne *et al*., 2010).

An important historical man-made source of naturally occurring radionuclides in the marine environment has been the phosphogypsum chemical plant at Whitehaven in Cumbria. An environmental legacy has occurred from these past operations (the plant closed in 1992). Historical discharges of naturally occurring radionuclides from this (non-nuclear) industrial activity are also monitored and assessed (see Section 7.4). From a radiological assessment perspective, the effects from the Sellafield and Whitehaven sites both influence the same area and therefore the contributions to doses are both considered in Section 2.3.1.

Monitoring of the environment and food around Sellafield reflects the historical and present-day Sellafield site

activities. In view of the importance of this monitoring and the assessment of public radiation exposures, the components of the programme are considered here in depth. The discussion is provided in four sub-sections, relating to the assessment of dose, the effects of gaseous discharges, the effects of liquid discharges and unusual pathways of exposure identified around the site.

### 2.3.1 Doses to the public

#### *Total dose* from all pathways and sources

The *total dose* from all pathways and sources is assessed using consumption and occupancy data from the full habits survey of 2013 (Clyne *et al.*, 2014) and the yearly review of shellfish and fish consumption, and intertidal occupancy in 2016 Review (Garrod and Clyne, 2017). Calculations are performed for four age groups (adults, 10 year-old children, 1 year-old infants and prenatal children). The effects on high-rate consumers of fish and shellfish from historical discharges of naturally occurring radionuclides from non-nuclear industrial activity from the former phosphate works at Whitehaven (see Section 7.4) are included to determine their contribution to the *total dose*. These works were demolished in 2004 and the authorisation to discharge radioactive wastes was revoked. The increase in concentrations of naturally occurring radionuclides due to the historical discharges is difficult to determine above a variable background (see Appendix 1, Annex 4).

In 2016, the highest *total dose* in the vicinity of Sellafield was assessed to have been 0.41 mSv, or 41 per cent of the dose limit to members of the public (Table 2.17). Most of this dose was due to radioactivity from sources other than those resulting from Sellafield discharges (predominately from the historical discharges at Whitehaven). As in most recent years, the representative person was an adult consuming molluscan shellfish at high-rates near Sellafield. The person also consumed significant quantities of other seafood. This represents a reduction in *total dose* in 2016, from 0.42 mSv in 2015. This decrease in *total dose* was mostly attributable to the revision of the habits information; from a decrease in the consumption rate (and a change in the mix of species) of crustaceans in 2016, in comparison to values in 2015. A much lesser reduction in *total dose* was due to lower americium-241 concentrations in lobster and a decrease in the lobster consumption rate (together with an increase in the proportion of lobster consumed, relative to other crustaceans), in 2016. Direct radiation from the Sellafield site (0.005 mSv, Table 1.1) was considered in the *total dose* assessments, but this made an insignificant contribution to the highest *total dose.*

In percentage terms, the most significant contributors to the *total dose* in 2016 were from crustacean consumption, mollusc consumption, external exposure over sediments and fish consumption (81, 10, 5 and 4 per cent, respectively), the important radionuclides were mostly polonium-210 and americium-241 (78, and 5 per cent, respectively).

Artificial radionuclides discharged by Sellafield (including external radiation) and historical discharges of naturally occurring radionuclides from Whitehaven contributed 0.074 mSv and 0.34 mSv, respectively (values are rounded to two significant figures). In 2015, the contributions were 0.078 mSv and 0.35 mSv, respectively. In 2016, the contribution from the external radiation was approximately 0.019 mSv (0.017 mSv in 2015). Data for naturally occurring radionuclides in fish and shellfish, and their variation in recent years, are discussed in Section 7.

The contribution to the *total dose* of 0.074 mSv in 2016 from artificial radionuclides (including external radiation) was lower (by a small amount) than in 2015 (0.078 mSv). In 2016, the contributing radionuclides were mostly americium-241, iodine-129, plutonium-239+240 and carbon-14 (29, 14, 14 and 7 per cent, respectively). External exposure was 26 per cent (22 per cent in 2015) of the *total dose* from artificial radionuclides. The decrease in the contribution to the *total dose* from 2015 was mostly attributed to lower americium-241 concentrations in lobster, and an increase in the proportion of lobster consumed (relative to other crustaceans), in 2016.

The contribution to the *total dose* of 0.34 mSv in 2016 from naturally occurring radionuclides was lower than in 2015 (0.35 mSv). In 2016, the most contributing radionuclide was polonium-210 (95 per cent). The decrease in the contribution to the *total dose* from 2015 was mostly attributable to the revision of the habits information; from a decrease in the consumption rate (and a change in the mix of species) of crustaceans in 2016, in comparison to values in 2015. In 2016, there was no contribution to the total dose from polonium-210 concentrations (above the expected background) in mollusc samples (0.007 mSv in 2015).

Contributions to the highest *total dose* each year, from all pathways and sources by specific radionuclides, are given in Figure 2.6 over the period 2004 – 2016. The trend of generally declining dose broadly reflects a general reduction in concentrations in seafood of both naturally occurring and artificial radionuclides from the non-nuclear and nuclear industries respectively. Inter-annual variations were more complex and governed by both natural variability in seafood concentrations and real changes in the consumption and occupancy characteristics of the local population.

The larger step changes (from 2004 to 2005, from 2008 to 2009 and from 2012 to 2013) were due to variations in naturally occurring radionuclides (mainly polonium-210 and lead-210). The changes in *total dose* in the intervening years from 2005 to 2007 were mainly a result of changes in seafood consumption rates. The decrease in 2010 was due to both reductions in naturally

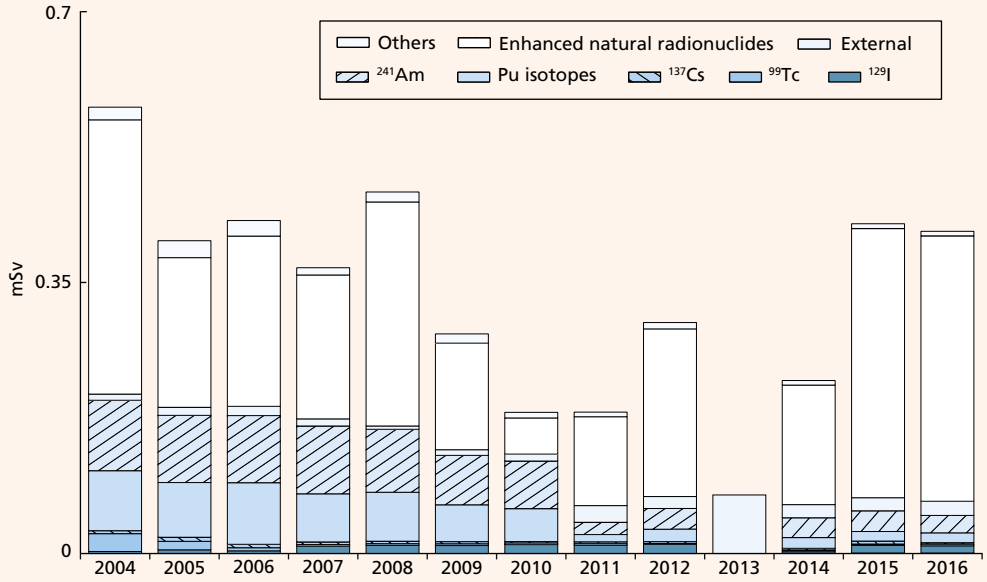



**Figure 2.6.** Contributions to *total dose* from all sources at Sellafield, 2004-2016 (The highest *total dose* in 2013 due to Sellafield discharges was to people living on houseboats near Barrow in Cumbria)

occurring radionuclides concentrations (polonium-210) and consumption rates, whilst the variation in the radionuclide contributors in 2011 (from previous years) resulted from a change in the representative person (from a consumer of molluscan shellfish to locally harvested marine plants). The largest proportion of the *total dose,* up till 2008 and again from 2011 – 2012 and 2014 – 2016, was mostly due to enhanced naturally occurring radionuclides from the historical discharges at Whitehaven and a smaller contribution from the historical discharges from Sellafield. From 2008 to 2010, the net result of progressive reductions of the naturally occurring radionuclides contribution to the *total dose* has been a relative increase in the proportion from artificial radionuclides. In 2013, the highest *total dose* (relating to the effects of Sellafield) was entirely due to external radiation from sediments. The change was due to both decreases in naturally occurring radionuclides concentrations (polonium-210) and a revision of habits information, resulting in a change in the representative person. In the following year (2014), the increase in *total dose* was due to a change in the habits information from the most recent survey. Thereafter, the relative increases in dose were largely due to an increase in polonium-210 concentrations (from the non-nuclear industry) in locally caught lobsters and crabs. The contributions to the highest *total dose* each year from the non-nuclear and nuclear industries (from all pathways and sources) are also given in Figure 2.7. The overall trend is a generally declining dose, broadly reflecting a general reduction in concentrations in seafood of artificial radionuclides from the nuclear industry, over the period 2004 – 2016.

Other age groups received less exposure than the adult *total dose* of 0.41 mSv in 2016 (10 year-old children: 0.21; 1 year-old infants: 0.13; prenatal children: 0.075, rounded to two significant figures). *Total doses* estimated for each age group may be compared with the dose for each person of approximately 2.3 mSv to members to the UK population from exposure to radiation in the environment (Oatway *et al.*, 2016) and to the annual dose limit to members of the public of 1 mSv.

## *Total dose* from gaseous discharges and direct radiation

In 2016, the dose to a representative person receiving the highest *total dose* from the pathways predominantly relating to gaseous discharges and direct radiation was 0.008 mSv (Table 2.17), and unchanged from 2015. The most exposed age group in 2016 was children (10 year-old) and the dominant contribution to this dose was direct radiation from the site, (as in 2015). The most significant contributors in 2016 to the *total dose* for children (10 year-old) were from direct radiation from the site, the consumption of potatoes, and the combined external and inhalation from the site (64, 18, and 10 per cent, respectively), the most important radionuclide was krypton-85 (9 per cent). Other ages received less exposure than the *total dose* for children (10 year-old) of 0.008 mSv in 2016 (adults: 0.008; 1 year-old infants: 0.007; prenatal children: 0.007, equivalent values rounded to one significant figure).

Contributions to the highest *total dose* each year, by specific radionuclides, are given in Figure 2.8 over the period 2004 – 2016. Up until 2007, there was a small decline in *total dose* due to a general reduction in concentrations of radionuclides in food and the environment caused, in part, by reductions in discharges in this period and beforehand. The main feature in the changes in *total dose* over the whole period was the increase in 2009. This resulted from an increase of total radiocaesium in game collected near the site. There is no evidence to suggest that this was caused by a change in site operations. Over the period 2010 – 2016, *total doses*

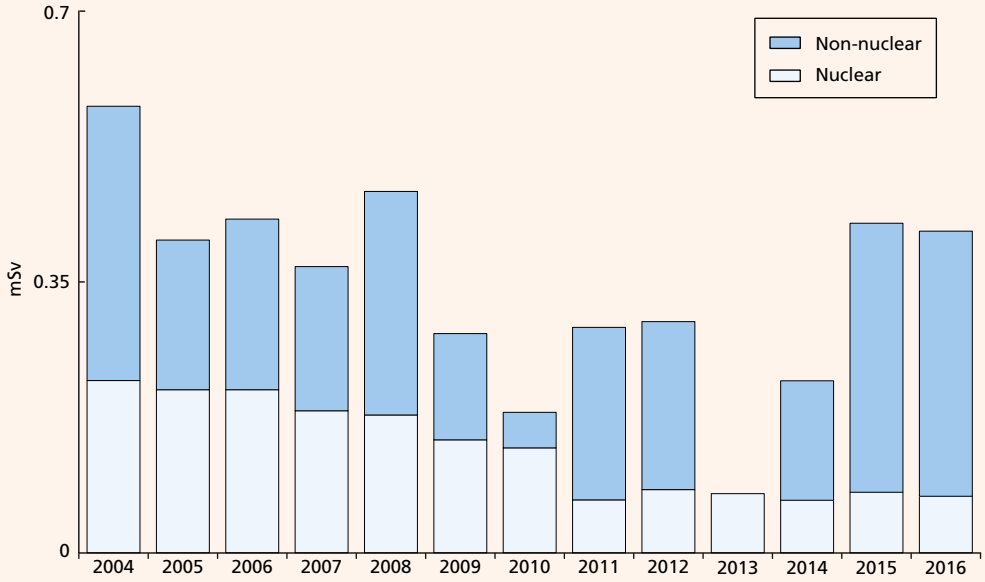



**Figure 2.7.** Contributions from nuclear and non-nuclear industries to *total dose* from all sources at Sellafield, 2004-2016 (The highest *total dose* in 2013 due to Sellafield discharges was to people living on houseboats near Barrow in Cumbria)

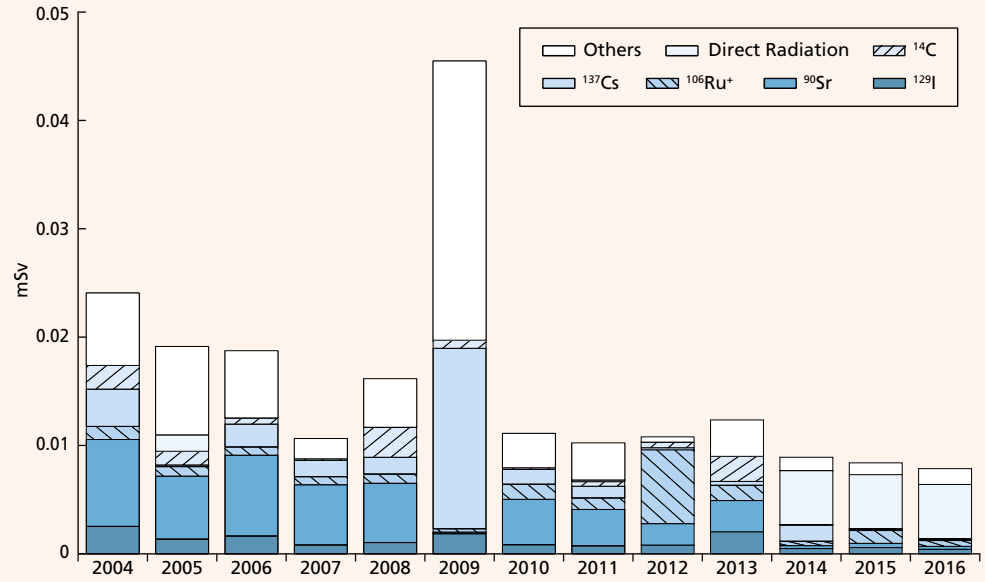



**Figure 2.8.** Contributions to *total dose* from gaseous discharge and direct radiation sources at Sellafield, 2004-2016 (+ based on limits of detection for concentrations in foods)

were generally similar between years. The lower *total dose* values in most recent years was mostly due to changes in the monitoring programme in 2014 (Environment Agency, FSA, FSS, NIEA, NRW and SEPA, 2015).

## *Total dose* from liquid discharges

The people receiving the highest *total dose* from the pathways predominantly relating to liquid discharges are given in Table 2.17. Each *total dose* is the same as that giving their maximum *total dose* for all sources and pathways.

## Source specific doses

Important source specific assessments of exposures, as a result of radioactive waste discharges from Sellafield, continued to be due to high-rate consumption of fish and shellfish and to external exposure from gamma rays over long periods. Other pathways were kept under review, particularly high-rate consumption of locally grown food (from atmospheric discharges), to account for the potential for sea to land transfer at the Ravenglass Estuary to the south of the site and exposure from contact with beta emitters during handling of sediments and/or handling of fishing gear.

## Doses from terrestrial food consumption

In 2016, infants (1 year-old) consuming milk at high-rates and exposed to external and inhalation pathways from gaseous discharges, received the highest dose for all ages. The estimated dose was 0.013 mSv (Table 2.17) or approximately 1 per cent of the dose limit to members of the public, and up from 2015. The reason for the small increase in dose (from 0.012 mSv in 2015) was mostly due to higher carbon-14 concentrations in milk in 2016. Other age groups received less exposure than the infants (1 year-old) dose of 0.013 mSv in 2016 (adults: 0.008; 10 year-old children: 0.009; prenatal children: 0.007).

## Doses from seafood consumption

Two sets of habits data are used in these dose assessments. One is based on the habits information seen in the area each year (2016 habits survey). The second is based on a five-year rolling average using habits data gathered from 2012 to 2016. Some changes were found in the amounts (and mixes) of species consumed. For molluscs, the consumption rates were unchanged in both the 2016 and 2012 – 2016 data sets. For fish and crustacean, consumption rates decreased by small amounts in 2016, but increased by small amounts for the 2012 – 2016 data sets (cod, other fish and lobster). The occupancy rate over sediments decreased in both the 2016 and 2012 – 2016 data sets. The revised habits data are given in Appendix 1 (Table X2.2). Aquatic pathway habits are normally the most important in terms of dose near Sellafield and are surveyed every year. This allows generation of a unique yearly set of data and also rolling five-year averages. The rolling averages are intended to smooth the effects of sudden changes in habits and provide an assessment of dose that follows more closely changes in radioactivity concentrations in food and the environment. These are used for the main assessment of doses from liquid discharges, and follow the recommendations of the report of the Consultative Exercise on Dose Assessments (CEDA) (FSA, 2001a).

Table 2.17 summarises source specific doses to seafood consumers in 2016. The doses from artificial radionuclides to people, who consume a large amount of seafood, were 0.084 mSv (0.098 mSv in 2015) and 0.083 mSv (0.084 mSv in 2015) using the annual and five-year rolling average habits data, respectively, in 2016. These doses each include a contribution due to external radiation exposure over sediments. Doses were similar using both sets of habits data in 2016.

The dose to a local person (high-rate consumer of seafood) due to the enhancement of concentrations of naturally occurring radionuclides from former non-nuclear industrial activity in the Sellafield area (using maximising assumptions for the dose coefficients and the five-year rolling average habits data) is estimated to have been 0.35 mSv in 2016. Most of this was due to polonium-210 (96 per cent). The reason for the change in dose in 2016 (from 0.29 mSv in 2015) is the same as that contributing to the *total dose* for all sources, i.e. a revision of the habits information in 2016. For comparison (with the assessment using the five-year rolling average habits data), the dose from the single-year assessment for the Sellafield seafood consumer from naturally occurring radionuclides (based on consumption rates and habits survey data in 2016) was 0.43 mSv (Table 2.17).

Taking artificial and enhanced natural radionuclides together, the source specific doses were 0.51 mSv and 0.43 mSv (values are rounded to two significant figures) for annual and five-year rolling average habits data, respectively. These estimates are larger than the estimate of *total dose* from all sources of 0.41 mSv. The main reason for this is a difference in the approach to selecting consumption rates for seafood for the representative person. The differences in dose are not unexpected, are within the uncertainties in the assessments and confirm *total dose* as a robust measure of exposure.

Exposures representative of the wider communities associated with fisheries in Whitehaven, Dumfries and Galloway, the Morecambe Bay area, Northern Ireland and North Wales have been kept under review in 2016 (Table 2.16). Those for fisheries in the Isle of Man and Fleetwood have been shown to be generally lower and dose data are available in earlier RIFE reports (e.g. Environment Agency, FSA, NIEA, NRW and SEPA, 2014). Where appropriate, the dose from consumption of seafood is summed with a contribution from external exposure over intertidal areas. The doses received in the wider communities were significantly lower than for the local Sellafield population because of the lower concentrations and dose rates further afield. There were generally small changes in the doses (and contribution to doses) in each area in 2015 (Table 2.16), in comparison to those in 2015. All doses were well within the dose limit for members of the public of 1 mSv.

The dose to a person, who typically consumes 15 kg of fish per year from landings at Whitehaven is also given in Table 2.17. This consumption rate used represents an average for a typical consumer of seafood from the north-east Irish Sea and the dose was less than 0.005 mSv in 2016.

## Doses from sediments

The main radiation exposure pathway associated with sediments is due to external dose from gamma-emitting radionuclides adsorbed on intertidal sediments in areas frequented by the public. This dose can make a significant contribution to the total exposure of members of the public in coastal communities of the north-east Irish Sea but particularly in Cumbria and Lancashire. Gamma dose rates currently observed in intertidal areas are mainly due to radiocaesium and naturally occurring radionuclides. For some people, the following pathways may also contribute

to doses from sediments: exposure due to beta-emitters during handling of sediments or fishing gear; inhalation of re-suspended beach sediments; and inadvertent ingestion of beach sediments. These pathways are considered later: in the main, they give rise to only minor doses compared with those due to external gamma emitters.

Gamma radiation dose rates over areas of the Cumbrian coast and further afield in 2016 are given in Table 2.9. The results of the assessment of external exposure pathways are included in Table 2.17. The highest whole body exposures due to external radiation resulting from Sellafield discharges, past and present, was received by a local houseboat dweller at Barrow, Cumbria. In 2016, the dose was 0.081 mSv, or approximately 8 per cent of the dose limit, and up from 0.050 mSv in 2015 (see Section 5.2). Other people received lower external doses in 2016. The estimated dose to a high-occupancy houseboat dweller in the River Ribble was 0.038 mSv (see Section 2.2). The dose to a person who spends a long time over the marsh in the Ravenglass Estuary was 0.011 mSv in 2016, and down from 0.013 mSv in 2015. The reason for the small decrease in dose was a combination of lower gamma dose rates measurements in the Ravenglass Estuary and a lower contribution from the inhalation of sediments (from amercium-241 and plutonium radionuclides) in 2016, in comparison to those in 2015.

The doses to people in 2016 were also estimated for a number of other activities. Assessments were undertaken for a typical resident using local beaches for recreational purposes at 300 hours per year, and for a typical tourist visiting the coast of Cumbria with a beach occupancy of 30 hours per year. The use by residents for two different environments, at a number of locations (at a distance from the Sellafield influence), were assessed: residents that visit and use beaches and residents that visit local muddy areas or salt marsh. Typical occupancy rates (Clyne *et al.*, 2008; 2010) are assumed and appropriate gamma dose rates have been used from Table 2.9. The activities for the typical tourist include consumption of local seafood and occupancy on beaches. Concentrations of radioactivity in fish and shellfish have been used from Tables 2.5 – 2.7, and appropriate gamma dose rates used from Table 2.9. The consumption and occupancy rates for activities of a typical resident and tourist are provided in Appendix 1 (Table X2.2).

In 2016, the doses to people from recreational use of beaches varied from 0.008 to 0.012 mSv with the higher doses being closer to the Sellafield source. The doses for recreational use of salt marsh and muddy areas had a greater variation from less than 0.005 to 0.014 mSv but were of a similar order of magnitude. The values for these activities were similar to those in recent years. The dose to a typical tourist visiting the coast of Cumbria, including a contribution from external exposure, was estimated to be less than 0.005 mSv.

## Doses from handling fishing gear and sediment

Exposures can also arise from contact with beta-emitters during handling of sediments, or fishing gear on which fine particulates have become entrained. Habits surveys keep under review the amounts of time spent by fishermen handling their fishing gear, and by bait diggers and shellfish collectors handling sediment. For those most exposed, the rates for handling nets and pots and for handling sediments are provided in Appendix 1 (Table X2.2). In 2016, the skin doses to a fisherman from handling fishing gear (including a component due to naturally occurring radiation), and a bait digger and shellfish collector from handling sediment, were 0.087 mSv and 0.064 mSv, respectively and both were less than 0.5 per cent of the appropriate annual dose limit of 50 mSv specifically for skin. Therefore, both handling of fishing gear and sediments continued to be minor pathways of radiation exposure.

## Doses from atmospheric sea to land transfer

At Ravenglass, the representative person was infants (1 year-old) from consuming terrestrial foods that were potentially affected by radionuclides transported to land by sea spray. In 2016, the dose (including contributions from Chernobyl and weapon test fallout) was estimated to be 0.019 mSv, which was less than 2 per cent of the dose limit for members of the public, and up from 0.017 mSv in 2015. The increase in dose was mostly due to the inclusion of results obtained for a domestic fruit sample (not collected in 2015) in the assessment in 2016, and thus including the contribution of ruthenium-106 in blackberries (reported as a less than value). The largest contribution to the dose was from ruthenium-106 in milk, as in recent years. As in previous years, sea-to-land transfer was not of radiological importance in the Ravenglass area.

## Doses from seaweed and seawashed pasture

Estimated doses for a high-rate consumer of laverbread (brown seaweed), and a high-rate consumer of vegetables (assuming these foods were obtained from the monitored plots near Sellafield and seaweeds were used as fertilisers and/or soil conditioners), are available in earlier RIFE reports (e.g. Environment Agency, FSA, NIEA, NRW and SEPA, 2014). It has been previously established establishing that the exposure pathway for a high-rate consumer of laverbread is of low radiological significance. No harvesting of *Porphyra* in west Cumbria, for consumption in the form of laverbread, was reported; this exposure pathway has therefore remained dormant in recent years. Previously reported doses from the consumption of vegetables using seaweed have remained similar (and low) from year to year, with only minor variations in exposure (due to different

foods being grown and sampled from the monitored plots). Exposures of vegetable consumers using seaweed from further afield in Northern Ireland, Scotland and North Wales are expected to be much lower than near Sellafield.

Animals may also graze on seaweeds on beaches in coastal areas. However, there has been no evidence of this taking place significantly near Sellafield. Further information on previously reported studies to investigate potential dose to a high-rate consumer of meat products, from animals grazing the seaweed, is available in earlier RIFE reports (e.g. Environment Agency, FSA, NIEA, NRW and SEPA, 2014).

### 2.3.2 Gaseous discharges

Regulated discharges to atmosphere are made from a wide range of facilities at the site including the fuel storage ponds, the reprocessing plants and waste treatment plants, as well as from Calder Hall Power Station. Discharges from Calder Hall are now much reduced since the power station ceased generating electricity in 2003. Discharges to atmosphere during 2016 are summarised in Appendix 2 (Table A2.1). The permit limits gaseous discharges for gross alpha and beta activities, and 13 specified radionuclides. In addition to overall site limits, individual limits have been set on discharges from the main contributing plants on site.

Discharges of gaseous wastes from Sellafield were much less than the permit limits in 2016. Gaseous discharges were generally similar in 2016, in comparison to those in 2015.

#### Monitoring around the site related to gaseous discharges

Monitoring of terrestrial foods in the vicinity of Sellafield is conducted by the FSA to reflect the scale and risk of discharges from the site. This monitoring is the most extensive of that for the nuclear licensed sites in the UK. A range of foodstuffs was sampled in 2016 including milk, fruit, vegetables, meat and offal, game, and environmental materials (grass and soil). Samples were obtained from different locations around the site to allow for variations due to the influence of meteorological conditions on the dispersal of gaseous discharges. The analyses conducted included gamma-ray spectrometry and specific measurements for tritium, carbon-14, strontium-90, technetium-99, iodine-129, uranium and transuranic radionuclides. In 2016, the Environment Agency carried out enhanced environmental monitoring of grass and soil samples (including around the River Calder) and revised the monitoring programme for gamma dose rate measurements, following the review of their programme.

The results of monitoring in 2016 are given in Table 2.4. The concentrations of all radionuclides around the site were low. Concentrations in terrestrial foodstuffs were generally similar to those in recent years. Concentrations of radionuclides in meat and offal from cattle and sheep were low with many reported as less than values with only limited evidence of the effects of Sellafield's atmospheric discharges detected in data for carbon-14. Plutonium concentrations and americium-241 in wood pigeon, when detectable, were low and much lower than those found in seafood.

A range of fruit, vegetables and terrestrial indicator materials was sampled in 2016 and the activity concentrations were generally similar to those found in previous years. In common with meat and offal samples, only limited evidence of the atmospheric discharges from Sellafield was found in some of these foods. Tritium was positively detected in locally picked blackberries and a grass sample, at low concentrations; likewise, cobalt-60 and strontium-90 in a soil sample (Seascale) and strontium-90 in food and grass samples. In 2016 (and 2015), the maximum iodine-129 concentration in milk was reported as a less than value (unlike in preceding years), however iodine-129 was positively detected in a beef sample (muscle) at a very low concentration. Small enhancements (above the expected background) in concentrations of carbon-14 were found in some food samples (including milk, meat and offal), as in recent years. Concentrations of transuranic radionuclides, when detectable in these foods, were very low. Antimony-125 concentrations were below limits of detection in all terrestrial samples in 2016, despite relatively enhanced discharges in recent years. Trends in maximum concentrations of radionuclides in milk, and corresponding discharge levels, near Sellafield over more than decade are shown in Figure 2.9. Over the whole period, concentrations of carbon-14 were relatively constant (with some variation between years, generally consistent with changes in discharges), and caesium-137 concentrations (and strontium-90 to a lesser extent) were declining overall.

### 2.3.3 Liquid discharges

Regulated liquid discharges derive from a variety of sources at the site including the fuel storage ponds, the reprocessing plants, from the retrieval and treatment of legacy wastes, the laundry and from general site drainage. Wastes from these sources are treated and then discharged to the Irish Sea via the sea pipelines that terminate 2.1 km beyond low water mark. Liquid wastes are also discharged from the factory sewer to the River Ehen Estuary and (since 2015) some liquid wastes are also discharged via the Calder Interceptor Sewer (Environment Agency, FSA, FSS, NIEA, NRW and SEPA, 2016). Discharges from the Sellafield pipelines during 2016 are summarised in Appendix 2 (Table A2.2). The current permit sets limits on gross alpha and beta, and 16 individual nuclides. In addition to overall site limits, individual limits have been set on discharges from the main contributing plants on site (Segregated Effluent Treatment Plant, Site Ion Exchange Plant (SIXEP), Enhanced Actinide Removal Plant (EARP) and THORP).

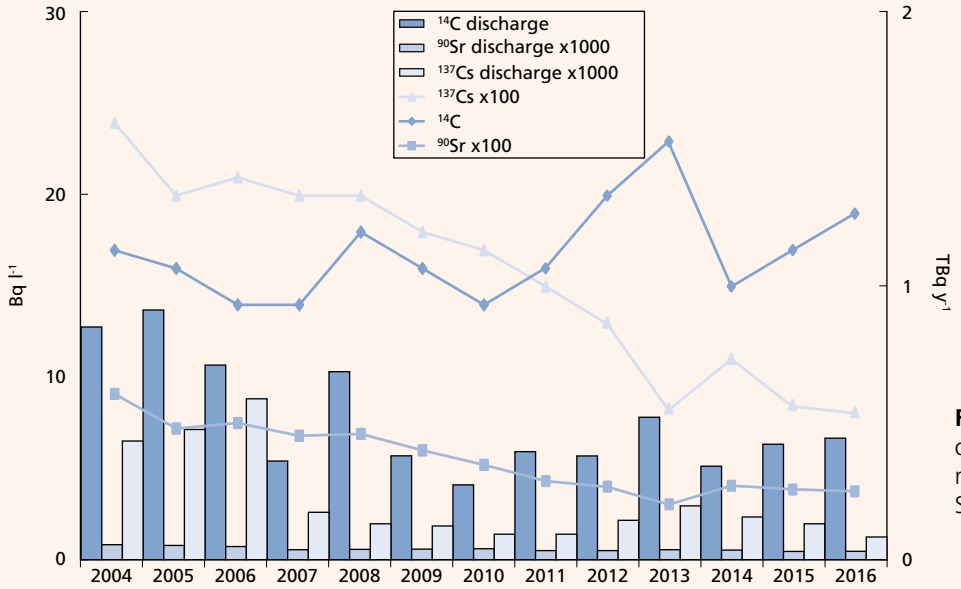



**Figure 2.9.** Discharges of gaseous wastes and monitoring of milk near Sellafield, 2004-2016

All discharges of liquid wastes from Sellafield were much less than the permit limits in 2016. Liquid discharges were generally similar in 2016, in comparison to those in 2015. Overall, the discharges continue to reflect the varying amounts of fuel reprocessed in the THORP and Magnox reprocessing plant, and periods of planned and unplanned reprocessing plant shutdown that occur from year to year.

Discharges of technetium-99 were low and similar in 2016, to those in 2015. The long-term downward trend, from their peak of 192 TBq in 1995, has continued (Figures 2.10 and 2.11). Technetium-99 discharges from Sellafield are now substantially reduced and met the target of below 10 TBq a year, set for 2006, in the UK National Discharges Strategy (Defra, 2002). The reduction of technetium-99 discharges was due to the diversion, since 2003, of the Medium Active Concentrate (MAC) waste stream from Magnox reprocessing to vitrification and, between 2003 and 2007, use of a chemical precipitant (Tetraphenylphosphonium Bromide) in EARP to remove technetium-99 from the historical stock of MAC.

## Monitoring of the marine environment

Regular monitoring of the marine environment near to Sellafield and further afield was conducted during 2016, by the Environment Agency and FSA (for England and Wales), NIEA (for Northern Ireland) and SEPA (for Scotland). The monitoring locations for seafood, water, environmental materials and dose rates near the Sellafield site are shown in Figures 2.12 and 2.13.

## Monitoring of fish and shellfish

Concentrations of beta/gamma activity in fish from the Irish Sea and from further afield are given in Table 2.5. Data are listed by location of sampling or landing point, north to south in Cumbria, then in approximate order of increasing distance from Sellafield. Results are available for previous specific surveys in the 'Sellafield Coastal Area' (extending 15 km to the north and to the south of Sellafield, from St Bees Head to Selker, and 11 km offshore) and the smaller 'Sellafield Offshore Area' (consisting of a rectangle, 1.8 km wide by 3.6 km long, situated south of the pipelines) in earlier RIFE reports (e.g. Environment Agency, FSA, NIEA, NRW and SEPA, 2014). Concentrations of specific naturally occurring radionuclides in fish and shellfish in the Sellafield area are given in Section 7.

The concentrations of most radionuclides have decreased over the previous decades in response to decreases in discharges. Concentrations generally continue to reflect changes in discharges over time periods, characteristic of radionuclide mobility and organism uptake. Trends in concentrations of radionuclides, and corresponding discharge levels, in seafood near Sellafield (over the last decade) are shown in Figures 2.14 – 2.19. There was variability from year to year, particularly for the more mobile radionuclides. Liquid discharges of technetium-99 in 2016 were similar to those in 2015. Overall, concentrations of technetium-99 in fish and shellfish have shown a continued reduction, from the relatively elevated levels shown at the beginning of the reported period, but were generally similar (with minor variations) over most recent years (Figure 2.16). For the transuranic elements (Figures 2.18 – 2.19), the long-term trends of reductions in concentrations from earlier decades appear to be slowing. Over the last decade, despite generally decreasing discharges, concentrations of americium-241 and plutonium-239+240 in fish and shellfish have shown some variations from year to year. The mean concentrations of caesium-137, plutonium-239+240 and americium-241 in lobster, and caesium-137 in fish, near Sellafield in 2016 are the lowest reported values in comparison to previous years. Overall, concentrations of plutonium radionuclides and americium-241 in winkles were generally similar (with minor variations) in 2016 compared to those in recent years.

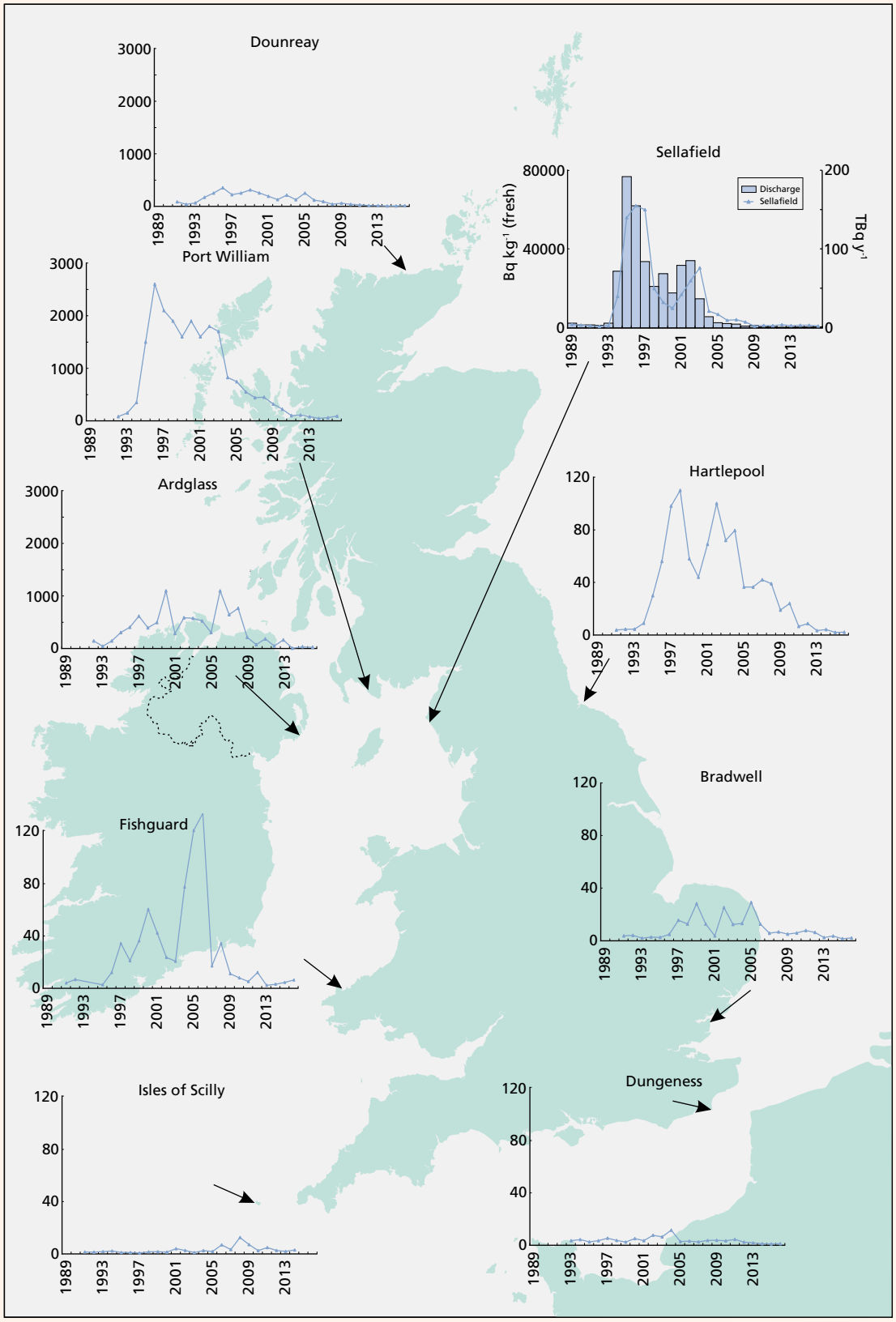



**Figure 2.10.** Technetium-99 in UK seaweed (*Fucus vesiculosus*) from Sellafield liquid discharges between 1989-2016 (Note different scales used for Ardglass, Dounreay, Port William and Sellafield)

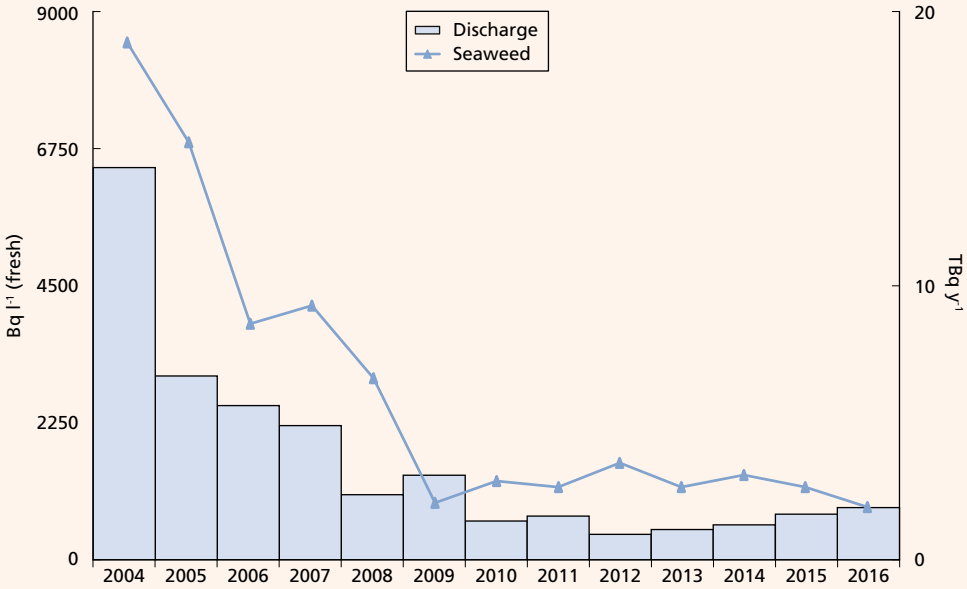



**Figure 2.11.** Technetium-99 in UK seaweed (*Fucus vesiculosus*) from Sellafield liquid discharges between, 2004-2016

Beta/gamma-emitting radionuclides detected in fish included: tritium, carbon-14, strontium-90 and caesium-137 (Table 2.5). Overall, concentrations of caesium-137 in fish species, across a wide range of sampling locations, were generally similar in comparison to those in 2015. Over the longer time period, activity concentrations in fish and shellfish appear to be generally declining (with minor variations) at a slow rate (Figure 2.17). Activity concentrations in fish (and shellfish) generally reflected progressive dilution with increasing distance from Sellafield. However, the rate of decline of caesium-137 concentrations with distance was not as marked as was the case when significant reductions in discharges were achieved some years ago. There was therefore a greater contribution from historical sources.

Up until 2013, brown trout was sampled for analysis from the River Calder, which flows through the Sellafield site. Results for previous measured caesium-137 concentrations, and long-term trend information, are available in earlier RIFE reports (e.g. Environment Agency, FSA, NIEA, NRW and SEPA, 2014). The changes in concentrations were likely to be due the combined effects of Sellafield discharges and fallout from Chernobyl, accentuated by the movement of such fish in the Calder river system.

Other artificial beta/gamma-emitting radionuclides detected in fish included carbon-14 and tritium. With an expected carbon-14 concentration from natural sources ~ 21 Bq $kg^{-1}$, the data suggest a continued local enhancement of carbon-14 due to discharges from Sellafield. In 2016, carbon-14 provided the highest activity concentration in marine fish (plaice, 120 Bq $kg^{-1}$) from Ravenglass, with lower concentrations of tritium (total) and Organically Bound Tritium (OBT). In previous years, virtually all of the total tritium was associated with organic matter. In 2016, the limited tritium results suggest that the total tritium in marine samples was a combination of OBT (associated with organic matter) and tritiated water. Nevertheless, due to the low radiotoxicity of this isotope of hydrogen and the low concentrations observed, the overall dose implication was very small.

For shellfish, a wide range of radionuclides is detectable, owing to generally greater uptake of radioactivity by these organisms from sediments. Generally, molluscs tend to contain higher concentrations than crustaceans and both contain higher concentrations than fish. Concentrations of beta/gamma-emitting radionuclides are shown in Table 2.6 (Table 2.7 for plutonium-241). There can be substantial variations between species; for example, lobsters tend to concentrate more technetium-99 than crabs (see also Knowles *et al.,* 1998; Swift and Nicholson, 2001). The highest concentrations from Sellafield discharges were of tritium, carbon-14, and technetium-99. Comparing 2016 and 2015 data across a wide range of sampling locations and shellfish species (where comparisons can be made), technetium-99 concentrations were similar (with minor variations), but reduced in comparison to those years prior to 2012 due to the progressive reductions in discharges of this radionuclide. Concentrations of other radionuclides (non-transuranic) in 2016 were also broadly similar (where comparisons can be made) to those in 2015.

Transuranic radionuclide data for fish and shellfish samples (chosen on the basis of potential radiological significance) in 2016 are given in Table 2.7. Transuranic elements are less mobile than other radionuclides in seawater and have a high affinity for sediments; this is reflected in higher concentrations of transuranic elements in shellfish compared with fish. Comparing 2016 and 2015 data across a wide range of sampling locations and shellfish species further afield from Sellafield, concentrations in shellfish were generally similar (where comparisons can be made). Those from the north-eastern Irish Sea were the highest transuranic concentrations found in foodstuffs in the UK. The concentrations in shellfish were generally similar for plutonium radionuclides and americium-241 in 2016 (in comparison to those in 2015) at most of the north-eastern Irish Sea locations,

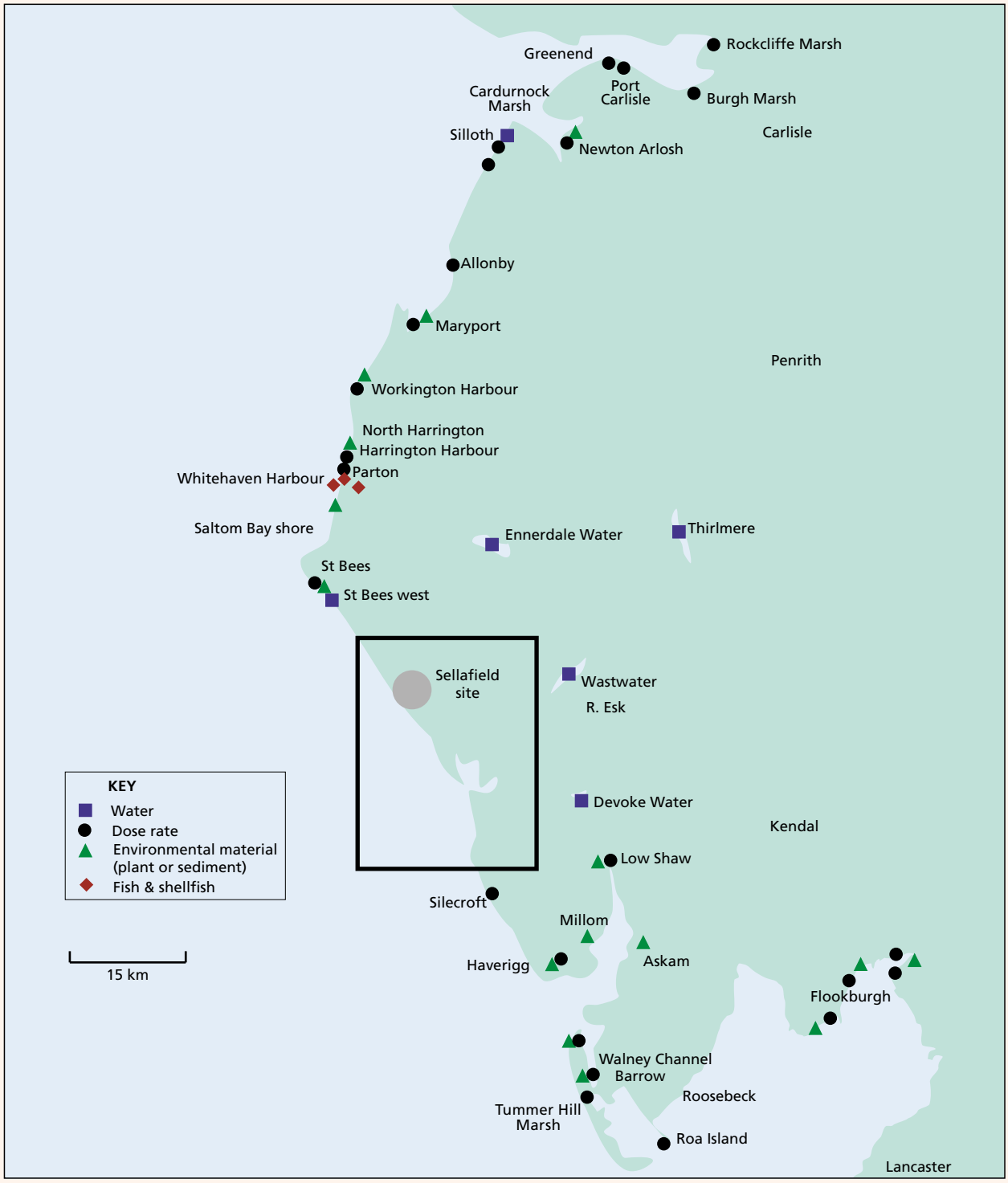



**Figure 2.12.** Monitoring locations in Cumbria, 2016 (not including farms)

albeit that the plutonium-239+240 and americium-241 concentrations in lobster (near Sellafield) are the lowest reported values in 2016 (in comparison to previous years). Overall, concentrations of plutonium radionuclides and americium-241 in winkles were generally similar (with minor variations) in 2016 compared to those in recent years. Variations of these observations in previous years were likely to have resulted from a combination of mechanisms including natural environmental variability and redistribution of sediments due to natural processes.

## Monitoring of sediments

Radionuclides in Sellafield liquid discharges are taken up into sediments along the Cumbrian Coast in particular in muddier (fine grained) areas such as estuaries. Some of these areas are used by the public. Levels of radionuclides are regularly monitored, both because of their relevance to exposure and in order to keep distributions of radioactivity under review. The results for 2016 are shown in Table 2.8. Radionuclides detected include cobalt-60, strontium-90,

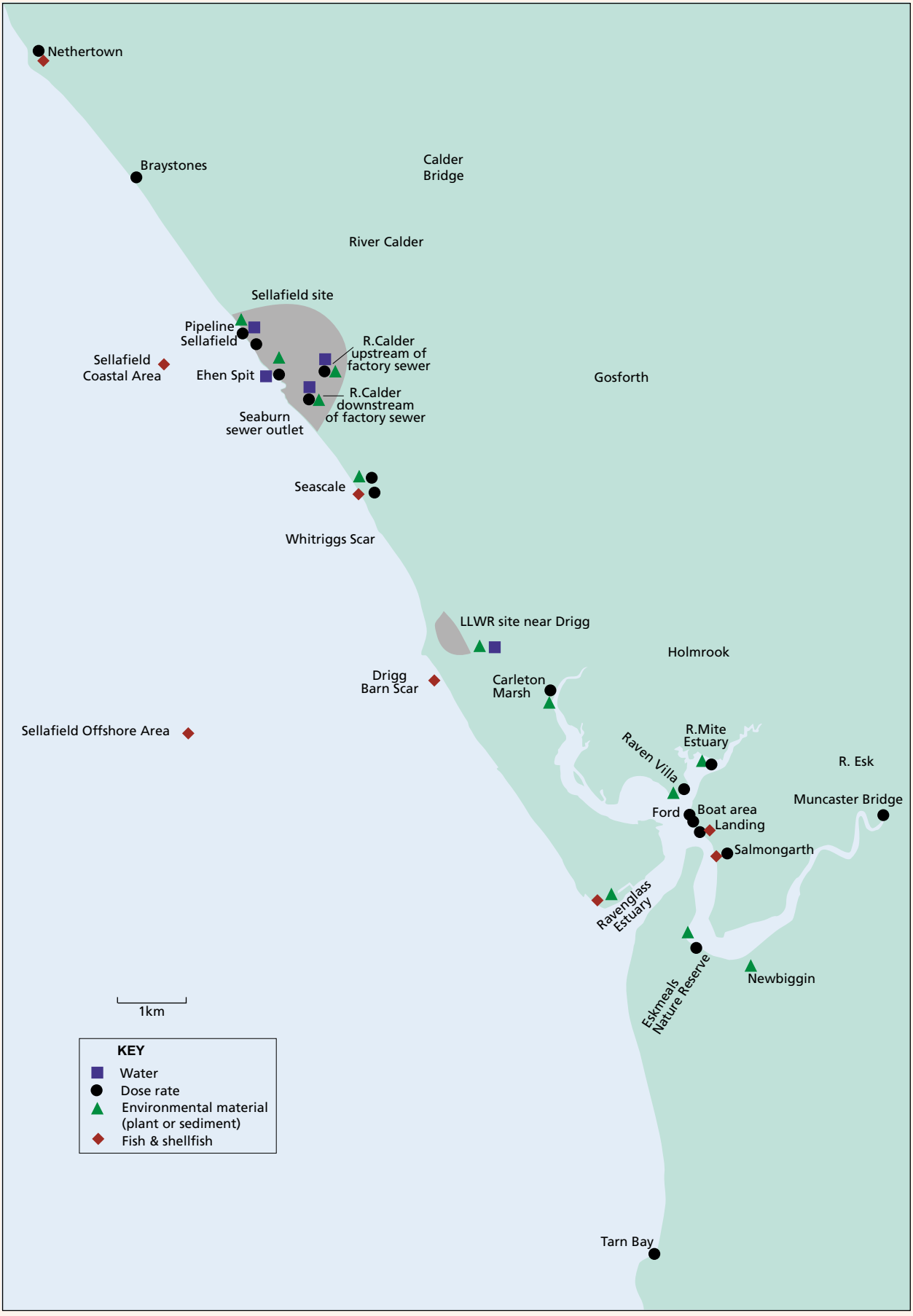



**Figure 2.13.** Monitoring locations at Sellafield, 2016 (not including farms)

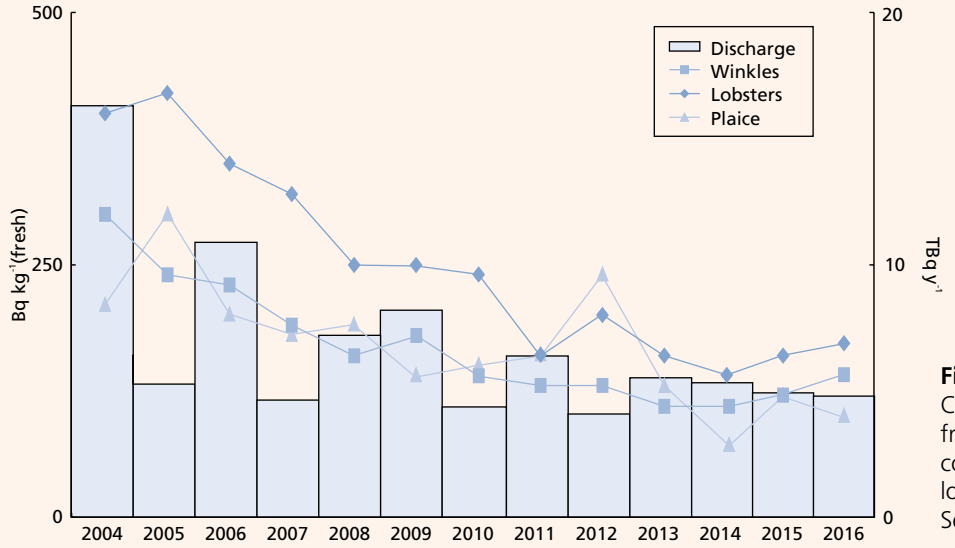



**Figure 2.14.**
Carbon-14 liquid discharge from Sellafield and concentrations in plaice, lobsters and winkles near Sellafield, 2004-2016

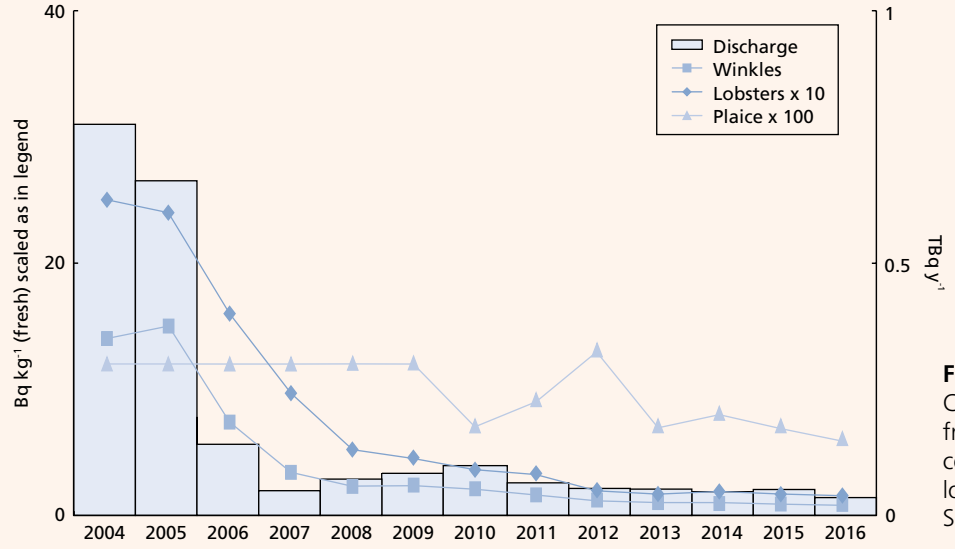



**Figure 2.15.**
Cobalt-60 liquid discharge from Sellafield and concentrations in plaice, lobsters and winkles near Sellafield, 2004-2016

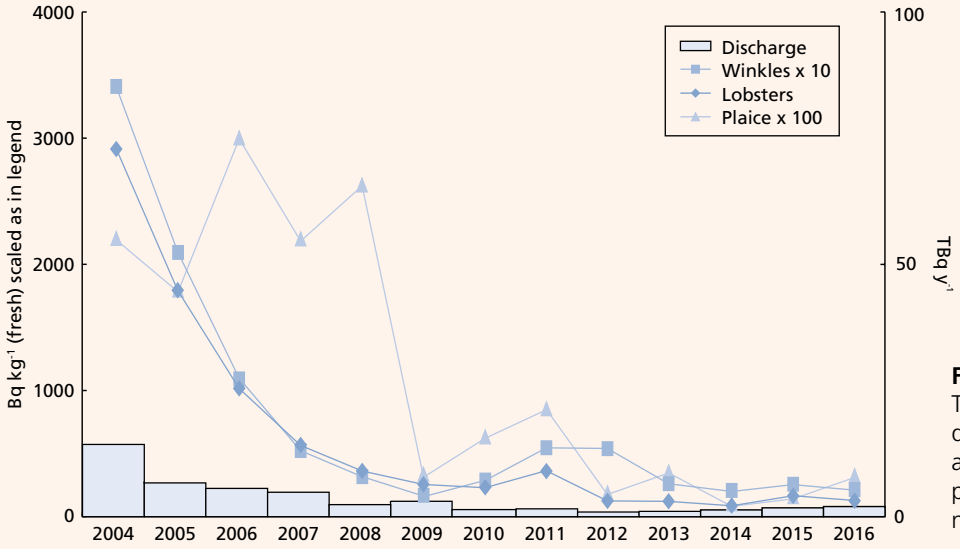



**Figure 2.16.**
Technetium-99 liquid discharge from Sellafield and concentrations in plaice, lobsters and winkles near Sellafield, 2004-2016

caesium-137 and transuranic elements. The highest concentrations found are close to the site and in fine particulate materials in estuaries and harbours, rather than the coarser-grained sands on open beaches. The concentrations of long-lived radionuclides, particularly caesium-137 and the transuranic elements, largely reflect past discharges from Sellafield, which were considerably higher than in recent years. Over the last 30 years discharges have fallen significantly as the site provided enhanced treatment to remove radionuclides prior to discharge. Overall, concentrations in sediments were generally similar in 2016, although lower concentrations of plutonium radionuclides and americium-241 were measured from the River Mite estuary and Ravenglass, in comparison to those in 2015.

The trends over time (1988 – 2016) for activity concentrations in mud from Ravenglass and liquid discharges from Sellafield are shown in Figures 2.20 – 2.23. The concentrations of most radionuclides have decreased over the past 25 years in response to decreases in discharges, with sustained reductions in discharges of caesium-137 and transuranic elements. Discharges of cobalt-60 have been variable in the earlier years but reduced over the last decade, as reflected in the sediment concentrations at Ravenglass, with some evidence of a lag time between discharge and sediment concentration (Figure 2.22). The cobalt-60 concentration in mud from Ravenglass is the lowest reported value in 2016, following the similar downward trend as recent years. Over the last decade, caesium-137 and transuranic concentrations in sediments have remained relatively constant (Figures 2.20, 2.21 and 2.23). Since the mid-1990s, discharges of caesium-137, plutonium isotopes and americium-241 have remained at low levels, but with some variability. There is as a suggestion of small progressive increases in caesium-137 and transuranic elements activities in sediments (peaking in 2006 and 2014). The likely explanation is that changes in these concentrations are due to remobilisation and subsequent accretion of fine-grained sediments containing higher activity concentrations. For americium-241, there is also an additional contribution due to radioactive in-growth from the parent plutonium-241 already present in the environment. The effect is less apparent in fish and shellfish (Figures 2.17 – 2.19) and will continue to be monitored.

Concentrations of caesium-137 and americium-241 in sediments from coastal locations of the north-east Irish Sea are also shown in Figure 2.24. Concentrations of both radionuclides diminish with distance from Sellafield. Overall, concentrations in 2016 at a given location were generally similar to those in 2015, and any fluctuations were most likely due to the normal variability expected to be in the environment. Limited evidence suggests that small peaks in activity concentrations have occurred in sediments at some locations at distance from Sellafield in recent years, but these are still below peak values reported over the whole period of time (except at Carsluith). The effect appears to be more pronounced for americium-241 and is likely to be due to the spreading of activity away from Sellafield combined with the effect of grow-in from plutonium-241 (Hunt *et al.*, 2013).

A research study, commissioned by FSA, determined the depth distributions of technetium-99 concentrations in sea-bed cores to produce an estimate of the total inventory residing in the sub-tidal sediments of the Irish Sea (Jenkinson *et al*., 2014). The study concluded that the inventory of technetium-99 was estimated to have been of the order of 30 TBq (or approximately 2 per cent of the total cumulative Sellafield discharge), with approximately 8 TBq present in surface material and thereby potentially most susceptible to re-dissolution or re-suspension.

## Monitoring of dose rates

Dose rates are regularly monitored at a large number of locations, both in the Sellafield vicinity and further afield, using environmental radiation dosimeters. Table 2.9 lists the locations monitored by the environment agencies and the gamma dose rates in air at 1 m above ground. Where comparisons can be made from similar ground types and locations, dose rates over intertidal areas throughout the Irish Sea in 2016 were generally similar to those in recent years. Any variations between years are likely to have been due to normal variability expected to be present in the environment. As in previous years, gamma dose rates were measured on the banks of the River Calder, which flows through the Sellafield site. Gamma dose rates were measured on a different ground type (grass) to that measured in 2015 (stones, pebbles and rock), and did not show an excess above natural background downstream of the site (of approximately 0.04 μGy $h^{-1}$) in 2016. Although these dose rates have been locally enhanced in previous years on the banks of the River Calder, occupancy by the public (mainly anglers) is low in this area (unlikely to be more than a few tens of hours per year). On this basis, the resulting doses (in previous years) were also much less than those at other intertidal areas as discussed earlier in this section.

Gamma dose rates above mud and salt marshes, from a range of coastal locations in the vicinity of Sellafield, are shown in Figure 2.25. Gamma dose rates at sandy locations are generally lower than those above mud or salt marshes. The general decrease in dose rates with increasing distance from Sellafield, which was apparent under conditions of higher discharges several decades ago, is no longer so prominent in recent years. Spatial variability of dose rates is expected, depending on ground type; generally higher dose rates being recorded over areas with finely divided sediments. For each location, there has been variation over time. Close to Sellafield (at Carleton Marsh and Newbiggin), there was limited evidence to suggest that dose rates were slowly declining over the whole period. Locations that are further afield from Sellafield show dose rate values that only marginally exceeded average UK natural background rates.

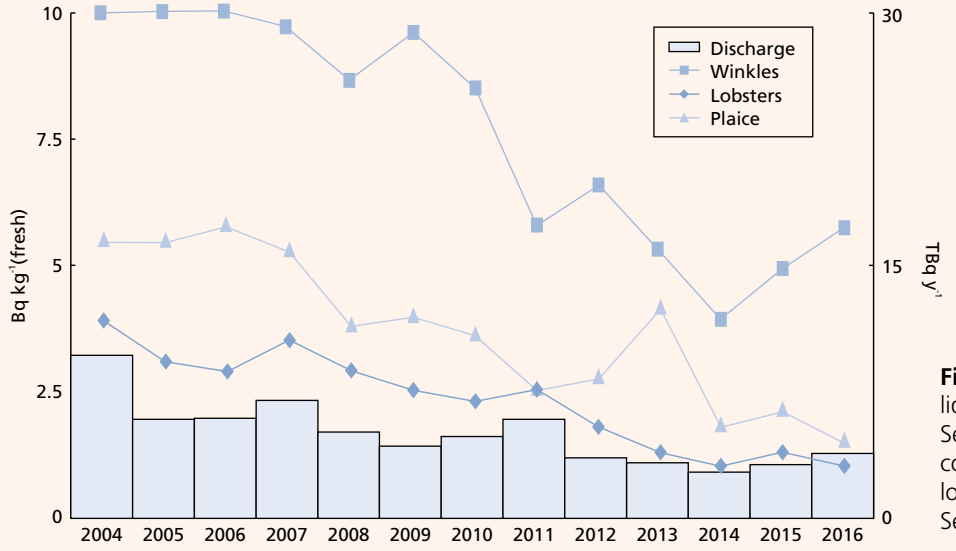



**Figure 2.17.** Caesium-137 liquid discharge from Sellafield and concentrations in plaice, lobsters and winkles near Sellafield, 2004-2016

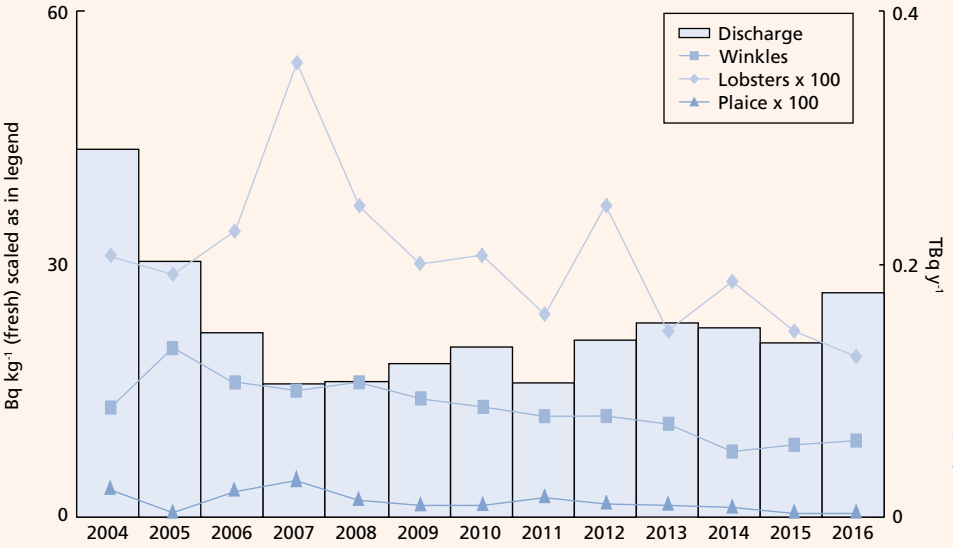



**Figure 2.18.** Plutonium-239+240 liquid discharge from Sellafield and concentrations in plaice, lobsters and winkles near Sellafield, 2004-2016

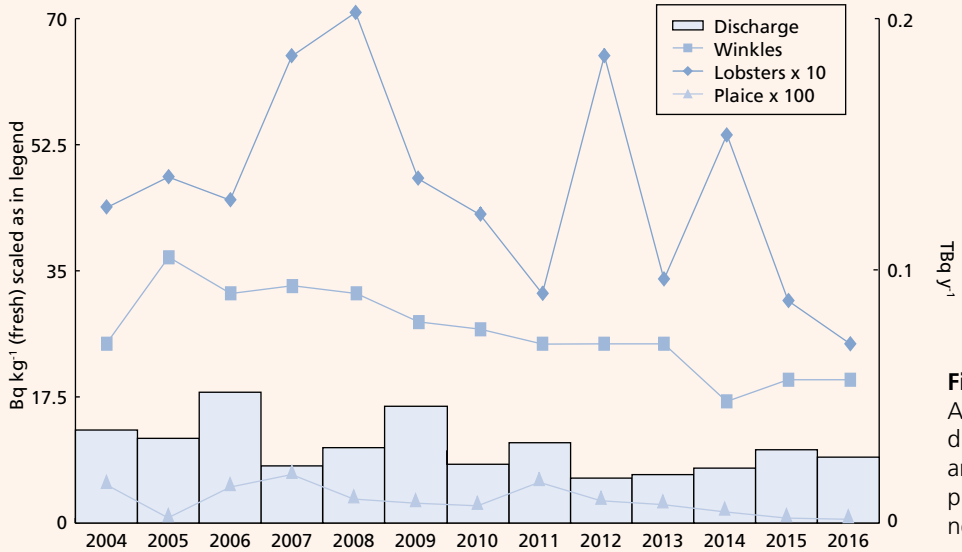



**Figure 2.19.** Americium-241 liquid discharge from Sellafield and concentrations in plaice, lobsters and winkles near Sellafield, 2004-2016

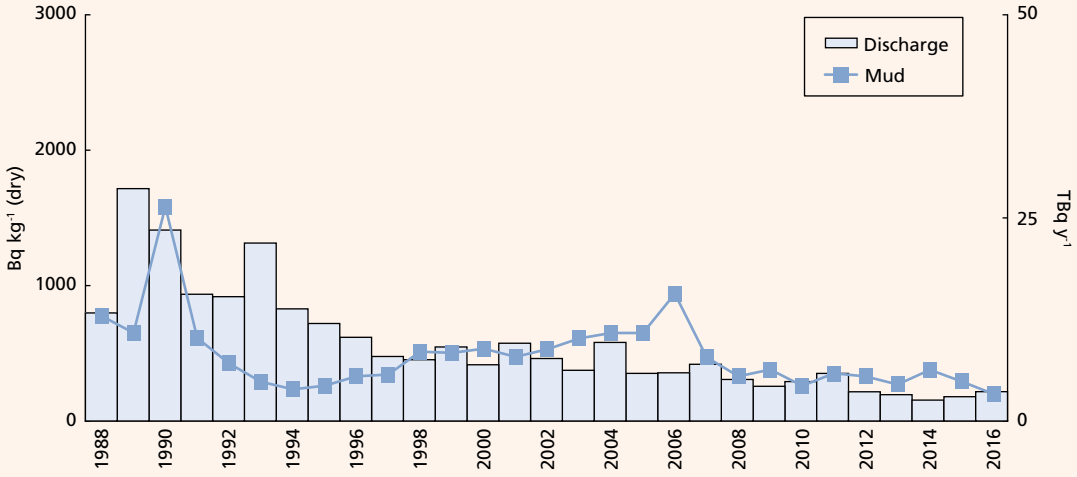



**Figure 2.20.** Caesium-137 liquid discharge from Sellafield and concentration in mud at Ravenglass, 1988-2016

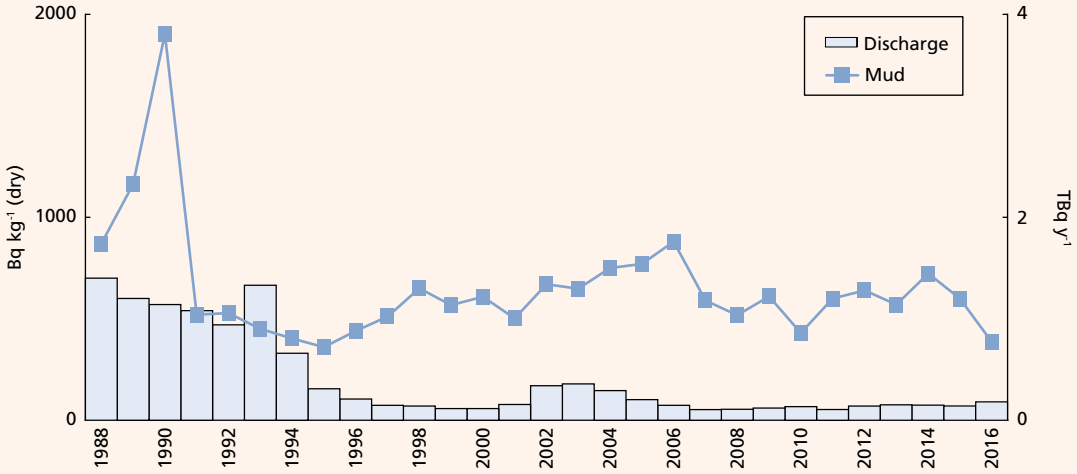



**Figure 2.21.** Plutonium-alpha liquid discharge from Sellafield and plutonium-239+240 concentration in mud at Ravenglass, 1988-2016

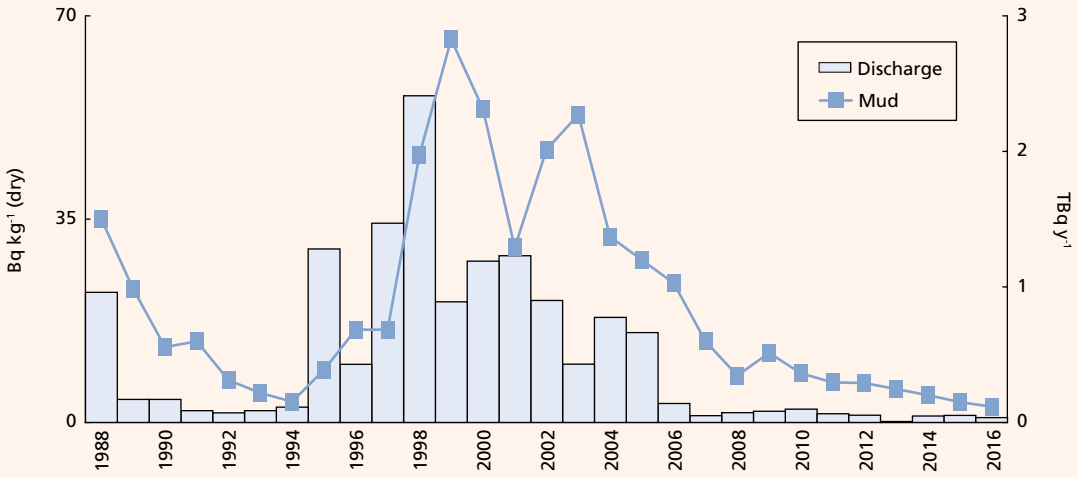



**Figure 2.22.** Cobalt-60 liquid discharge from Sellafield and concentration in mud at Ravenglass, 1988-2016

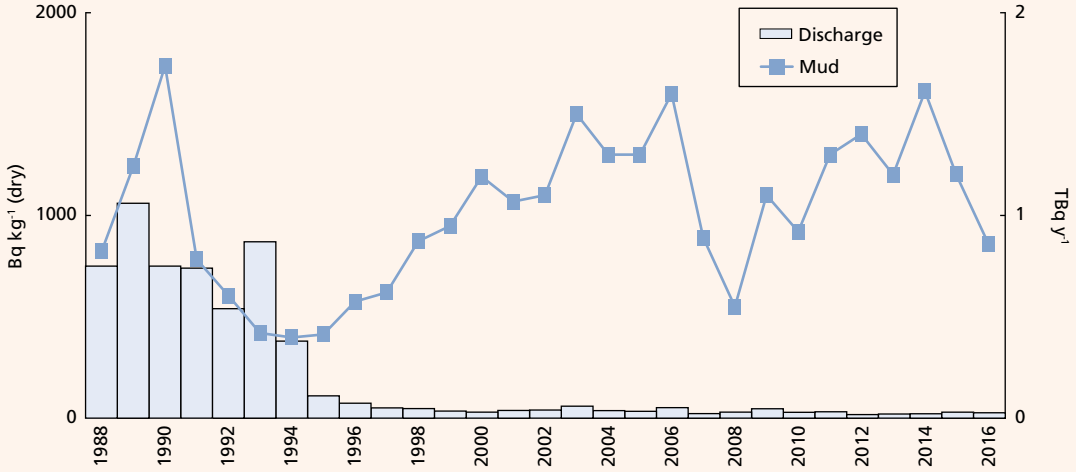



**Figure 2.23.** Americium-241 liquid discharge from Sellafield and concentration in mud at Ravenglass, 1988-2016

Over the last 30 years, levels of radioactivity in the environment around Sellafield have declined as a result of reduced discharges. In more recent years the levels in the Esk estuary have shown a less clear trend, with concentrations of some radionuclides fluctuating from year to year (for example, see Figure 2.21). This effect could be due to the dynamic nature of the sediment in the estuary, which is eroded and transported by tide and freshwater, periodically exposing older deeper sediment containing radioactivity from historical discharges. Due to the variations seen in recent years and local concerns, the Environment Agency initiated a more detailed study of dose rates in the Esk Estuary in 2007. Further information providing background information, and describing the objectives and results of this study, is available in earlier RIFE reports (e.g. Environment Agency, FSA, FSS, NIEA, NRW and SEPA, 2015).

## Monitoring of fishing gear

During immersion in seawater, fishing gear may entrain particles of sediment on which radioactivity is adsorbed. Fishermen handling this gear may be exposed to external radiation, mainly to skin from beta particles. Fishing gear is regularly monitored using surface contamination monitors. Results for 2016 are given in Table 2.10. Overall, where comparisons can be made, measured dose rates were generally similar to those in 2016.

## Contact dose-rate monitoring of intertidal areas

Results from measurements of beta dose rates on shoreline sediments (using contamination monitors), to allow estimation of exposure of people who handle sediments regularly, are given in Table 2.11. Overall, positively detected dose rates in 2016 were generally similar to those in 2015 (where comparisons can be made from similar ground types and locations).

More general beta/gamma monitoring for the Environment Agency of contamination on beaches using portable probes continued to establish whether there are any localised 'hot spots' of activity, particularly in strand lines and beach debris. In 2016, no material was found using these probes in excess of the action level equivalent to 0.01 mSv $h^{-1}$.

In 2008, the Environment Agency published a formal programme of work for the assessment of contamination by radioactive particles on and around the west Cumbrian coastline. The assessment was focused on public protection from high activity discrete radioactive particles that have been released to the environment from activities at the Sellafield site (Environment Agency, 2008). The work so far has included investigating the distribution and behaviour of Sellafield-related particles, particle analysis and identification, risks from particles, and a review of particle dispersion and transport models focused on the Eastern Irish Sea and Solway Firth.

Since vehicle-mounted beach survey work began in November 2006, and up to the end of March 2016, approximately 2,000 hectares of beach area has been surveyed by the Sellafield site operator's contractors (Sellafield Limited, 2016). The survey equipment used currently (since August 2009) is the Groundhog™ Synergy system, which is an improvement on the use of the original Groundhog™ Evolution system. The Groundhog™ Synergy system has a specific capability in relation to the detection of medium/high energy gamma emitting radionuclides and also provides improved detection capability for low energy gamma emissions, increasing the ability of detection of particles containing americium-241.

During 2016/17, further beach monitoring was completed in line with the Environment Agency's specification, of approximately 175 hectares (Sellafield Limited, 2017), against a programme target of 160 hectares. In 2017, there was a change implemented to the beach finds categories in that the 'stone' category will be replaced

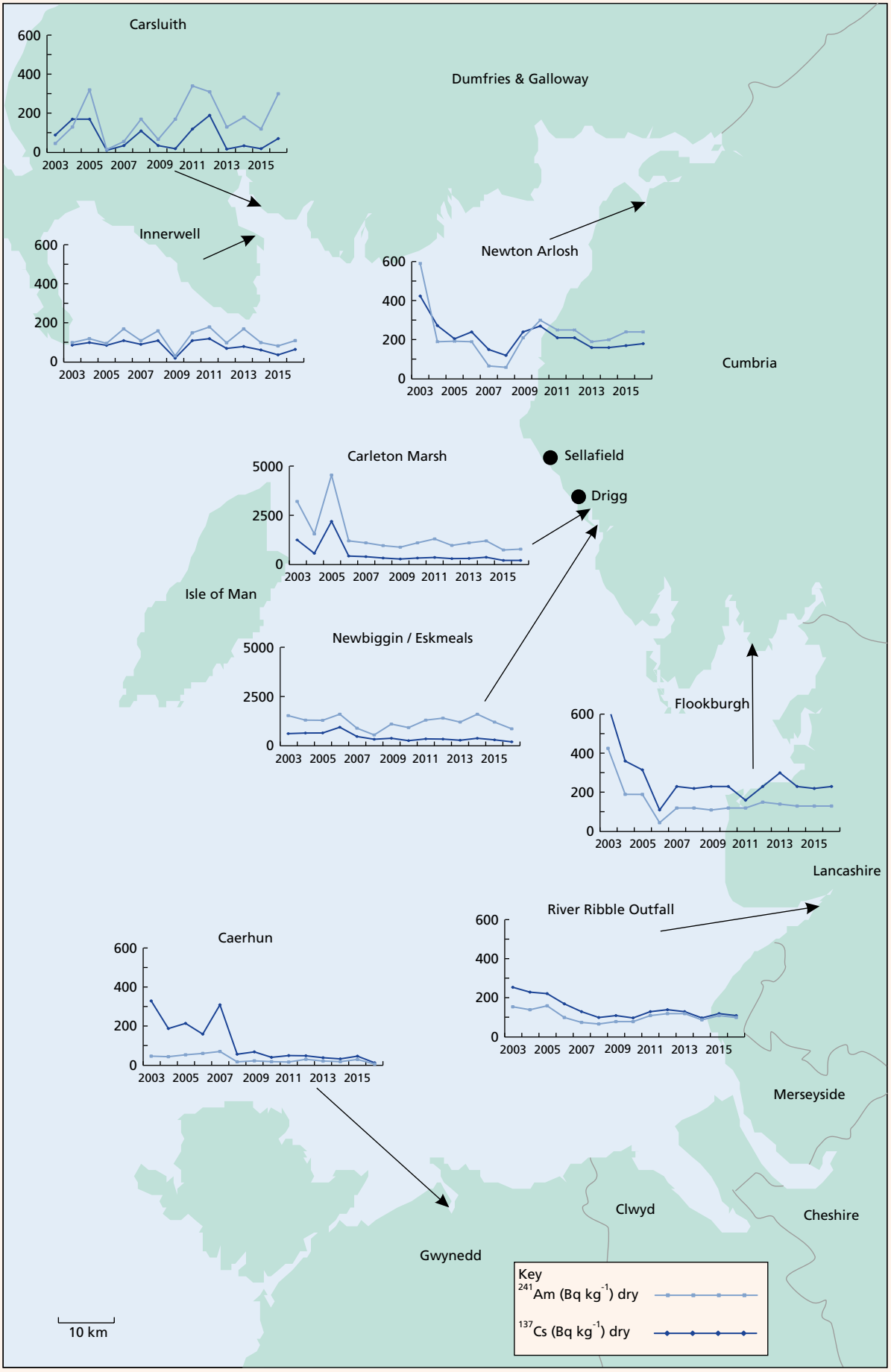



**Figure 2.24.** Concentrations of americium-241 and caesium-137 in coastal sediments in North West England and South West Scotland between 2003-2016 (Note different scales used for Newbiggin and Carleton Marsh)

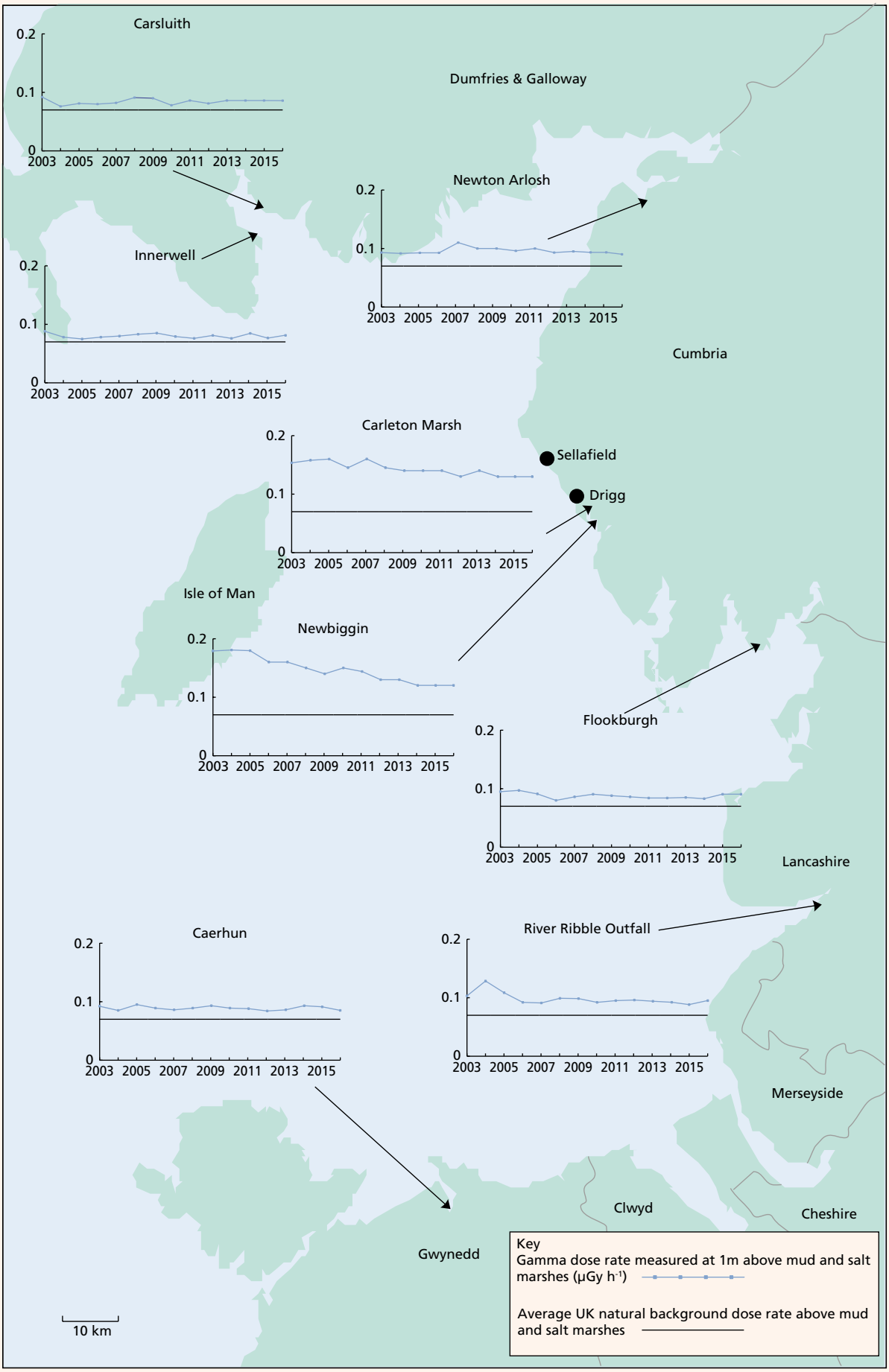



**Figure 2.25.** Gamma dose rates above fine coastal sediments (mud and salt marshes) in North West England and South West Scotland between 2003-2016

by 'object'. This means that all items larger than 2 mm in size (e.g. granules, gravel, wire, pebble and stones) will be classified as objects. The number of radioactive finds identified in the period from April 2016 to March 2017 was 254 (compared with 349 in 2015/2016), of which 81 per cent were classified as particles (less than 2 mm in size) and the remainder as objects (larger than 2 mm in size). The number of finds were typical of those in recent years. Most of the finds (82%) were concentrated on a 5 km stretch of beach running NW from the Sellafield site. All have been removed from the beaches.

During 2016/2017, two of the finds detected exceeded the characterisation triggers set within the draft Environment Agency's intervention criteria or the PHE risk assessment. The finds were separated from the rest of the sample and size analysis showed that both finds were stones. Both finds were within the range of previous measurements; therefore, these finds do not require immediate further consideration and do not challenge the PHE risk assessment.

Monitoring along the Cumbrian coast will continue, with the current proposal being a further 150 hectares to be surveyed. The 2017 beach monitoring programme will align with the calendar year (rather than the financial year) to allow the beach monitoring to run alongside the operator's wider environmental monitoring programme. A programme of work is in place to address the remaining uncertainties in the origins, fate and effects of the particles with the aim of returning the work to a routine monitoring programme only by about 2018.

In 2012, PHE reported their review of the results and position on risk following the introduction of the improved Synergy™ monitoring system. The report concluded that the increase in particle finds following the introduction of this system was a result of its improved capability and also that advice previously given by PHE to the Environment Agency following a detailed assessment of risks in 2010 remained valid (Brown and Etherington, 2011; Etherington *et al*., 2012). The report restated the conclusion that based on the currently available information, the overall health risks to beach users are very low and significantly lower than other risks people accept when using the beaches. As such, PHE advice remained that no special precautionary actions were required to limit access to or use of the beaches. A more recent report by PHE describes the assessed health risks from the consumption of seafood (including those to commercial fishermen) from radioactive particles in the vicinity of the Sellafield Site (Oatway and Brown, 2015). Based on currently available information, it is concluded that the overall health risks to both seafood consumers and commercial fishermen are very low.

In relation to food safety, and following a previous assessment of the particles frequency and the activity concentrations, FSA's guidance to the Environment Agency supported PHE's advice. The Environment Agency will also continue to work with relevant authorities to keep the situation under review.

In 2007, SEPA published a strategy document for the assessment of the potential impact of Sellafield radioactive particles on members of the public in south-west Scotland (SEPA, 2007) and the beach monitoring programme was temporarily extended to include two locations on the north Solway coastline (Kirkcudbright Bay and Southerness). This was based on some limited modelling work on the movement of particles undertaken for the Environment Agency following a request by SEPA. No particles were detected at these locations. SEPA is maintaining a watching brief on the situation in as much as it may affect Scotland.

Between 2010 and 2013, the Environment Agency provided updates on further progress of the enhanced beach monitoring (Environment Agency, 2010b; 2011; 2013c) with work prior to 2010 described elsewhere (Environment Agency, FSA, NIEA and SEPA, 2010).

Further detail on enhanced beach monitoring data compiled so far can be obtained from Sellafield Limited website:

**http://sustainability.sellafieldsites.com/environment/environment-page/particles-in-the-environment/**

## Monitoring of seaweed

In addition to occasional use in foods and as fertilisers, seaweeds are useful environmental indicator materials (as radionuclides are concentrated by seaweeds), facilitating assessments and assisting the tracing of these radionuclides in the environment. Table 2.12 gives the results of measurements in 2016 of seaweeds from shorelines of the Cumbrian coast and further afield. Comparing 2016 and 2015 data across a wide range of sampling locations, radionuclide concentrations were generally similar (where comparisons can be made) in seaweeds.

*Fucus* seaweeds are particularly useful indicators of most fission product radionuclides: samples of *Fucus vesiculosus* are collected both in the Sellafield vicinity and further afield to show the extent of Sellafield contamination in north European waters. The effects of technetium-99 discharges from Sellafield on concentrations in seaweed (1989 to 2016 and 2004 to 2016), are shown in Figures 2.10 and 2.11, respectively. In the north-east Irish Sea, technetium-99 concentrations have been reasonably constant over the present decade, consistent with the relatively low discharges; the highest concentrations which were found near Sellafield were much less than those in the mid-1990s and the decade thereafter (in response to the progressive reduction in discharges). In general, there was also a large reduction in concentrations of technetium-99 in *Fucus vesiculosus* with distance from Sellafield, as the effect of the discharges becomes diluted in moving further afield.

Technetium-99 concentrations in seaweed (Table 2.12) collected from sites in Cumbria were generally higher (by small amounts) in comparison to those in 2015. Over the last 5 years, small enhancements have been found, year on year, but technetium-99 concentrations in seaweed in 2016 were still below values reported prior to 2009 (Figure 2.11). At one specific location (Auchencairn, Scotland), known to have had fluctuating concentrations in previous years, activity concentrations in seaweed (*Fucus*) were lower in 2016 compared with those in 2015. Variations in concentrations in the past were most likely the result of complex hydrographic transport patterns in the Irish Sea, with technetium-99 being dispersed to a variable degree before arriving at distant locations (Leonard *et al.,* 2004). It may also be noted that as the effects of the high technetium discharges of the 1990s continue to disperse, there is the potential for areas distant from Sellafield to exhibit concentrations greater than those in closer proximity, such as Auchencairn, and as observed in seawater in Liverpool Bay for 1998 (McCubbin *et al.*, 2002).

## Monitoring of seawashed pasture

The potential transfer of technetium-99 to milk, meat and offal from animals grazing tide-washed pasture was considered using a modelling approach in the report for 1997 (MAFF and SEPA, 1998). The maximum potential dose was calculated to be 0.009 mSv at that time. Follow-up sampling of tide-washed pastures at Newton Arlosh, Cumbria and Hutton Marsh, Lancashire in 2006 suggested that this dose estimate remains valid (Environment Agency, Environment and Heritage Service, FSA and SEPA, 2007).

## Monitoring of sea to land transfer

Terrestrial foodstuffs are monitored near Ravenglass to check on the extent of transfer of radionuclides from sea to land in this area. In 2016, samples of milk and livestock were collected and analysed, for radionuclides which were released in liquid effluent discharges from Sellafield. Results from surveys for activity concentrations in crops, fruit and environmental indicators are available in earlier RIFE reports (e.g. Environment Agency, FSA, NIEA, NRW and SEPA, 2014).

The results of measurements in 2016 are given in Table 2.13. In 2016, a domestic fruit sample was collected (not collected in recent years). Generally, the activity concentrations, where positively detected, show lower concentrations than were found in the immediate vicinity of Sellafield (Table 2.4). In 2016, a very low concentration of tritium was positively detected in beef sample (muscle). As in previous years, the evidence for sea to land transfer was very limited in 2016. Technetium-99 and plutonium-238 concentrations are reported as less than values (or close to the less than value). Small concentrations of artificial nuclides were detected in some samples but the concentrations were very low. In recent years, where detectable, observed isotopic ratios of $^{238}Pu$:$^{239+240}Pu$ concentrations were somewhat higher than 0.025, a value which might be expected if the source was only (or entirely) due to fallout. This may suggest a Sellafield influence.

## Monitoring of fishmeal

A theoretical study has established that any indirect onward transmission of man-made radioactivity into the human diet from the fishmeal pathway (i.e. fed to farmed fish, poultry, pigs, cows and sheep) is unlikely to be of radiological significance (Smith and Jeffs, 1999). A detailed survey was undertaken to confirm these findings (FSA, 2003). Samples, obtained from 14 fish farms in Scotland and three in Northern Ireland, contained very low radionuclide concentrations (most being less than the limits of detection) and the few positively detected values were all less than 1 Bq $kg^{-1}$. Annually reported RIFE results for activity concentrations in farmed salmon from the west of Scotland confirm the findings of the FSA study (e.g. Environment Agency, FSA, NIEA, NRW and SEPA, 2014, Tables 2.5 and 2.7).

## Monitoring of waters

Evidence of the effects of liquid discharges from Sellafield on concentrations of radionuclides in seawater is determined by sampling from research vessels and the shore. The results of the seawater programme are given in Section 8.

Sampling of fresh water from rivers and lakes in west Cumbria is conducted as part of the regular environmental monitoring programme around Sellafield; however, other environmental materials are likely to be more indicative of direct site-related effects. Some of the sources monitored provide public drinking water. The results for 2016 are included in Table 2.14. Tritium, gross alpha and gross beta concentrations in public supplies were below the investigation levels for drinking water in the European Directive 2013/51.

Small amounts of activity are discharged from Sellafield under permit via the factory sewer outfall to the River Ehen Estuary, immediately prior to the confluence with the River Calder. In 2016, an additional sample was taken upstream of the site (River Ehen). As in recent years, there was no evidence of tritium 100 m downstream (nor upstream) of the outfall in 2016 (Table 2.14). These waters are not potable and any low concentrations observed previously are of no radiological significance. Table 2.14 also includes the results of monitoring from the Ehen Spit (Figure 2.12) near Sellafield where water issues from the ground at low tide. This release is not due to regulated discharges of liquid wastes but to ground water migration from the Sellafield site. The water is brackish so it will not be

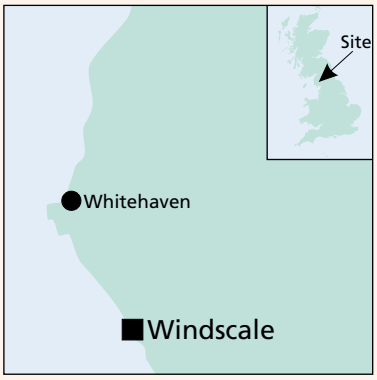
used as a drinking water source and therefore the only consumption would be inadvertent. Enhanced gross beta and tritium concentrations were observed in 2016 with concentrations similar to those in recent years. The dose from inadvertent consumption of water from Ehen Spit has been shown to be insignificant (Environment Agency, 2002a).

### 2.3.4 Monitoring of unusual pathways

In 1998, high caesium-137 concentrations (up to 110,000 Bq $kg^{-1}$) were found in feral pigeons sampled in Seascale by MAFF. Further information providing background information, and describing the consequences of this monitoring, is available in earlier RIFE reports (e.g. Environment Agency, FSA, FSS, NIEA, NRW and SEPA, 2015). Since then, the site operator has undertaken remedial measures, including a substantial cull of feral pigeons in the area and preventing access to the loft spaces in buildings on the Sellafield site. Results of the analysis of a wood pigeon sample collected in 2016 are included in Table 2.4. The caesium-137 concentrations in the muscle of wood pigeon are reported as less than values in 2016, and lower than the maximum value reported in 2015 (0.09 Bq $kg^{-1}$). These radiocaesium concentrations have had fluctuating levels in recent years prior to 2011. Concentrations of artificial radionuclides were low and would add little to the exposure of local consumers. The FSA will continue to monitor this pathway.

Following a review of the pigeon incident, the Environment Agency began to sample and analyse sediments from road drains (gully pots) in Seascale and Whitehaven in 1999. Gully pots in road drains collect sediments washed off road surfaces and provide good indicators of contamination of urban environments. The results of analyses in 2016 are shown in Table 2.15, and were generally similar to those in recent years. In 2010, elevated concentrations (of strontium-90, caesium-137, americium-241 and plutonium radionuclides) in sediments were reported for one of the five Seascale road drains (Seascale SS 233). Investigations, including monitoring of additional Seascale road drains, were conducted in 2011 to confirm that the elevation had ceased or to inform appropriate action. The results indicate that the elevated levels in 2010 were not sustained during the period 2011 to 2013, and that these results were mostly consistent with other road drains sampled. The enhancements may have arisen from unusual weather conditions in that year, releasing radioactivity trapped within the drainage path. Generally, over a longer period, activity concentrations in road drains have fallen significantly since remedial measures were taken to reduce contamination.

## 2.4 Windscale, Cumbria




Windscale was historically a separate licensed site located at Sellafield. NDA has ownership of the site. In 2008, the Windscale permit was transferred from UKAEA to Sellafield Limited, and combined with the Sellafield site permit. At Windscale there are three nuclear reactors, two of which were shut down in 1957 and the third in 1981. Most of the radioactive wastes derive from decontamination and decommissioning operations, some of which are of the early Windscale reactor buildings. Decommissioning activities began in the mid-1980s and these activities are continuing. The reactor decommissioning of the Windscale Advanced Gas Cooled Reactor (AGR) was completed in 2011. The current plan is to achieve complete decommissioning of Windscale by 2050 (NDA, 2016a). Gaseous wastes are regulated from specific stacks on the Windscale site; liquid radioactive wastes are disposed of, after appropriate treatment, to the Irish Sea via the Sellafield site pipelines. Both gaseous and liquid discharges are included as part of the regulated Sellafield discharges (Appendix 2). Discharges of both gaseous and liquid radioactive wastes are minor compared to those from the Sellafield nuclear licensed site.

Regular monitoring of the environment by the Environment Agency and FSA in relation to any releases from the Windscale site is conducted as part of the overall programme for the Sellafield site. The results of this monitoring and the implications in terms of dose to people in Cumbria are described in Section 2.3.

## Table 2.1 Individual doses – Capenhurst and Springfields, 2016

| Site | Representative person[a] | Exposure, mSv per year | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | All pathways | Seafood | Other local food | External radiation from intertidal areas, river banks or fishing gear[d] | Intakes of sediment and water | Gaseous plume related pathways | Direct radiation from site |
| Capenhurst | | | | | | | | |
| ***Total dose* – all sources** | **Infant local inhabitants (0.25–0.5km)** | **0.17[c]** | **–** | **<0.005** | **–** | **–** | **<0.005** | **0.17** |
| Source specific doses | Infant inhabitants and consumers of locally grown food | <0.005[c] | – | <0.005 | – | – | <0.005 | – |
| | Children playing at Rivacre Brook | 0.011[c] | – | – | 0.011 | <0.005 | – | – |
| Springfields | | | | | | | | |
| ***Total dose* – all sources** | **Adult occupants on houseboats** | **0.038** | **–** | **–** | **0.038** | **–** | **–** | **–** |
| Source specific doses | Seafood consumers | 0.019[c] | <0.005 | – | 0.018 | – | – | – |
| | Fishermen handling nets or pots[b] | 0.022 | – | – | 0.022 | – | – | – |
| | Houseboat occupants | 0.038 | – | – | 0.038 | – | – | – |
| | Children playing at Lower Penwortham[c] | <0.005 | – | – | <0.005 | <0.005 | – | – |
| | External in intertidal areas (farmers) | 0.033 | – | – | 0.033 | – | – | – |
| | Wildfowl consumer | 0.005[c] | – | <0.005 | 0.005 | – | – | – |
| | Inhabitants and consumers of locally grown food | <0.005[c] | – | <0.005 | – | – | <0.005 | – |

[a] *The* total dose *is the dose which accounts for all sources including gaseous and liquid discharges and direct radiation. The* total dose *for the representative person with the highest dose is presented. Other dose values are presented for specific sources, either liquid discharges or gaseous discharges, and their associated pathways. They serve as a check on the validity of the* total dose *assessment. The representative person is an adult unless otherwise stated*

[b] *Exposure to skin for comparison with the 50 mSv dose limit*

[c] *Includes a component due to natural sources of radionuclides*

[d] *Doses (*total dose *and source specific doses) only include estimates of anthropogenic inputs (by substracting background and cosmic sources from measured gamma dose rates)*

## Table 2.2(a) Concentrations of radionuclides in food and the environment near Capenhurst, 2016

| Material | Location | No. of sampling observ-ations | Mean radioactivity concentration (fresh)[a], Bq kg$^{-1}$ | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | $^{3}$H | $^{99}$Tc | $^{137}$Cs | $^{234}$Th | $^{234}$U | $^{235}$U | $^{238}$U | $^{237}$Np |
| **Marine/Freshwater samples** | | | | | | | | | | |
| Flounder | Liverpool Bay | 1 | 29 | | 1.1 | | | | | |
| Shrimps | Wirral | 1 | <25 | 0.14 | 0.48 | | | | | |
| Mussels | Liverpool Bay | 1 | <25 | | 0.90 | | | | | |
| Cockles | Dee Estuary | 1 | <25 | 0.63 | 1.1 | 4.2 | | | | |
| Sediment | Rivacre Brook (1.5km downstream) | 2[E] | | 31 | 1.3 | 21 | 32 | <2.1 | 22 | <3.5 |
| Sediment | Rossmore (3.1km downstream) | 2[E] | | 27 | 1.0 | 17 | 23 | <1.5 | 16 | <4.0 |
| Sediment | Rivacre Brook (4.3km downstream) | 2[E] | | 12 | <0.27 | 9.5 | 12 | <1.1 | 10 | <4.0 |
| Freshwater | Rivacre Brook | 2[E] | <4.7 | <0.12 | | | 0.022 | <0.0013 | 0.012 | <0.055 |
| Freshwater | Rivacre Brook (1.5km downstream) | 2[E] | <3.3 | <0.087 | | | 0.020 | <0.0015 | 0.013 | <0.055 |
| Freshwater | Rossmore (3.1km downstream) | 2[E] | <3.1 | <0.087 | | | 0.015 | <0.0021 | 0.010 | <0.055 |
| Freshwater | Rivacre Brook (4.3km downstream) | 2[E] | <3.1 | <0.091 | | | 0.014 | <0.0021 | 0.011 | <0.055 |

| Material | Location | No. of sampling observ-ations | Mean radioactivity concentration (fresh)[a], Bq kg$^{-1}$ | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | $^{238}$Pu | $^{239}$Pu + $^{240}$Pu | $^{241}$Am | $^{242}$Cm | $^{243}$Cm + $^{244}$Cm | Gross alpha | Gross beta |
| **Marine/Freshwater samples** | | | | | | | | | |
| Flounder | Liverpool Bay | 1 | | | <0.17 | | | | |
| Shrimps | Wirral | 1 | 0.00073 | 0.0046 | 0.012 | * | * | | |
| Mussels | Liverpool Bay | 1 | | | 1.5 | | | | |
| Cockles | Dee Estuary | 1 | 0.070 | 0.45 | 1.5 | * | * | | |
| Sediment | Rivacre Brook (1.5km downstream) | 2[E] | | | | | | 120 | 550 |
| Sediment | Rossmore (3.1km downstream) | 2[E] | | | | | | <130 | 580 |
| Sediment | Rivacre Brook (4.3km downstream) | 2[E] | | | | | | <110 | 350 |
| Freshwater | Rivacre Brook | 2[E] | | | | | | <0.047 | 0.62 |
| Freshwater | Rivacre Brook (1.5km downstream) | 2[E] | | | | | | <0.029 | 0.28 |
| Freshwater | Rossmore (3.1km downstream) | 2[E] | | | | | | <0.029 | 0.28 |
| Freshwater | Rivacre Brook (4.3km downstream) | 2[E] | | | | | | <0.028 | <0.21 |

| Material | Location or selection[b] | No. of sampling observ-ations[d] | Mean radioactivity concentration (fresh)[a], Bq kg$^{-1}$ | | | | |
|---|---|---|---|---|---|---|---|
| | | | $^{3}$H[c] | $^{99}$Tc | $^{234}$U | $^{235}$U | $^{238}$U |
| **Terrestrial samples** | | | | | | | |
| Milk | | 2 | <3.0 | <0.016 | <0.00050 | <0.00031 | <0.00051 |
| Milk | max | | <3.2 | <0.017 | <0.00053 | <0.00034 | <0.00055 |
| Beetroot | | 1 | | <0.082 | 0.0081 | 0.00068 | 0.0095 |
| Grass | | 1 | | <0.091 | 0.0087 | <0.0010 | 0.0080 |
| Grass/herbage | North of Ledsham | 1[E] | | <0.53 | <0.52 | <0.15 | 0.45 |
| Grass/herbage | South of Capenhurst | 1[E] | | <0.33 | <0.22 | <0.11 | <0.099 |
| Grass/herbage | Capenhurst to Dunkirk Lane | 1[E] | | <1.2 | 0.27 | <0.13 | 0.22 |
| Grass/herbage | Dunkirk Lane (0.9 km South of Site) | 1[E] | | <1.1 | <0.21 | <0.11 | <0.22 |
| Soil | North of Ledsham | 1[E] | | <2.2 | 21 | <2.3 | 21 |
| Soil | South of Capenhurst | 1[E] | | <2.2 | 20 | <1.4 | 21 |
| Soil | Capenhurst to Dunkirk Lane | 1[E] | | <1.2 | 22 | <1.6 | 22 |

* *Not detected by the method used*

[a] *Except for milk and water where units are Bq l$^{-1}$, and for soil and sediment where dry concentrations apply*

[b] *Data are arithmetic means unless stated as 'Max' in this column. 'Max' data are selected to be maxima. If no 'max' value is given the mean value is the most appropriate for dose assessments*

[c] *In distillate fraction of sample*

[d] *The number of farms from which milk is sampled. The number of analyses is greater than this and depends on the bulking regime*

[E] *Measurements labelled "E" are made on behalf of the Environment Agency, all other measurements are made on behalf of the Food Standards Agency*

**Table 2.2(b) Monitoring of radiation dose rates near Capenhurst, 2016**

| Location | Ground type | No. of sampling observations | μGy $h^{-1}$ |
|---|---|---|---|
| **Mean gamma dose rates at 1m over substrate** | | | |
| East of railway station | Grass | 1 | 0.077 |
| Dunkirk Lane | Grass | 1 | 0.086 |
| Near Lower Brook Farm | Grass | 1 | 0.080 |
| Rivacre Brook Plant outlet | Grass | 2 | 0.091 |
| Rivacre Brook 1.5 km downstream | Grass | 2 | 0.086 |
| Rossmore Road West 3.1 km downstream | Grass | 2 | 0.083 |
| Rivacre Brook 4.3 km downstream | Grass | 2 | 0.082 |
| North of Ledsham | Grass/herbage | 1 | 0.086 |

## Table 2.3(a) Concentrations of radionuclides in food and the environment near Springfields, 2016

| Material | Location | No. of sampling observ-ations | Mean radioactivity concentration (fresh)[b], Bq kg$^{-1}$ | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $^{3}$H | $^{14}$C | $^{90}$Sr | $^{99}$Tc | $^{129}$I | $^{137}$Cs | $^{228}$Th | $^{230}$Th | $^{232}$Th |
| **Marine samples** | | | | | | | | | | | |
| Flounder | Ribble Estuary | 1 | | | | | | 2.1 | | | |
| Grey mullet | Ribble Estuary | 1 | | | | | | 2.7 | | | |
| Shrimps[d] | Ribble Estuary | 1 | | 44 | | <0.33 | | 0.77 | 0.012 | 0.0027 | 0.0016 |
| Mussels[e] | Ribble Estuary | 1 | | | | | | 0.77 | 0.25 | 0.22 | 0.13 |
| Wildfowl | Ribble Estuary | 1 | <3.5 | 49 | <0.045 | | <0.90 | 0.55 | | 0.016 | 0.0038 |
| Samphire | Marshside Sands | 1 | | | | 0.064 | | 0.12 | | | |
| Sediment | River Ribble outfall | 4[E] | | | | | | 110 | 32 | 51 | 29 |
| Sediment | Lea Gate | 2[E] | | | | | | 120 | 36 | 73 | 33 |
| Sediment | Lower Penwortham Park | 4[E] | | | | | | 130 | 40 | 65 | 35 |
| Sediment | Penwortham road bridge – West bank | 2[E] | | | | | | 81 | 26 | 59 | 28 |
| Sediment | Penwortham position 1 | 4[E] | | | | | | 50 | 24 | 33 | 22 |
| Sediment | Lytham Yacht Club | 1[E] | | | | | | 180 | 42 | 100 | 41 |
| Sediment | Becconsall | 4[E] | | | | | | 97 | 28 | 46 | 28 |
| Sediment | Freckleton | 1[E] | | | | | | 200 | 44 | 85 | 44 |
| Sediment | Hutton Marsh | 1[E] | | | | | | 260 | 56 | 140 | 42 |
| Sediment | Longton Marsh | 1[E] | | | | | | 460 | 47 | 280 | 50 |
| Grass (washed) | Hutton Marsh | 1[E] | | | | <0.29 | | | | | |
| Grass (unwashed) | Hutton Marsh | 1[E] | | | | <0.84 | | | | | |
| Soil | Hutton Marsh | 1[E] | | | | 40 | | | | | |

| Material | Location | No. of sampling observ-ations | Mean radioactivity concentration (fresh)[b], Bq kg$^{-1}$ | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $^{234}$Th | $^{234}$U | $^{235}$U | $^{238}$U | $^{237}$Np | $^{238}$Pu | $^{239}$Pu + $^{240}$Pu | $^{241}$Am | Gross alpha | Gross beta |
| **Marine samples** | | | | | | | | | | | | |
| Flounder | Ribble Estuary | 1 | | | | | | | | <0.28 | | |
| Grey mullet | Ribble Estuary | 1 | | | | | | | | <0.63 | | |
| Shrimps[d] | Ribble Estuary | 1 | | | | | 0.000091 | 0.0010 | 0.0065 | 0.013 | | |
| Mussels[e] | Ribble Estuary | 1 | | | | | | 0.072 | 0.48 | 0.86 | | |
| Wildfowl | Ribble Estuary | 1 | | | | | | 0.00092 | 0.0062 | 0.010 | | |
| Samphire | Marshside Sands | 1 | | | | | | | | <0.03 | | |
| Sediment | River Ribble outfall | 4[E] | 94 | 21 | <1.2 | 22 | | | | 100 | 460 | 910 |
| Sediment | Lea Gate | 2[E] | 320 | 33 | <2.1 | 33 | | | | 110 | 465 | 1300 |
| Sediment | Lower Penwortham Park | 4[E] | 280 | 25 | <1.4 | 26 | | | | 110 | <480 | 1200 |
| Sediment | Penwortham road bridge – West bank | 2[E] | 170 | 21 | <1.2 | 21 | | | | 70 | 340 | 890 |
| Sediment | Penwortham position 1 | 4[E] | <66 | 19 | <1.3 | 20 | | | | 44 | <410 | 710 |
| Sediment | Lytham Yacht Club | 1[E] | 100 | 30 | <1.3 | 30 | | | | 160 | 560 | 1400 |
| Sediment | Becconsall | 4[E] | 99 | 21 | <1.5 | 22 | | | | 92 | 450 | 940 |
| Sediment | Freckleton | 1[E] | 120 | 33 | 1.5 | 32 | | | | 170 | 610 | 1200 |
| Sediment | Hutton Marsh | 1[E] | 43 | 30 | <1.6 | 34 | | | | 200 | 700 | 1300 |
| Sediment | Longton Marsh | 1[E] | <22 | 33 | 2.3 | 35 | | | | 280 | 1100 | 1300 |

## Table 2.3(a) continued

| Material | Location or selection[a] | No. of sampling observ-ations[c] | Mean radioactivity concentration (fresh)[b], Bq kg$^{-1}$ | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $^{3}$H | $^{14}$C | $^{90}$Sr | $^{129}$I | $^{137}$Cs | Total Cs | $^{230}$Th | $^{232}$Th | $^{234}$Th |
| **Terrestrial samples** | | | | | | | | | | | |
| Beetroot | | 1 | <2.5 | 16 | <0.040 | <0.019 | 0.15 | <0.077 | 0.015 | 0.011 | |
| Sediment | Deepdale Brook | 2[E] | | | | | 1.2 | | | | 56 |
| Grass | | 1 | <2.9 | 9.3 | 0.21 | <0.019 | 0.13 | 0.20 | 0.015 | 0.013 | |
| Freshwater[f] | Ulnes Walton | 1[E] | <4.9 | | | | <0.25 | | 0.0027 | <0.0023 | |

| Material | Location or selection[a] | No. of sampling observ-ations[c] | Mean radioactivity concentration (fresh)[b], Bq kg$^{-1}$ | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $^{234}$U | $^{235}$U | $^{238}$U | $^{238}$Pu | $^{239}$Pu + $^{240}$Pu | $^{241}$Pu | $^{241}$Am | Gross alpha | Gross beta |
| **Terrestrial samples** | | | | | | | | | | | |
| Milk | | 2 | <0.0023 | <0.00052 | <0.00084 | | | | | | |
| Milk | Max | | <0.00057 | <0.00073 | <0.00046 | | | | | | |
| Beetroot | | 1 | 0.011 | 0.00045 | 0.011 | <0.000059 | 0.000046 | <0.23 | 0.00011 | | |
| Sediment | Deepdale Brook | 2[E] | 39 | 1.8 | 40 | | | | | 510 | 630 |
| Grass | | 1 | 0.024 | 0.00084 | 0.019 | 0.00027 | 0.0017 | <0.20 | 0.003 | | |
| Grass | Opposite site entrance | 1[E] | 0.49 | <0.0078 | 0.32 | | | | | | |
| Grass | Opposite windmill | 1[E] | 0.36 | <0.11 | 0.29 | | | | | | |
| Grass | Deepdale Brook | 1[E] | <0.40 | <0.14 | <0.33 | | | | | | |
| Grass | N of Lea Town | 1[E] | 0.73 | <0.19 | 0.72 | | | | | | |
| Soil | Opposite site entrance | 1[E] | 110 | 4.2 | 100 | | | | | | |
| Soil | Opposite windmill | 1[E] | 92 | 3.6 | 94 | | | | | | |
| Soil | Deepdale Brook | 1[E] | 78 | 3.9 | 74 | | | | | | |
| Soil | N of Lea Town | 1[E] | 46 | 2.0 | 50 | | | | | | |
| Freshwater | Deepdale Brook | 4[E] | 0.18 | <0.0060 | 0.18 | | | | | 0.21 | 0.57 |
| Freshwater[f] | Ulnes Walton | 1[E] | <0.0019 | <0.00039 | <0.0020 | | | | | 0.17 | 0.24 |

[a] *Data are arithmetic means unless stated as 'max'.' Max' data are selected to be maxima. If no 'max' value is given the mean value is the most appropriate for dose assessments*

[b] *Except for milk and freshwater where units are Bq l$^{-1}$ and for sediment and soil where dry concentrations apply*

[c] *The number of farms from which milk is sampled. The number of analyses is greater than this and depends on the bulking regime*

[d] *The concentrations of $^{242}$Cm and $^{243+244}$Cm were 0.000089 and 0.000029 Bq kg$^{-1}$ respectively*

[e] *The concentrations of $^{242}$Cm and $^{243+244}$Cm were not detected by the method used*

[f] *The concentration of $^{228}$Th was <0.011 Bq kg$^{-1}$*

[E] *Measurements are made on behalf of the Food Standards Agency unless labelled "E". In that case they are made on behalf of the Environment Agency*

| Table 2.3(b) Monitoring of radiation dose rates near Springfields, 2016 | | | |
|---|---|---|---|
| Location | Material or ground type | No. of sampling observations | μGy $h^{-1}$ |
| **Mean gamma dose rates at 1m over substrate** | | | |
| Lytham Yacht Club | Grass | 1 | 0.098 |
| Warton Marsh | Salt marsh | 1 | 0.11 |
| Warton Marsh | Salt marsh[a] | 1 | 0.12 |
| Warton Salt Marsh | Salt marsh | 1 | 0.093 |
| Warton Salt Marsh | Salt marsh[a] | 1 | 0.098 |
| Freckleton | Grass | 1 | 0.079 |
| Naze Point | Salt marsh | 2 | 0.11 |
| Banks Marsh | Salt marsh | 1 | 0.11 |
| Banks Marsh | Salt marsh[a] | 1 | 0.11 |
| Banks Marsh (alternative) | Salt marsh | 1 | 0.11 |
| Banks Marsh (alternative) | Salt marsh[a] | 1 | 0.12 |
| Becconsall Boatyard | Grass and mud | 2 | 0.082 |
| Becconsall Boatyard | Grass | 1 | 0.083 |
| Becconsall Boatyard | Salt marsh | 1 | 0.089 |
| Longton Marsh | Grass | 1 | 0.11 |
| Hutton Marsh | Salt marsh | 1 | 0.11 |
| River Ribble outfall | Mud | 1 | 0.089 |
| River Ribble outfall | Salt marsh | 3 | 0.095 |
| Savick Brook, confluence with Ribble | Grass | 2 | 0.090 |
| Savick Brook, Lea Gate | Grass | 2 | 0.093 |
| South bank opposite outfall | Salt marsh | 1 | 0.10 |
| Penwortham road bridge | Mud | 2 | 0.092 |
| Lower Penwortham Park | Grass | 4 | 0.082 |
| River Darwen | Grass | 4 | 0.086 |
| Riverbank Angler location 1 | Herbage and sand | 1 | 0.081 |
| Riverbank Angler location 1 | Grass and sand | 1 | 0.085 |
| Riverbank Angler location 1 | Grass | 2 | 0.078 |
| Ulnes Walton, BNFL area survey | Grass | 3 | 0.081 |
| | | | |
| **Mean beta dose rates** | | | μSv $h^{-1}$ |
| Lytham - Granny's Bay | Mud | 1 | 0.13 |
| Banks Marsh | Salt marsh | 1 | 0.058 |
| Banks Marsh (alternative) | Salt marsh | 1 | 0.057 |
| Warton Marsh | Salt marsh | 1 | 0.20 |
| Warton Salt Marsh | Salt marsh | 1 | 0.091 |
| Springfields[b] | Fishing net 1 | 1 | 0.049 |
| Springfields[b] | Tarpaulin under fishing net 1 | 1 | 0.066 |
| Springfields[b] | Fishing net 2 | 1 | 0.070 |
| Springfields[b] | Tarpaulin under fishing net 2 | 1 | 0.079 |

[a] *15cm above substrate*

[b] *At the end of the fishing season two fishing nets and the tarpaulin on which they were stored were measured at the fisherman's premises. The beta dose rates range from 0.049 - 0.079 μGy $hr^{-1}$*

## Table 2.4 Concentrations of radionuclides in terrestrial food and the environment near Sellafield, 2016

| Material | Location or selection[a] | No. of sampling observ-ations[c] | Mean radioactivity concentration (fresh)[b], Bq kg$^{-1}$ | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Organic $^{3}$H | $^{3}$H | $^{14}$C | $^{60}$Co | $^{90}$Sr | $^{99}$Tc | $^{106}$Ru |
| Milk | | 9 | <3.3 | <3.1 | 19 | <0.05 | <0.037 | <0.014 | <0.43 |
| Milk | max | | <5.0 | <5.0 | 21 | <0.06 | <0.076 | | <0.51 |
| Beef kidney | | 1 | <4.0 | <4.0 | 23 | <0.02 | 0.044 | <0.097 | <0.41 |
| Beef liver | | 1 | <4.5 | <4.5 | 23 | <0.04 | <0.048 | <0.099 | <0.41 |
| Beef muscle | | 1 | <10 | <10 | 20 | <0.07 | 0.033 | <0.096 | <0.36 |
| Blackberries | | 1 | 7.8 | 7.8 | 21 | <0.06 | 0.40 | <0.095 | <0.64 |
| Beetroot | | 1 | <2.4 | <2.4 | 17 | <0.08 | 0.12 | | <0.71 |
| Cabbage | | 1 | <2.3 | <2.3 | 13 | <0.08 | 0.10 | | <0.68 |
| Carrots | | 1 | <2.5 | <2.5 | 13 | <0.04 | 0.036 | <0.095 | <0.63 |
| Eggs | | 1 | <5.4 | <5.4 | 17 | <0.03 | <0.044 | | <0.28 |
| Mushrooms | | 1 | <3.4 | <3.4 | 11 | <0.05 | <0.045 | | <0.36 |
| Pheasant | | 1 | <4.9 | <4.9 | 37 | <0.06 | <0.060 | <0.097 | <0.40 |
| Potatoes | | 1 | <2.8 | <2.8 | 18 | <0.04 | 0.032 | | <0.29 |
| Rabbit | | 1 | 23 | 23 | 15 | <0.09 | <0.040 | <0.090 | <0.56 |
| Sheep muscle | | 2 | <5.7 | <5.7 | 26 | <0.07 | <0.043 | <0.11 | <0.39 |
| Sheep muscle | max | | <7.5 | <7.5 | 31 | <0.09 | <0.044 | <0.12 | <0.45 |
| Sheep offal | | 2 | <4.9 | <4.9 | 38 | <0.04 | <0.045 | <0.096 | <0.40 |
| Sheep offal | max | | <5.3 | <5.3 | 49 | <0.05 | <0.048 | <0.098 | <0.43 |
| Wood pigeon muscle | | 2 | <4.6 | <4.6 | 41 | <0.06 | <0.044 | | <0.46 |
| Wood pigeon muscle | max | | <5.3 | <5.3 | 43 | <0.08 | <0.045 | | <0.52 |
| Grass | Seascale | 1 | 9.1 | 9.1 | 53 | <0.11 | 3.1 | | <0.82 |
| Grass | Braystones | 1[E] | | <12 | 14 | | 0.73 | | <5.7 |
| Grass | River Calder (upstream) | 1[E] | | <11 | 12 | | 1.6 | | <5.4 |
| Grass | River Calder (downstream) | 1[E] | | <6.5 | <7.5 | | 1.8 | | <7.2 |
| Soil[d] | Seascale | 1 | <2.2 | <2.2 | 13 | 0.71 | 7.7 | <1.4 | <2.0 |
| Soil | Braystones | 1[E] | | <4.8 | <4.5 | | <2.0 | | <9.7 |
| Soil | River Calder (upstream) | 1[E] | | <6.0 | <5.4 | | <2.0 | | <9.3 |

**Table 2.4 continued**

| Material | Location or selection[a] | No. of sampling observ-ations[c] | Mean radioactivity concentration (fresh)[b], Bq kg$^{-1}$ | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | $^{125}$Sb | $^{129}$I | $^{131}$I | $^{134}$Cs | $^{137}$Cs | Total Cs |
| Milk | | 9 | <0.13 | <0.0055 | <0.0043 | <0.06 | <0.10 | <0.084 |
| Milk | max | | <0.15 | <0.0076 | <0.0060 | <0.07 | <0.16 | 0.15 |
| Beef kidney | | 1 | <0.14 | <0.014 | | <0.04 | <0.13 | 0.087 |
| Beef liver | | 1 | <0.10 | <0.016 | | <0.05 | <0.05 | 0.088 |
| Beef muscle | | 1 | <0.18 | 0.022 | | <0.10 | 0.18 | 0.17 |
| Blackberries | | 1 | <0.19 | <0.044 | | <0.09 | 0.34 | 0.12 |
| Beetroot | | 1 | <0.14 | <0.016 | | <0.08 | <0.09 | 0.047 |
| Cabbage | | 1 | <0.17 | <0.019 | | <0.06 | <0.08 | 0.032 |
| Carrots | | 1 | <0.12 | <0.025 | | <0.08 | <0.15 | 0.095 |
| Eggs | | 1 | <0.08 | <0.023 | | <0.03 | <0.03 | 0.037 |
| Mushrooms | | 1 | <0.10 | <0.020 | | <0.04 | 0.40 | 0.38 |
| Pheasant | | 1 | <0.10 | <0.015 | | <0.05 | 0.06 | 0.060 |
| Potatoes | | 1 | <0.12 | <0.019 | | <0.06 | <0.06 | 0.041 |
| Rabbit | | 1 | <0.17 | <0.020 | | <0.09 | 7.5 | 6.8 |
| Sheep muscle | | 2 | <0.15 | <0.018 | | <0.07 | 1.3 | 1.2 |
| Sheep muscle | max | | <0.20 | <0.020 | | <0.11 | 1.4 | 1.3 |
| Sheep offal | | 2 | <0.12 | <0.018 | | <0.05 | 0.44 | 0.60 |
| Sheep offal | max | | <0.13 | | | | 0.58 | 0.67 |
| Wood pigeon muscle | | 2 | <0.11 | <0.017 | | <0.05 | <0.06 | 0.056 |
| Wood pigeon muscle | max | | <0.12 | | | <0.06 | <0.08 | 0.094 |
| Grass | Seascale | 1 | <0.23 | 0.14 | | <0.12 | 1.4 | 1.8 |
| Grass | Braystones | 1[E] | <3.4 | | <0.98 | | <0.72 | |
| Grass | River Calder (upstream) | 1[E] | <3.3 | | <0.85 | | <0.69 | |
| Grass | River Calder (downstream) | 1[E] | <4.0 | | <1.1 | | 2.6 | |
| Soil[d] | Seascale | 1 | <0.73 | 0.059 | | <0.28 | 63 | 67 |
| Soil | Braystones | 1[E] | <4.8 | | <1.8 | | 55 | |
| Soil | River Calder (upstream) | 1[E] | <4.6 | | <1.4 | | 35 | |

**Table 2.4 continued**

| Material | Location or selection[a] | No. of sampling observ-ations[c] | Mean radioactivity concentration (fresh)[b], Bq kg$^{-1}$ | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | $^{234}$U | $^{235}$U | $^{238}$U | $^{238}$Pu | $^{239}$Pu + $^{240}$Pu | $^{241}$Pu | $^{241}$Am |
| Milk | | 9 | | | | <0.000035 | <0.000028 | <0.12 | <0.000032 |
| Milk | max | | | | | <0.000041 | <0.000030 | <0.13 | <0.000040 |
| Beef kidney | | 1 | 0.0079 | 0.00044 | 0.0072 | 0.000063 | 0.00043 | <0.19 | 0.0015 |
| Beef liver | | 1 | | | | 0.00043 | 0.0031 | <0.28 | 0.0034 |
| Beef muscle | | 1 | | | | <0.000080 | 0.00017 | <0.30 | 0.00013 |
| Blackberries | | 1 | | | | 0.000092 | 0.00069 | <0.22 | 0.0013 |
| Beetroot | | 1 | <0.00047 | <0.00047 | 0.0076 | | | | <0.14 |
| Cabbage | | 1 | | | | <0.000066 | 0.00013 | <0.20 | 0.00013 |
| Carrots | | 1 | | | | | | | <0.11 |
| Eggs | | 1 | | | | <0.000033 | 0.000070 | <0.21 | 0.00021 |
| Mushrooms | | 1 | | | | 0.0031 | 0.017 | <0.23 | 0.036 |
| Pheasant | | 1 | | | | <0.000094 | 0.000055 | <0.45 | 0.00010 |
| Potatoes | | 1 | 0.013 | 0.00058 | 0.0095 | <0.000074 | 0.00074 | <0.37 | 0.00063 |
| Rabbit | | 1 | | | | 0.000034 | 0.000097 | <0.28 | 0.00016 |
| Sheep muscle | | 2 | | | | 0.000067 | 0.00014 | <0.21 | 0.00012 |
| Sheep muscle | max | | | | | 0.000078 | 0.00019 | | 0.00015 |
| Sheep offal | | 2 | 0.0040 | <0.00027 | 0.0036 | 0.00027 | 0.0024 | <0.25 | 0.0022 |
| Sheep offal | max | | 0.0041 | 0.00031 | 0.0044 | 0.00029 | 0.0027 | <0.26 | |
| Wood pigeon muscle | | 2 | | | | <0.00013 | 0.00015 | <0.21 | 0.00014 |
| Wood pigeon muscle | max | | | | | 0.00017 | 0.00025 | <0.23 | 0.00016 |
| Grass | Seascale | 1 | | | | 0.010 | 0.14 | 0.38 | 0.086 |
| Grass | Braystones | 1[E] | | | | <0.14 | <0.14 | <13 | <0.70 |
| Grass | River Calder (upstream) | 1[E] | | | | <0.15 | <0.12 | <13 | <0.63 |
| Grass | River Calder (downstream) | 1[E] | | | | <0.17 | 0.24 | <16 | <0.86 |
| Soil[d] | Seascale | 1 | | | | 1.0 | 43 | 45 | 10 |
| Soil | Braystones | 1[E] | | | | 0.68 | 4.9 | <42 | 4.7 |
| Soil | River Calder (upstream) | 1[E] | | | | <0.45 | 5.4 | <46 | <1.4 |

[a] *Data are arithmetic means unless stated as 'max'. 'Max' data are selected to be maxima. If no 'max' value is given the mean value is the most appropriate for dose assessments*

[b] *Except for milk where units are Bq l$^{-1}$*

[c] *The number of farms from which milk is sampled. The number of analyses is greater than this and depends on the bulking regime*

[d] *The concentration of $^{226}$Ra was 14 Bq kg$^{-1}$*

[E] *Measurements labelled "E" are made on behalf of the Environment Agency*

## Table 2.5 Beta/gamma radioactivity in fish from the Irish Sea vicinity and further afield, 2016

| Location | Material | No. of sampling observ-ations | Mean radioactivity concentration (fresh), Bq kg$^{-1}$ | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Organic $^{3}$H | $^{3}$H | $^{14}$C | $^{60}$Co | $^{90}$Sr | $^{95}$Nb | $^{95}$Zr | $^{99}$Tc |
| **Cumbria** | | | | | | | | | | |
| Parton | Cod[c] | 2 | | | 77 | <0.09 | <0.033 | <0.29 | <0.26 | <0.53 |
| Whitehaven | Cod[c] | 2 | | | 86 | <0.08 | 0.028 | <0.32 | <0.27 | <0.58 |
| Whitehaven | Plaice[a,c] | 2 | 56 | 51 | 100 | <0.06 | <0.044 | <0.35 | <0.25 | 3.6 |
| Ravenglass | Plaice[b,c] | 2 | 43 | 53 | 120 | <0.06 | 0.036 | <0.31 | <0.22 | 3.4 |
| **Lancashire and Merseyside** | | | | | | | | | | |
| Morecambe Bay (Morecambe) | Flounder | 2 | <33 | <41 | 68 | <0.09 | <0.018 | <0.21 | <0.22 | 0.23 |
| Ribble Estuary | Flounder | 1 | | | | <0.10 | | <0.34 | <0.31 | |
| Ribble Estuary | Grey mullet | 1 | | | | <0.34 | | <0.56 | <0.70 | |
| Liverpool Bay | Flounder | 1 | | 29 | | <0.06 | | <0.19 | <0.18 | |
| **Scotland** | | | | | | | | | | |
| The Minch | Herring | 1[S] | | | | <0.10 | | <0.89 | <0.54 | |
| The Minch | Mackerel | 1[S] | | | | <0.10 | | <0.67 | <0.36 | |
| Shetland | Fish meal (salmon) | 1[S] | | | | <0.12 | | <0.16 | <0.23 | |
| Shetland | Fish meal (herring) | 1[S] | | | | <0.14 | | <0.20 | <0.28 | |
| Shetland | Fish oil (salmon) | 1[S] | | | | <0.11 | | 0.23 | <0.24 | |
| Shetland | Fish oil (herring) | 1[S] | | | | <0.10 | | <0.14 | <0.20 | |
| Ardrossan South Bay | Mackerel | 1[S] | | | | <0.10 | | | <1.2 | |
| Ardrossan South Bay | Salmon | 1[S] | | | | <0.10 | | <0.30 | <0.21 | |
| Kircudbright | Plaice | 2[S] | | | 20 | <0.10 | | <0.47 | <0.37 | <0.31 |
| Inner Solway | Flounder | 2[S] | | | 21 | <0.10 | <0.10 | <0.36 | <0.32 | <0.39 |
| Inner Solway | Salmon | 1[S] | | <5.0 | | <0.10 | | <0.40 | <0.35 | |
| Inner Solway | Sea trout | 1[S] | | <5.0 | | <0.10 | | <0.23 | <0.24 | |
| **Wales** | | | | | | | | | | |
| North Anglesey | Plaice | 1 | <25 | <25 | 40 | <0.05 | | <0.07 | <0.09 | |
| **Northern Ireland** | | | | | | | | | | |
| North coast | Spurdog | 2[N] | | | | <0.18 | | <1.1 | <0.78 | |
| North coast | Lesser spotted dogfish | 2[N] | | | | <0.19 | | <0.94 | <1.5 | |
| Ardglass | Herring | 2[N] | | | | <0.11 | | <1.7 | <0.75 | |
| Kilkeel | Cod | 4[N] | | | 31 | <0.05 | | <0.39 | <0.21 | |
| Kilkeel | Plaice | 4[N] | | | | <0.07 | | <0.55 | <0.33 | |
| Kilkeel | Skates / rays | 4[N] | | | | <0.12 | | <1.4 | <0.63 | |
| Kilkeel | Haddock | 4[N] | | | | <0.06 | | <0.40 | <0.25 | |
| **Further afield** | | | | | | | | | | |
| Norwegian Sea | Haddock | 1 | | | | <0.04 | | <0.70 | <0.30 | |
| Norwegian Sea | Saithe | 1 | | | | <0.06 | | <1.2 | <0.48 | |

**Table 2.5 continued**

| Location | Material | No. of sampling observ-ations | Mean radioactivity concentration (fresh), Bq kg$^{-1}$ | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | $^{106}$Ru | $^{125}$Sb | $^{134}$Cs | $^{137}$Cs | $^{144}$Ce | $^{155}$Eu | Gross beta |
| **Cumbria** | | | | | | | | | |
| Parton | Cod[c] | 2 | <0.74 | <0.21 | <0.09 | 3.7 | <0.38 | <0.18 | 170 |
| Whitehaven | Cod[c] | 2 | <0.65 | <0.19 | <0.08 | 3.7 | <0.42 | <0.19 | 180 |
| Whitehaven | Plaice[a,c] | 2 | <0.53 | <0.15 | <0.06 | 1.5 | <0.33 | <0.15 | 95 |
| Ravenglass | Plaice[b,c] | 2 | <0.46 | <0.13 | <0.06 | 1.7 | <0.25 | <0.10 | 110 |
| **Lancashire and Merseyside** | | | | | | | | | |
| Morecambe Bay (Morecambe) | Flounder | 2 | <0.75 | <0.22 | <0.08 | 4.0 | <0.40 | <0.18 | |
| Ribble Estuary | Flounder | 1 | <0.87 | <0.25 | <0.10 | 2.1 | <0.48 | <0.23 | |
| Ribble Estuary | Grey mullet | 1 | <2.7 | <0.70 | <0.31 | 2.7 | <1.2 | <0.54 | |
| Liverpool Bay | Flounder | 1 | <0.50 | <0.15 | <0.06 | 1.1 | <0.30 | <0.14 | |
| **Scotland** | | | | | | | | | |
| The Minch | Herring | 1[S] | <0.96 | <0.26 | <0.11 | <0.10 | <0.56 | <0.22 | |
| The Minch | Mackerel | 1[S] | <0.55 | <0.15 | <0.10 | 0.49 | <0.31 | <0.11 | |
| Shetland | Fish meal (salmon) | 1[S] | <0.98 | <0.30 | <0.11 | 0.18 | <0.55 | <0.24 | |
| Shetland | Fish meal (herring) | 1[S] | <1.2 | <0.37 | <0.14 | 0.11 | <0.72 | <0.34 | |
| Shetland | Fish oil (salmon) | 1[S] | <1.0 | <0.29 | <0.12 | <0.11 | <0.62 | <0.29 | |
| Shetland | Fish oil (herring) | 1[S] | <0.84 | <0.25 | <0.10 | <0.10 | <0.48 | <0.21 | |
| Ardrossan South Bay | Mackerel | 1[S] | <1.1 | <0.25 | <0.11 | 0.33 | <0.61 | <0.19 | |
| Ardrossan South Bay | Salmon | 1[S] | <0.42 | <0.10 | <0.10 | 0.30 | <0.28 | <0.12 | |
| Kircudbright | Plaice | 2[S] | <0.84 | <0.24 | <0.10 | <0.10 | <0.52 | <0.20 | |
| Inner Solway | Flounder | 2[S] | <0.86 | <0.25 | <0.10 | <0.10 | <0.48 | <0.20 | |
| Inner Solway | Salmon | 1[S] | <0.85 | <0.24 | <0.10 | 0.21 | <0.49 | <0.20 | |
| Inner Solway | Sea trout | 1[S] | <0.73 | <0.22 | <0.10 | <0.10 | <0.50 | <0.19 | |
| **Wales** | | | | | | | | | |
| North Anglesey | Plaice | 1 | <0.38 | <0.11 | <0.05 | 0.59 | <0.20 | <0.10 | |
| **Northern Ireland** | | | | | | | | | |
| North coast | Spurdog | 2[N] | <1.5 | <0.39 | <0.18 | 0.94 | <0.76 | <0.30 | |
| North coast | Lesser spotted dogfish | 2[N] | <1.8 | <0.44 | <0.20 | 0.80 | <0.91 | <0.32 | |
| Ardglass | Herring | 2[N] | <1.1 | <0.27 | <0.12 | 0.46 | <0.66 | <0.24 | |
| Kilkeel | Cod | 4[N] | <0.42 | <0.12 | <0.05 | 1.1 | <0.25 | <0.11 | |
| Kilkeel | Plaice | 4[N] | <0.66 | <0.18 | <0.08 | 1.2 | <0.40 | <0.16 | |
| Kilkeel | Skates / rays | 4[N] | <0.99 | <0.27 | <0.11 | 0.67 | <0.52 | <0.19 | |
| Kilkeel | Haddock | 4[N] | <0.51 | <0.14 | <0.06 | 0.30 | <0.33 | <0.14 | |
| **Further afield** | | | | | | | | | |
| Norwegian Sea | Haddock | 1 | <0.34 | <0.08 | <0.04 | 0.11 | <0.20 | <0.07 | |
| Norwegian Sea | Saithe | 1 | <0.58 | <0.13 | <0.07 | 0.18 | <0.28 | <0.10 | |

[a] *The concentrations of $^{129}$I was <1.0 Bq kg$^{-1}$*
[b] *The concentrations of $^{129}$I and $^{147}$Pm were <0.91 and <0.014 Bq kg$^{-1}$ respectively*
[c] *Data for natural radionuclides for some of these samples may be available in Table 7.6*
[N] *Measurements labelled "N" are made on behalf of the Northern Ireland Environment Agency*
[S] *Measurements labelled "S" are made on behalf of the Scottish Environment Protection Agency*

## Table 2.6 Beta/gamma radioactivity in shellfish from the Irish Sea vicinity and further afield, 2016

| Location | Material | No. of sampling observ-ations | Mean radioactivity concentration (fresh), Bq kg$^{-1}$ | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Organic $^{3}$H | $^{3}$H | $^{14}$C | $^{60}$Co | $^{90}$Sr | $^{95}$Nb | $^{95}$Zr | $^{99}$Tc | $^{106}$Ru |
| **Cumbria** | | | | | | | | | | | |
| Parton | Crabs[d] | 2 | | | 150 | 0.14 | 0.097 | <0.65 | <0.36 | 4.4 | <0.60 |
| Parton | Lobsters[d] | 2 | | | 110 | <0.08 | 0.040 | <0.46 | <0.32 | 37 | <0.64 |
| Parton | Winkles[d] | 2 | | | 110 | <0.35 | 0.98 | <0.22 | <0.24 | 34 | <2.3 |
| Whitehaven | *Nephrops*[a,d] | 1 | <25 | <25 | 89 | <0.04 | 0.11 | <0.27 | <0.18 | 23 | <0.37 |
| Whitehaven outer harbour | Mussels[d] | 2 | | | 100 | 0.27 | 0.25 | <0.12 | <0.14 | 27 | <0.61 |
| Nethertown | Winkles[b,d] | 4 | <31 | <36 | 140 | 0.76 | 1.8 | <0.23 | <0.22 | 22 | <3.0 |
| Sellafield coastal area | Crabs[cd] | 2 | 48 | 46 | 130 | <0.16 | 0.099 | <0.15 | <0.16 | 4.6 | <0.50 |
| Sellafield coastal area | Lobsters[d] | 2 | 100 | 100 | 170 | <0.15 | 0.071 | <0.15 | <0.19 | 140 | <0.73 |
| Ravenglass | Mussels[d] | 2 | | | 160 | 0.46 | 0.36 | <0.15 | <0.16 | 68 | <3.2 |
| Seascale Area | Common prawns[d] | 2 | 45 | 31 | 120 | <0.14 | 0.029 | <0.42 | <0.40 | 0.35 | <1.1 |
| **Lancashire and Merseyside** | | | | | | | | | | | |
| Morecambe Bay (Morecambe) | Shrimps | 2 | 54 | 55 | 72 | <0.08 | <0.041 | <0.25 | <0.22 | 0.44 | <0.62 |
| Morecambe Bay (Morecambe) | Mussels | 2 | 81 | 72 | 74 | <0.08 | 0.20 | <0.15 | <0.18 | 39 | <0.63 |
| Morecambe Bay (Middleton Sands) | Winkles | 2 | 35 | 27 | 50 | <0.08 | 0.17 | <0.15 | <0.18 | 16 | <0.62 |
| Ribble Estuary | Shrimps | 1 | | | 44 | <0.09 | | <0.24 | <0.24 | <0.33 | <0.76 |
| Ribble Estuary | Mussels | 1 | | | | <0.05 | | <0.43 | <0.26 | | <0.50 |
| Liverpool Bay | Mussels | 1 | | <25 | | <0.17 | | <0.39 | <0.45 | | <1.4 |
| Dee Estuary | Cockles | 1 | | <25 | | <0.05 | | <0.08 | <0.11 | 0.63 | <0.44 |
| Wirral | Shrimps | 1 | | <25 | | <0.05 | | <0.20 | <0.17 | 0.14 | <0.46 |
| **Scotland** | | | | | | | | | | | |
| Kinlochbervie | Crabs | 2[S] | | | | <0.10 | | <0.44 | <0.31 | <0.26 | <0.67 |
| Lewis | Mussels | 1[S] | | | | <0.10 | | <0.48 | <0.34 | | <0.68 |
| Skye | Lobsters | 1[S] | | | | <0.10 | | <0.55 | <0.35 | 3.4 | <0.70 |
| Skye | Mussels | 1[S] | | | | <0.10 | | <0.32 | <0.25 | | <0.59 |
| Islay | Crabs | 1[S] | | | | <0.10 | | <0.62 | <0.43 | | <0.79 |
| Islay | Scallops | 1[S] | | | | <0.10 | | <0.27 | <0.18 | | <0.33 |
| Kirkcudbright | Crabs[d] | 1[S] | | | 25 | <0.10 | | <0.15 | <0.17 | <0.43 | <0.65 |
| Kirkcudbright | Lobsters[d] | 2[S] | | | 46 | <0.10 | | <0.26 | <0.25 | 34 | <0.70 |
| Kirkcudbright | Limpets[d] | 1[S] | | | | <0.10 | | <0.46 | <0.36 | | <0.88 |
| Kirkcudbright | Winkles[d] | 2[S] | | | | <0.10 | | <0.30 | <0.26 | 35 | <0.66 |
| Kirkcudbright | Scallops | 2[S] | | | | <0.10 | | <0.49 | <0.38 | 0.29 | <0.82 |
| Kirkcudbright | Queens | 2[S] | | | | <0.10 | | <0.41 | <0.33 | <0.44 | <0.79 |
| Cutters Pool | Winkles | 1[S] | | | | <0.10 | | <0.66 | <0.45 | | <0.94 |
| Southerness | Winkles | 2[S] | | <5.0 | | <0.10 | | <0.31 | <0.21 | 16 | <0.64 |
| North Solway coast | Cockles | 1[S] | | | | <0.10 | | <0.25 | <0.21 | | <0.53 |
| North Solway coast | Mussels | 2[S] | | <5.0 | 54 | <0.10 | | <0.24 | <0.20 | 11 | <0.51 |
| Inner Solway | Shrimps | 2[S] | | <5.0 | | <0.10 | <0.10 | <0.37 | <0.31 | <0.21 | <0.74 |
| **Wales** | | | | | | | | | | | |
| North Anglesey | Crabs | 1 | <25 | <25 | 39 | <0.08 | | <0.12 | <0.16 | | <0.65 |
| North Anglesey | Lobsters | 1 | 28 | 33 | 61 | <0.08 | | <0.14 | <0.17 | 18 | <0.62 |
| **Northern Ireland** | | | | | | | | | | | |
| Ballycastle | Lobsters | 2[N] | | | | <0.06 | | <0.76 | <0.35 | 12 | <0.52 |
| County Down | Scallops | 2[N] | | | | <0.06 | | <0.15 | <0.16 | | <0.50 |
| Kilkeel | Crabs | 4[N] | | | | <0.06 | | <0.62 | <0.32 | | <0.56 |
| Kilkeel | Lobsters | 4[N] | | | | <0.08 | | <0.55 | <0.34 | 8.0 | <0.69 |
| Kilkeel | *Nephrops* | 4[N] | | | | <0.13 | | <1.5 | <0.74 | 5.5 | <1.2 |
| Minerstown | Winkles | 4[N] | | | | <0.05 | | <0.08 | <0.11 | | <0.40 |
| Carlingford Lough | Mussels | 2[N] | | | | <0.12 | | <1.6 | <0.72 | 1.6 | <1.2 |
| **Further afield** | | | | | | | | | | | |
| Cromer | Crabs | 2 | | | | <0.06 | | <0.10 | <0.13 | | <0.51 |
| Southern North Sea | Cockles | 2 | | | | <0.05 | | <0.08 | <0.11 | | <0.39 |

**Table 2.6 continued**

| Location | Material | No. of sampling observ-ations | Mean radioactivity concentration (fresh), Bq kg$^{-1}$ | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | $^{110m}$Ag | $^{125}$Sb | $^{134}$Cs | $^{137}$Cs | $^{144}$Ce | $^{147}$Pm | $^{155}$Eu | Gross beta |
| **Cumbria** | | | | | | | | | | |
| Parton | Crabs[d] | 2 | <0.11 | <0.15 | <0.07 | 0.76 | <0.31 | | <0.11 | 89 |
| Parton | Lobsters[d] | 2 | <0.11 | <0.17 | <0.08 | 1.1 | <0.34 | | <0.13 | 160 |
| Parton | Winkles[d] | 2 | <0.13 | <0.25 | <0.10 | 4.2 | <0.46 | 0.16 | <0.22 | 140 |
| Whitehaven | *Nephrops*[a,d] | 1 | <0.06 | <0.10 | <0.04 | 1.8 | <0.18 | 0.041 | <0.07 | 130 |
| Whitehaven outer harbour | Mussels[d] | 2 | <0.08 | 0.30 | <0.06 | 1.2 | <0.25 | | <0.12 | 91 |
| Nethertown | Winkles[b,d] | 4 | <0.12 | <0.34 | <0.08 | 5.7 | <0.40 | 0.77 | <0.18 | 180 |
| Sellafield coastal area | Crabs[cd] | 2 | <0.08 | <0.14 | <0.06 | 0.65 | <0.29 | 0.059 | <0.12 | 100 |
| Sellafield coastal area | Lobsters[d] | 2 | <0.12 | <0.21 | <0.08 | 0.95 | <0.40 | | <0.19 | 240 |
| Ravenglass | Mussels[d] | 2 | <0.08 | 0.30 | <0.06 | 1.1 | <0.26 | | <0.12 | 130 |
| Seascale Area | Common prawns[d] | 2 | <0.19 | <0.30 | <0.14 | 0.92 | <0.56 | | <0.23 | 100 |
| **Lancashire and Merseyside** | | | | | | | | | | |
| Morecambe Bay (Morecambe) | Shrimps | 2 | <0.10 | <0.19 | <0.07 | 2.1 | <0.39 | | <0.18 | |
| Morecambe Bay (Morecambe) | Mussels | 2 | <0.10 | <0.19 | <0.08 | 1.5 | <0.35 | | <0.18 | 140 |
| Morecambe Bay (Middleton Sands) | Winkles | 2 | <0.10 | <0.19 | <0.08 | 2.1 | <0.39 | | <0.18 | 160 |
| Ribble Estuary | Shrimps | 1 | <0.12 | <0.19 | <0.09 | 0.77 | <0.32 | | <0.14 | |
| Ribble Estuary | Mussels | 1 | <0.08 | <0.13 | <0.06 | 0.77 | <0.25 | | <0.10 | |
| Liverpool Bay | Mussels | 1 | <0.21 | <0.39 | <0.16 | 0.90 | <0.68 | | <0.30 | |
| Dee Estuary | Cockles | 1 | <0.06 | <0.13 | <0.05 | 1.1 | <0.25 | | <0.13 | |
| Wirral | Shrimps | 1 | <0.07 | <0.13 | <0.06 | 0.48 | <0.24 | | <0.10 | |
| **Scotland** | | | | | | | | | | |
| Kinlochbervie | Crabs | 2[S] | <0.10 | <0.18 | <0.10 | <0.10 | <0.39 | | <0.15 | |
| Lewis | Mussels | 1[S] | <0.10 | <0.20 | <0.10 | <0.10 | <0.44 | | <0.17 | |
| Skye | Lobsters | 1[S] | <0.10 | <0.20 | <0.10 | <0.10 | <0.44 | | <0.17 | |
| Skye | Mussels | 1[S] | <0.10 | <0.16 | <0.10 | <0.10 | <0.38 | | <0.13 | |
| Islay | Crabs | 1[S] | <0.12 | <0.22 | <0.10 | <0.10 | <0.47 | | <0.17 | |
| Islay | Scallops | 1[S] | <0.10 | <0.10 | <0.10 | <0.10 | <0.25 | | <0.11 | |
| Kirkcudbright | Crabs[d] | 1[S] | <0.10 | <0.19 | <0.10 | <0.10 | <0.44 | | <0.17 | |
| Kirkcudbright | Lobsters[d] | 2[S] | <0.11 | <0.20 | <0.10 | 0.44 | <0.44 | | <0.18 | |
| Kirkcudbright | Limpets[d] | 1[S] | <0.17 | <0.26 | <0.10 | 3.2 | <0.52 | | <0.21 | |
| Kirkcudbright | Winkles[d] | 2[S] | <0.12 | <0.21 | <0.10 | 0.40 | <0.43 | | <0.18 | |
| Kirkcudbright | Scallops | 2[S] | <0.13 | <0.24 | <0.10 | <0.15 | <0.50 | | <0.20 | |
| Kirkcudbright | Queens | 2[S] | <0.12 | <0.23 | <0.10 | <0.14 | <0.49 | | <0.20 | |
| Cutters Pool | Winkles | 1[S] | <0.15 | <0.26 | <0.10 | 0.42 | <0.52 | | <0.20 | |
| Southerness | Winkles | 2[S] | <0.11 | <0.18 | <0.10 | 0.16 | <0.38 | | <0.15 | |
| North Solway coast | Cockles | 1[S] | <0.10 | <0.15 | <0.10 | 2.0 | <0.32 | | <0.13 | |
| North Solway coast | Mussels | 2[S] | <0.12 | <0.15 | <0.10 | 0.98 | <0.36 | | <0.15 | |
| Inner Solway | Shrimps | 2[S] | <0.15 | <0.22 | <0.10 | 3.1 | <0.46 | | <0.19 | |
| **Wales** | | | | | | | | | | |
| North Anglesey | Crabs | 1 | <0.10 | <0.18 | <0.08 | <0.08 | <0.32 | | <0.14 | |
| North Anglesey | Lobsters | 1 | <0.10 | <0.19 | <0.08 | 0.37 | <0.34 | | <0.17 | 110 |
| **Northern Ireland** | | | | | | | | | | |
| Ballycastle | Lobsters | 2[N] | <0.09 | <0.12 | <0.06 | 0.19 | <0.26 | | <0.09 | |
| County Down | Scallops | 2[N] | <0.08 | <0.14 | <0.06 | 0.17 | <0.31 | | <0.14 | |
| Kilkeel | Crabs | 4[N] | <0.10 | <0.14 | <0.06 | 0.12 | <0.28 | | <0.11 | |
| Kilkeel | Lobsters | 4[N] | <0.12 | <0.18 | <0.08 | 0.14 | <0.38 | | <0.15 | |
| Kilkeel | *Nephrops* | 4[N] | <0.22 | <0.32 | <0.14 | 0.61 | <0.70 | | <0.25 | |
| Minerstown | Winkles | 4[N] | <0.06 | <0.11 | <0.05 | 0.17 | <0.23 | | <0.10 | |
| Carlingford Lough | Mussels | 2[N] | <0.18 | <0.29 | <0.12 | 0.28 | <0.54 | | <0.18 | |
| **Further afield** | | | | | | | | | | |
| Cromer | Crabs | 2 | <0.08 | <0.15 | <0.06 | <0.06 | <0.27 | | <0.13 | |
| Southern North Sea | Cockles | 2 | <0.06 | <0.11 | <0.05 | <0.05 | <0.21 | | <0.10 | |

[a] *The concentration of $^{129}$I was <1.1 Bq kg$^{-1}$*
[b] *The concentration of $^{129}$I was <1.4 Bq kg$^{-1}$*
[c] *The concentration of $^{129}$I was <0.96 Bq kg$^{-1}$*
[d] *Data for natural radionuclides for some of these samples may be available in Table 7.6*
[N] *Measurements labelled "N" are made on behalf of the Northern Ireland Environment Agency*
[S] *Measurements labelled "S" are made on behalf of the Scottish Environment Protection Agency*

**Table 2.7 Concentrations of transuranic radionuclides in fish and shellfish from the Irish Sea vicinity and further afield, 2016**

| Location | Material | No. of sampling observ-ations | Mean radioactivity concentration (fresh), Bq kg$^{-1}$ | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | $^{237}$Np | $^{238}$Pu | $^{239}$Pu + $^{240}$Pu | $^{241}$Pu | $^{241}$Am | $^{242}$Cm | $^{243}$Cm + $^{244}$Cm |
| **Cumbria** | | | | | | | | | |
| Parton | Cod | 2 | | 0.0016 | 0.0087 | <0.25 | 0.018 | * | * |
| Parton | Crabs | 2 | | 0.035 | 0.20 | 0.63 | 0.87 | * | 0.0011 |
| Parton | Lobsters | 2 | | 0.027 | 0.17 | 2.1 | 0.72 | * | 0.0026 |
| Parton | Winkles | 2 | 0.010 | 0.96 | 5.3 | 28 | 12 | * | * |
| Whitehaven | Cod | 2 | | 0.0029 | 0.016 | <0.12 | 0.032 | 0.000036 | 0.000030 |
| Whitehaven | Plaice | 2 | | 0.0087 | 0.0048 | 0.19 | 0.0094 | * | * |
| Whitehaven | *Nephrops* | 2 | 0.001 | 0.043 | 0.25 | 0.84 | 1.4 | * | * |
| Whitehaven outer harbour | Mussels | 2 | | 0.54 | 2.9 | 17 | 6.9 | * | 0.011 |
| Nethertown | Winkles | 4 | 0.019 | 1.7 | 9.0 | 53 | 19 | * | 0.020 |
| Sellafield coastal area | Crabs | 2 | 0.00070 | 0.054 | 0.29 | 1.6 | 1.3 | * | 0.0011 |
| Sellafield coastal area | Lobsters | 2 | | 0.038 | 0.19 | 1.4 | 2.4 | * | 0.0061 |
| Ravenglass | Plaice | 2 | 0.000090 | 0.0010 | 0.0067 | <0.17 | 0.013 | * | * |
| Ravenglass | Mussels | 2 | | 0.66 | 3.7 | 24 | 8.1 | * | 0.083 |
| Seascale | Prawns | 2 | | 0.0044 | 0.029 | <0.44 | 0.061 | 0.000081 | 0.000074 |
| **Lancashire and Merseyside** | | | | | | | | | |
| Morecambe Bay (Morecambe) | Flounder | 2 | | 0.00027 | 0.0016 | | 0.0035 | 0.000062 | 0.000028 |
| Morecambe Bay (Morecambe) | Shrimps | 2 | | 0.0025 | 0.017 | | 0.030 | * | * |
| Morecambe Bay (Morecambe) | Mussels | 2 | | 0.22 | 1.3 | 6.7 | 2.5 | * | * |
| Morecambe Bay (Middleton Sands) | Winkles | 2 | | 0.19 | 1.2 | 5.8 | 2.3 | * | * |
| Ribble Estuary | Flounder | 1 | | | | | <0.28 | | |
| Ribble Estuary | Grey mullet | 1 | | | | | <0.63 | | |
| Ribble Estuary | Shrimps | 1 | 0.000091 | 0.0010 | 0.0065 | | 0.013 | 0.000089 | 0.000029 |
| Ribble Estuary | Mussels | 1 | | 0.072 | 0.48 | | 0.86 | * | * |
| Liverpool Bay | Flounder | 1 | | | | | <0.17 | | |
| Liverpool Bay | Mussels | 1 | | | | | 1.5 | | |
| Dee Estuary | Cockles | 1 | | 0.070 | 0.45 | | 1.5 | * | * |
| Wirral | Shrimps | 1 | | 0.00073 | 0.0046 | | 0.012 | * | * |
| | | | | | | | | | |
| **Scotland** | | | | | | | | | |
| The Minch | Herring | 1[S] | | <0.0016 | 0.0013 | | 0.0045 | | |
| The Minch | Mackerel | 1[S] | | 0.0013 | 0.0013 | | 0.0067 | | |
| Shetland | Fish meal (salmon) | 1[S] | | 0.0049 | 0.019 | | 0.0063 | | |
| Shetland | Fish meal (herring) | 1[S] | | 0.0077 | 0.0088 | | 0.017 | | |
| Shetland | Fish oil (salmon) | 1[S] | | 0.0058 | 0.0034 | | 0.0038 | | |
| Shetland | Fish oil (herring) | 1[S] | | 0.0093 | 0.0037 | | 0.0081 | | |
| Kinlochbervie | Crabs | 2[S] | | <0.040 | 0.069 | | 0.080 | | |
| Lewis | Mussels | 1[S] | | | | | <0.10 | | |
| Skye | Lobsters | 1[S] | | | | | <0.10 | | |
| Skye | Mussels | 1[S] | | | | | <0.10 | | |
| Islay | Crabs | 1[S] | | | | | <0.10 | | |
| Islay | Scallops | 1[S] | | | | | <0.11 | | |
| Ardrossan South Bay | Mackerel | 1[S] | | <0.0036 | <0.0052 | | 0.0069 | | |
| Ardrossan South Bay | Salmon | 1[S] | | <0.0014 | 0.0011 | | 0.0049 | | |

**Table 2.7 continued**

| Location | Material | No. of sampling observ-ations | Mean radioactivity concentration (fresh), Bq kg$^{-1}$ | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | $^{237}$Np | $^{238}$Pu | $^{239}$Pu + $^{240}$Pu | $^{241}$Pu | $^{241}$Am | $^{242}$Cm | $^{243}$Cm + $^{244}$Cm |
| **Scotland continued** | | | | | | | | | |
| Kirkcudbright | Plaice | 2$^{S}$ | | 0.00042 | 0.00071 | | 0.0015 | | |
| Kirkcudbright | Scallops | 2$^{S}$ | | 0.016 | 0.060 | | 0.011 | | |
| Kirkcudbright | Queens | 2$^{S}$ | | 0.0074 | 0.033 | | 0.033 | | |
| Kirkcudbright | Crabs | 1$^{S}$ | | 0.048 | 0.027 | | <0.11 | | |
| Kirkcudbright | Lobsters | 2$^{S}$ | | 0.013 | 0.057 | | 0.35 | | |
| Kirkcudbright | Winkles | 2$^{S}$ | | 0.23 | 1.4 | | 1.9 | | |
| Kirkcudbright | Limpets | 1$^{S}$ | | | | | 11 | | |
| Cutters Pool | Winkles | 1$^{S}$ | | | | | 2.1 | | |
| Southerness | Winkles | 2$^{S}$ | | 0.23 | 1.3 | | 2.3 | | |
| North Solway coast | Cockles | 1$^{S}$ | | 0.41 | 3.0 | | 5.2 | | |
| North Solway coast | Mussels | 2$^{S}$ | | 0.34 | 2.0 | | 4.4 | | |
| Inner Solway | Flounder | 1$^{S}$ | | 0.013 | 0.0074 | | 0.0074 | | |
| Inner Solway | Salmon | 1$^{S}$ | | | | | <0.12 | | |
| Inner Solway | Sea trout | 1$^{S}$ | | | | | <0.11 | | |
| Inner Solway | Shrimps | 1$^{S}$ | | 0.031 | 0.0019 | | 0.015 | | |
| **Wales** | | | | | | | | | |
| North Anglesey | Plaice | 1 | | | | | <0.13 | | |
| North Anglesey | Crabs | 1 | | | | | <0.09 | | |
| North Anglesey | Lobsters | 1 | | 0.0033 | 0.021 | 0.30 | 0.12 | * | * |
| **Northern Ireland** | | | | | | | | | |
| North coast | Spurdog | 2$^{N}$ | | | | | <0.22 | | |
| North coast | Lesser spotted dogfish | 2$^{N}$ | | | | | <0.27 | | |
| Ballycastle | Lobsters | 2$^{N}$ | | | | | 0.25 | | |
| County Down | Scallops | 2$^{N}$ | | | | | <0.17 | | |
| Ardglass | Herring | 2$^{N}$ | | | | | <0.19 | | |
| Kilkeel | Cod | 4$^{N}$ | | | | | <0.10 | | |
| Kilkeel | Plaice | 4$^{N}$ | | | | | <0.14 | | |
| Kilkeel | Skates / rays | 4$^{N}$ | | | | | <0.14 | | |
| Kilkeel | Haddock | 4$^{N}$ | | | | | <0.13 | | |
| Kilkeel | Crabs | 4$^{N}$ | | | | | <0.10 | | |
| Kilkeel | Lobsters | 4$^{N}$ | | | | | <0.12 | | |
| Kilkeel | *Nephrops* | 1$^{N}$ | | 0.0041 | 0.024 | | 0.11 | * | 0.000059 |
| Minerstown | Winkles | 1$^{N}$ | | 0.029 | 0.17 | | 0.13 | * | * |
| Carlingford Lough | Mussels | 2$^{N}$ | | | | | <0.10 | | |
| **Further afield** | | | | | | | | | |
| Norwegian Sea | Haddock | 1 | | | | | <0.04 | | |
| Norwegian Sea | Saithe | 1 | | | | | <0.06 | | |
| Cromer | Crabs | 2 | | | | | <0.13 | | |
| Southern North Sea | Cockles | 1 | | | | | <0.09 | | |
| Southern North Sea | Mussels | 1 | | 0.0013 | 0.010 | | 0.0081 | * | 0.000019 |

* *Not detected by the method used*

$^{N}$ *Measurements labelled "N" are made on behalf of the Northern Ireland Environment Agency*

$^{S}$ *Measurements labelled "S" are made on behalf of the Scottish Environment Protection Agency*

## Table 2.8 Concentrations of radionuclides in sediment from the Cumbrian coast and further afield, 2016

| Location | Material | No. of sampling observ-ations | Mean radioactivity concentration (dry), Bq kg$^{-1}$ | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $^{60}$Co | $^{90}$Sr | $^{95}$Zr | $^{95}$Nb | $^{106}$Ru | $^{125}$Sb | $^{134}$Cs | $^{137}$Cs | $^{144}$Ce |
| **Cumbria** | | | | | | | | | | | |
| Newton Arlosh | Sediment | 2 | <0.57 | | <2.2 | <0.39 | <4.6 | <2.2 | <0.57 | 180 | <2.7 |
| Maryport Outer Harbour | Sediment | 2 | <0.74 | | <1.6 | <0.31 | <3.4 | <1.7 | <0.42 | 87 | <2.0 |
| Workington Harbour | Sediment | 2 | <0.46 | | <1.8 | <0.44 | <3.2 | <1.7 | <0.44 | 39 | <2.1 |
| Harrington Harbour | Sediment | 2 | <0.44 | | <1.5 | <0.41 | <3.2 | <1.6 | <0.51 | 110 | <2.2 |
| Whitehaven Outer Harbour | Sediment | 4 | <0.45 | <3.6 | <1.2 | <0.37 | <3.0 | <1.6 | <0.38 | 60 | <1.7 |
| St Bees beach | Sediment | 4 | <0.62 | | <0.73 | <0.22 | <2.1 | <1.1 | <0.28 | 46 | <1.3 |
| Ehen spit | Sediment | 4 | <0.83 | <2.0 | <1.4 | <0.34 | <12 | <1.8 | <0.42 | 140 | <2.5 |
| Sellafield beach, S of former pipeline | Sediment | 4 | <0.39 | | <1.1 | <0.23 | <2.5 | <1.3 | <0.32 | 44 | <1.4 |
| River Calder – downstream | Sediment | 4 | <0.37 | | <0.98 | <0.28 | <2.3 | <1.3 | <0.32 | 58 | <1.7 |
| River Calder – upstream | Sediment | 4 | <0.61 | | <1.7 | <0.48 | <3.6 | <1.8 | <0.53 | 34 | <2.2 |
| Seascale beach | Sediment | 4 | <0.39 | | <1.0 | <0.27 | <2.3 | <1.2 | <0.32 | 28 | <1.5 |
| Ravenglass – Carleton Marsh | Sediment | 4 | 2.1 | 44 | <1.9 | <0.51 | <12 | <2.3 | <0.55 | 210 | <2.7 |
| River Mite Estuary (erosional) | Sediment | 4 | 1.4 | 32 | <0.98 | <0.38 | <3.5 | <1.8 | <0.42 | 240 | <2.5 |
| Ravenglass – Raven Villa | Sediment | 4 | <1.1 | | <1.5 | <0.41 | <5.2 | <1.8 | <0.44 | 110 | <2.1 |
| Newbiggin (Eskmeals) | Sediment | 4 | 2.7 | 61 | <1.8 | <0.49 | <5.8 | <2.2 | <0.54 | 200 | <2.7 |
| Haverigg | Sediment | 2 | <0.36 | | <0.83 | <0.23 | <2.2 | <1.1 | <0.31 | 30 | <1.4 |
| Millom | Sediment | 2 | <0.71 | | <1.0 | <0.37 | <3.0 | <1.5 | <0.39 | 120 | <2.1 |
| Askam Pier | Sediment | 2 | <0.40 | <2.0 | <1.4 | <0.28 | <2.6 | <1.3 | <0.35 | 36 | <1.6 |
| Low Shaw | Sediment | 2 | <0.43 | | <0.94 | <0.30 | <2.6 | <1.4 | <0.37 | 46 | <1.5 |
| Walney Channel – N of discharge point | Sediment | 2 | <0.52 | | <1.7 | <0.38 | <3.5 | <1.8 | <0.45 | 60 | <1.9 |
| Sand Gate Marsh | Sediment | 1 | <0.32 | | <0.55 | <0.28 | <2.1 | <1.1 | <0.29 | 50 | <1.4 |
| Kents Bank | Sediment | 1 | <0.41 | | <0.68 | <0.38 | <3.1 | <1.7 | <0.38 | 230 | <2.2 |
| Arnside | Sediment | 1 | <0.62 | | <1.1 | <0.41 | <4.9 | <2.6 | <0.58 | 300 | <2.5 |

| Location | Material | No. of sampling observ-ations | Mean radioactivity concentration (dry), Bq kg$^{-1}$ | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | $^{154}$Eu | $^{155}$Eu | $^{238}$Pu | $^{239}$Pu + $^{240}$Pu | $^{241}$Pu | $^{241}$Am | Gross alpha | Gross beta |
| **Cumbria** | | | | | | | | | | |
| Newton Arlosh | Sediment | 2 | <1.4 | <1.1 | | | | 240 | 650 | 870 |
| Maryport Outer Harbour | Sediment | 2 | <1.2 | <0.76 | | | | 220 | 630 | 650 |
| Workington Harbour | Sediment | 2 | <1.1 | <0.82 | | | | 26 | 400 | 870 |
| Harrington Harbour | Sediment | 2 | <1.0 | <0.87 | | | | 52 | 390 | 790 |
| Whitehaven Outer Harbour | Sediment | 4 | <1.2 | <0.69 | 12 | 67 | 430 | 100 | 310 | 550 |
| St Bees beach | Sediment | 4 | <0.77 | <0.56 | | | | 130 | 250 | 380 |
| Ehen spit | Sediment | 4 | <1.2 | <0.81 | 11 | 68 | | 180 | 420 | 820 |
| Sellafield beach, S of former pipeline | Sediment | 4 | <0.93 | <0.58 | | | | 98 | 180 | 460 |
| River Calder – downstream | Sediment | 4 | <0.85 | <0.70 | | | | 63 | 200 | 670 |
| River Calder – upstream | Sediment | 4 | <1.5 | <0.90 | | | | | 300 | 1300 |
| Seascale beach | Sediment | 4 | <0.90 | <0.60 | | | | 100 | 250 | 510 |
| Ravenglass – Carleton Marsh | Sediment | 4 | 2.2 | <2.4 | 68 | 390 | 2700 | 780 | 1200 | 1100 |
| River Mite Estuary (erosional) | Sediment | 4 | 2.0 | <1.2 | 75 | 440 | 2100 | 890 | 1400 | 1100 |
| Ravenglass – Raven Villa | Sediment | 4 | 1.1 | <0.86 | | | | 390 | 870 | 820 |
| Newbiggin (Eskmeals) | Sediment | 4 | 2.0 | <1.1 | 70 | 400 | 2600 | 860 | 1400 | 950 |
| Haverigg | Sediment | 2 | <0.87 | <0.59 | | | | 120 | 300 | 460 |
| Millom | Sediment | 2 | <1.0 | <0.93 | | | | 290 | 730 | 880 |
| Askam Pier | Sediment | 2 | <0.93 | <0.64 | 1.1 | 1.3 | | 92 | 250 | 510 |
| Low Shaw | Sediment | 2 | <1.0 | <0.62 | | | | 76 | 250 | 550 |
| Walney Channel – N of discharge point | Sediment | 2 | <1.3 | <0.75 | | | | 130 | 410 | 680 |
| Sand Gate Marsh | Sediment | 1 | <0.77 | <0.63 | | | | 47 | 140 | 970 |
| Kents Bank | Sediment | 1 | <0.97 | <0.99 | | | | 130 | 370 | 850 |
| Arnside | Sediment | 1 | <1.6 | <1.1 | | | | 180 | 480 | 1100 |

**Table 2.8 continued**

| Location | Material | No. of sampling observ-ations | Mean radioactivity concentration (dry), Bq kg$^{-1}$ | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | $^{60}$Co | $^{95}$Zr | $^{95}$Nb | $^{106}$Ru | $^{125}$Sb | $^{134}$Cs | $^{137}$Cs | $^{144}$Ce |
| **Lancashire** | | | | | | | | | | |
| Morecambe | Sediment | 2 | <0.31 | | | | | | 20 | |
| Half Moon Bay | Sediment | 2 | <0.46 | | | | | | 75 | |
| Red Nab Point | Sediment | 2 | <0.35 | | | | | | 15 | |
| Potts Corner | Sediment | 2 | <0.41 | | | | | | 13 | |
| Sunderland Point | Sediment | 2 | <0.52 | <1.3 | <0.48 | <3.6 | <1.9 | <0.50 | 68 | <2.0 |
| Conder Green | Sediment | 2 | <0.50 | <1.1 | <0.46 | <3.5 | <1.9 | <0.48 | 78 | <2.0 |
| Hambleton | Sediment | 2 | <0.58 | <1.4 | <0.49 | <4.2 | <2.1 | <0.52 | 190 | <2.6 |
| Skippool Creek | Sediment | 2 | <0.70 | <1.6 | <0.56 | <4.8 | <2.5 | <0.61 | 190 | <2.5 |
| Fleetwood | Sediment | 2 | <0.35 | <0.77 | <0.26 | <2.1 | <1.2 | <0.31 | 7.4 | <1.2 |
| Blackpool | Sediment | 2 | <0.36 | <0.77 | <0.23 | <2.1 | <1.1 | <0.31 | 2.0 | <1.0 |
| Crossens Marsh | Sediment | 2 | <0.89 | <2.6 | <0.69 | <7.0 | <3.7 | <0.85 | 220 | <4.2 |
| Ainsdale | Sediment | 2 | <0.26 | <0.60 | <0.17 | <1.6 | <0.83 | <0.23 | 2.8 | <0.91 |
| Rock Ferry | Sediment | 2 | <0.34 | <0.73 | <0.22 | <2.0 | <1.1 | <0.29 | 21 | <1.4 |

| Location | Material | No. of sampling observ-ations | Mean radioactivity concentration (dry), Bq kg$^{-1}$ | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | $^{154}$Eu | $^{155}$Eu | $^{238}$Pu | $^{239}$Pu + $^{240}$Pu | $^{241}$Am | Gross alpha | Gross beta |
| **Lancashire** | | | | | | | | | |
| Morecambe | Sediment | 2 | | | | | 22 | | |
| Half Moon Bay | Sediment | 2 | | | 7.5 | 46 | 91 | | |
| Red Nab Point | Sediment | 2 | | | | | 14 | | |
| Potts Corner | Sediment | 2 | | | | | 12 | | |
| Sunderland Point | Sediment | 2 | <1.4 | <0.85 | | | 78 | 270 | 750 |
| Conder Green | Sediment | 2 | <1.2 | <0.88 | | | 85 | 400 | 830 |
| Hambleton | Sediment | 2 | <1.4 | <1.1 | | | 190 | 720 | 1300 |
| Skippool Creek | Sediment | 2 | <1.7 | <1.1 | | | 200 | 610 | 1100 |
| Fleetwood | Sediment | 2 | <0.85 | <0.50 | | | 11 | <110 | 380 |
| Blackpool | Sediment | 2 | <0.85 | <0.45 | | | 3.3 | <100 | 240 |
| Crossens Marsh | Sediment | 2 | <2.2 | <3.1 | | | 160 | 590 | 1200 |
| Ainsdale | Sediment | 2 | <0.63 | <0.41 | | | 2.5 | <93 | 220 |
| Rock Ferry | Sediment | 2 | <0.79 | <0.61 | | | 14 | 230 | 540 |

**Table 2.8 continued**

| Location | Material | No. of sampling observ-ations | Mean radioactivity concentration (dry), Bq kg$^{-1}$ | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | $^{54}$Mn | $^{60}$Co | $^{95}$Zr | $^{95}$Nb | $^{106}$Ru | $^{125}$Sb | $^{134}$Cs | $^{137}$Cs |
| **Scotland** | | | | | | | | | | |
| Campbeltown | Sediment | 1[S] | <0.10 | <0.10 | <0.31 | <0.46 | <0.63 | <0.19 | <0.10 | 6.6 |
| Garlieston | Sediment | 1[S] | <0.10 | <0.10 | <0.26 | <0.61 | <0.73 | <0.24 | <0.10 | 32 |
| Innerwell | Sediment | 2[S] | <0.10 | <0.29 | <0.32 | <0.50 | <0.94 | <0.33 | <0.12 | 65 |
| Carsluith | Sediment | 1[S] | <0.10 | 0.46 | <0.37 | <0.53 | <0.93 | <0.33 | <0.12 | 71 |
| Skyreburn | Sediment | 2[S] | <0.10 | <0.10 | <0.26 | <0.46 | <0.81 | <0.26 | <0.11 | 27 |
| Kirkcudbright | Sediment[a] | 2[S] | <0.10 | <0.24 | <0.33 | <0.76 | <0.78 | <0.37 | <0.11 | 53 |
| Rascarrel Bay | Sediment[a] | 1[S] | <0.10 | 0.26 | <0.18 | <0.38 | <0.75 | 0.29 | <0.10 | 45 |
| Palnackie Harbour | Sediment | 2[S] | <0.10 | 0.33 | <0.24 | <0.61 | <0.99 | <0.37 | <0.12 | 86 |
| Gardenburn | Sediment | 2[S] | <0.10 | 0.40 | <0.29 | <0.51 | <1.1 | <0.41 | <0.13 | 120 |
| Kippford Slipway | Sediment | 2[S] | <0.10 | 0.54 | <0.27 | <0.66 | <1.2 | 0.46 | <0.13 | 110 |
| Kippford Merse | Sediment | 1[S] | <0.10 | 0.61 | <0.27 | <0.72 | <0.99 | 0.53 | <0.12 | 130 |
| Kirkconnell Merse | Sediment | 1[S] | <0.10 | <0.10 | <0.32 | <0.88 | <1.5 | <0.70 | <0.15 | 430 |
| Southerness | Sediment | 1[S] | <0.10 | <0.10 | <0.10 | <0.10 | <0.26 | <0.10 | <0.10 | 7.5 |

| Location | Material | No. of sampling observ-ations | Mean radioactivity concentration (dry), Bq kg$^{-1}$ | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | $^{144}$Ce | $^{154}$Eu | $^{155}$Eu | $^{238}$Pu | $^{239}$Pu + $^{240}$Pu | $^{241}$Am | Gross alpha | Gross beta |
| **Scotland** | | | | | | | | | | |
| Campbeltown | Sediment | 1[S] | <0.72 | <0.17 | 0.90 | | | | | |
| Garlieston | Sediment | 1[S] | <0.73 | <0.17 | 0.56 | 4.0 | 30 | 53 | | |
| Innerwell | Sediment | 2[S] | <0.97 | <0.19 | 1.0 | 11 | 61 | 110 | | |
| Carsluith | Sediment | 1[S] | <0.95 | 0.44 | 0.98 | 18 | 110 | 300 | 370 | 2200 |
| Skyreburn | Sediment | 2[S] | <0.79 | <0.19 | 0.62 | 3.5 | 22 | 34 | | |
| Kirkcudbright | Sediment[a] | 2[S] | <0.87 | <0.17 | 1.1 | 4.9 | 37 | 87 | | |
| Rascarrel Bay | Sediment[a] | 1[S] | <0.81 | 0.40 | 0.47 | | | 88 | | |
| Palnackie Harbour | Sediment | 2[S] | <1.2 | 0.46 | 0.77 | 16 | 89 | 180 | | |
| Gardenburn | Sediment | 2[S] | <1.1 | 0.55 | 1.6 | 16 | 99 | 180 | | |
| Kippford Slipway | Sediment | 2[S] | <1.2 | 0.6 | 0.78 | 20 | 120 | 250 | | |
| Kippford Merse | Sediment | 1[S] | <1.2 | 0.72 | 1.5 | 21 | 140 | 210 | | |
| Kirkconnell Merse | Sediment | 1[S] | <1.8 | 0.48 | 0.70 | 22 | 140 | 260 | 240 | 1400 |
| Southerness | Sediment | 1[S] | <0.26 | <0.10 | 0.43 | 2.1 | 16 | 26 | | |

## Table 2.8 continued

| Location | Material | No. of sampling observ-ations | Mean radioactivity concentration (dry), Bq kg$^{-1}$ | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $^{54}$Mn | $^{60}$Co | $^{95}$Zr | $^{95}$Nb | $^{106}$Ru | $^{125}$Sb | $^{134}$Cs | $^{137}$Cs | $^{144}$Ce |
| **Wales** | | | | | | | | | | | |
| Rhyl | Sediment | 2 | | <0.51 | <1.6 | <0.44 | <3.3 | <1.8 | <0.50 | 47 | <2.4 |
| Llandudno | Sediment | 1 | | <0.28 | <0.91 | <0.19 | <1.9 | <0.91 | <0.26 | 1.2 | <1.0 |
| Caerhun | Sediment | 1 | | <0.42 | <1.5 | <0.38 | <2.8 | <1.5 | <0.42 | 13 | <1.7 |
| Llanfairfechan | Sediment | 1 | | <0.36 | <1.2 | <0.25 | <2.3 | <1.2 | <0.34 | 15 | <1.7 |
| **Northern Ireland** | | | | | | | | | | | |
| Carrichue | Sand, shells and mud | 1$^{N}$ | <0.25 | <0.20 | <1.4 | <2.9 | <2.1 | <0.58 | <0.27 | 2.8 | <1.7 |
| Portrush | Sand | 2$^{N}$ | <0.21 | <0.18 | <1.1 | <1.9 | <1.9 | <0.52 | <0.23 | 0.36 | <1.5 |
| Oldmill Bay | Mud and sand | 1$^{N}$ | <0.16 | <0.15 | <0.55 | <0.68 | <1.3 | <0.38 | <0.17 | 6.4 | <0.89 |
| Oldmill Bay | Mud | 1$^{N}$ | <0.33 | <0.33 | <0.92 | <0.84 | <3.0 | <0.93 | <0.40 | 41 | <1.8 |
| Ballymacormick | Mud and sand | 1$^{N}$ | <0.23 | <0.20 | <0.83 | <1.0 | <2.0 | <0.61 | <0.27 | 12 | <1.7 |
| Ballymacormick | Mud | 1$^{N}$ | <0.48 | <0.36 | <4.5 | * | <3.7 | <0.90 | <0.46 | 10 | <2.1 |
| Strangford Lough – Nicky's Point | Mud | 2$^{N}$ | <0.43 | <0.32 | <3.5 | <1.6 | <3.3 | <0.89 | <0.43 | 13 | <2.4 |
| Dundrum Bay | Mud | 2$^{N}$ | <0.60 | <0.42 | <4.5 | <1.4 | <4.3 | <1.2 | <0.60 | 18 | <2.8 |
| Carlingford Lough | Mud | 2$^{N}$ | <0.69 | <0.55 | <5.6 | <2.2 | <5.6 | <1.5 | <0.76 | 42 | <4.0 |

| Location | Material | No. of sampling observ-ations | Mean radioactivity concentration (dry), Bq kg$^{-1}$ | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $^{154}$Eu | $^{155}$Eu | $^{238}$Pu | $^{239}$Pu + $^{240}$Pu | $^{241}$Am | $^{242}$Cm | $^{243}$Cm+ $^{244}$Cm | Gross alpha | Gross beta |
| **Wales** | | | | | | | | | | | |
| Rhyl | Sediment | 2 | <1.3 | <1.0 | | | 38 | | | 480 | 840 |
| Llandudno | Sediment | 1 | <0.72 | <0.41 | | | 1.3 | | | <90 | 260 |
| Caerhun | Sediment | 1 | <1.1 | <2.7 | | | 6.9 | | | 180 | 620 |
| Llanfairfechan | Sediment | 1 | <0.86 | <0.70 | | | 13 | | | 150 | 540 |
| **Northern Ireland** | | | | | | | | | | | |
| Carrichue | Sand, shells and mud | 1$^{N}$ | <0.61 | <0.69 | 0.18 | 1.2 | 2.3 | 0.0041 | 0.0012 | | |
| Portrush | Sand | 2$^{N}$ | <0.56 | <0.63 | | | <0.75 | | | | |
| Oldmill Bay | Mud and sand | 1$^{N}$ | <0.44 | <0.37 | | | 12 | | | | |
| Oldmill Bay | Mud | 1$^{N}$ | <0.97 | <0.81 | | | 11 | | | | |
| Ballymacormick | Mud and sand | 1$^{N}$ | <0.65 | <0.78 | | | 7.9 | | | | |
| Ballymacormick | Mud | 1$^{N}$ | <1.1 | <0.76 | | | 12 | | | | |
| Strangford Lough – Nicky's Point | Mud | 2$^{N}$ | <0.93 | <0.93 | | | 3.6 | | | | |
| Dundrum Bay | Mud | 2$^{N}$ | <1.4 | <1.1 | | | 6.9 | | | | |
| Carlingford Lough | Mud | 2$^{N}$ | <1.8 | <1.6 | 2.1 | 14 | 10 | * | * | | |

* *Not detected by the method used*

$^{S}$ *Measurements labelled "S" are made on behalf of the Scottish Environment Protection Agency*

$^{N}$ *Measurements labelled "N" are made on behalf of the Northern Ireland Environment Agency*

*All other measurements are made on behalf of the Environment Agency*

$^{a}$ *Data for natural radionuclides for some of these samples may be available in Table 7.6*

**Table 2.9 Gamma radiation dose rates over areas of the Cumbrian coast and further afield, 2016**

| Location | Ground type | No. of sampling observations | Mean gamma dose rate in air at 1m, μGy $h^{-1}$ |
|---|---|---|---|
| **Cumbria, Rockcliffe-Harrington** | | | |
| Rockcliffe Marsh | Salt marsh | 2 | 0.080 |
| Burgh Marsh | Salt marsh | 2 | 0.082 |
| Port Carlisle 1 | Sand | 1 | 0.085 |
| Port Carlisle 1 | Mud | 1 | 0.086 |
| Port Carlisle 2 | Grass | 1 | 0.088 |
| Port Carlisle 2 | Grass and salt marsh | 1 | 0.082 |
| Newton Arlosh | Salt marsh | 2 | 0.090 |
| Silloth harbour | Sand and stones | 2 | 0.099 |
| Allonby | Sand | 2 | 0.084 |
| Maryport harbour | Sand | 2 | 0.087 |
| Workington harbour | Sand and shingle | 2 | 0.11 |
| Harrington harbour | Sand and stones | 2 | 0.11 |
| | | | |
| **Cumbria, Whitehaven-Drigg** | | | |
| Whitehaven – outer harbour | Sand | 3 | 0.094 |
| Whitehaven – outer harbour | Sand and stones | 1 | 0.10 |
| St Bees | Sand | 4 | 0.075 |
| Nethertown beach | Shingle | 3 | 0.12 |
| Nethertown beach | Pebbles | 1 | 0.12 |
| Ehen spit | Sand and shingle | 3 | 0.11 |
| Ehen spit | Shingle | 1 | 0.12 |
| Braystones | Grass | 1 | 0.091 |
| Braystones beach | Sand and shingle | 1 | 0.11 |
| Braystones beach | Shingle | 3 | 0.11 |
| Sellafield dunes | Grass | 4 | 0.11 |
| North of former pipeline on foreshore | Sand | 3 | 0.096 |
| North of former pipeline on foreshore | Sand and shingle | 1 | 0.11 |
| South of former pipeline on foreshore | Sand | 4 | 0.089 |
| River Calder downstream of site | Grass | 4 | 0.090 |
| River Calder upstream of site | Grass | 1 | 0.093 |
| Seascale beach | Sand and shingle | 4 | 0.086 |
| | | | |
| **Cumbria, Ravenglass-Askam** | | | |
| Ravenglass - Carleton Marsh | Salt marsh | 3 | 0.13 |
| Ravenglass - Carleton Marsh | Grass | 1 | 0.13 |
| Ravenglass - River Mite estuary (erosional) | Salt marsh | 3 | 0.14 |
| Ravenglass - Raven Villa | Salt marsh | 4 | 0.13 |
| Ravenglass - boat area | Pebbles and sand | 3 | 0.11 |
| Ravenglass - boat area | Pebbles and stones | 1 | 0.10 |
| Ravenglass - ford | Sand | 4 | 0.094 |
| Muncaster Bridge | Grass | 4 | 0.11 |
| Ravenglass - salmon garth | Sand | 4 | 0.11 |
| Ravenglass - Eskmeals Nature Reserve | Salt marsh | 4 | 0.11 |
| Newbiggin/Eskmeals viaduct | Salt marsh | 2 | 0.12 |
| Newbiggin/Eskmeals viaduct | Mud and salt marsh | 2 | 0.12 |
| Newbiggin/Eskmeals Bridge | Salt marsh | 4 | 0.12 |
| Tarn Bay | Sand | 4 | 0.078 |
| Silecroft | Shingle | 2 | 0.12 |
| Haverigg | Sand | 1 | 0.074 |
| Haverigg | Sand and stones | 1 | 0.092 |
| Millom | Sand | 1 | 0.10 |
| Millom | Slag and stones | 1 | 0.10 |
| Low Shaw | Salt marsh | 2 | 0.080 |
| Askam | Sand | 4 | 0.073 |
| Askam Pier | Sand | 3 | 0.081 |
| Askam Pier | Salt marsh | 1 | 0.078 |

**Table 2.9 continued**

| Location | Ground type | No. of sampling observations | Mean gamma dose rate in air at 1m, μGy $h^{-1}$ |
|---|---|---|---|
| **Cumbria, Walney-Arnside** | | | |
| Walney Channel, N of discharge point | Sand | 1 | 0.089 |
| Walney Channel, N of discharge point | Mud and sand | 2 | 0.086 |
| Walney Channel, N of discharge point | Mud | 1 | 0.083 |
| Tummer Hill Marsh | Salt marsh | 2 | 0.11 |
| Roa Island | Sand | 1 | 0.094 |
| Roa Island | Sand and mud | 1 | 0.087 |
| Sand Gate Marsh | Salt marsh | 1 | 0.082 |
| Sand Gate Marsh | Grass | 1 | 0.080 |
| Kents Bank 2 | Salt marsh | 2 | 0.084 |
| Arnside 2 | Salt marsh | 1 | 0.093 |
| Arnside 2 | Grass | 1 | 0.083 |
| **Lancashire and Merseyside** | | | |
| Morecambe Central beach | Sand | 1 | 0.071 |
| Morecambe Central beach | Sand and shingle | 1 | 0.076 |
| Half Moon Bay | Sand | 1 | 0.081 |
| Half Moon Bay | Sand and stones | 1 | 0.081 |
| Red Nab Point | Sand and shingle | 1 | 0.081 |
| Red Nab Point | Pebbles | 1 | 0.083 |
| Middleton Sands | Sand | 2 | 0.078 |
| Sunderland Point | Mud and sand | 2 | 0.097 |
| Colloway Marsh | Salt marsh | 2 | 0.11 |
| Lancaster | Grass and sand | 1 | 0.084 |
| Lancaster | Grass | 1 | 0.083 |
| Aldcliffe Marsh | Salt marsh | 2 | 0.094 |
| Conder Green | Mud | 1 | 0.092 |
| Conder Green | Mud and salt marsh | 1 | 0.092 |
| Pilling Marsh | Salt marsh | 2 | 0.095 |
| Knott End | Sand | 1 | 0.078 |
| Knott End | Mud and sand | 1 | 0.083 |
| Height o' th' hill - River Wyre | Salt marsh | 2 | 0.10 |
| Hambleton | Salt marsh | 2 | 0.10 |
| Skippool Creek 1 | Salt marsh | 2 | 0.10 |
| Skippool Creek 2 | Salt marsh | 2 | 0.10 |
| Fleetwood shore 1 | Sand | 1 | 0.078 |
| Fleetwood shore 1 | Pebbles and sand | 1 | 0.088 |
| Fleetwood shore 2 | Salt marsh | 2 | 0.12 |
| Blackpool | Sand | 2 | 0.067 |
| Crossens Marsh | Salt marsh | 2 | 0.089 |
| Ainsdale | Sand | 2 | 0.065 |
| Rock Ferry | Sand | 2 | 0.081 |
| West Kirby | Sand | 2 | 0.074 |
| Flint 1 | Sand | 1 | 0.092 |
| Flint 1 | Mud | 1 | 0.089 |
| Flint 2 | Salt marsh | 2 | 0.099 |

**Table 2.9 continued**

| Location | Ground type | No. of sampling observations | Mean gamma dose rate in air at 1m, μGy $h^{-1}$ |
|---|---|---|---|
| **Scotland** | | | |
| Piltanton Burn | Sand | 2[S] | 0.072 |
| Garlieston | Sand | 2[S] | 0.071 |
| Innerwell | Sand | 2[S] | 0.081 |
| Bladnoch | Sediment | 2[S] | 0.084 |
| Carsluith | Sand | 2[S] | 0.085 |
| Skyreburn Bay (Water of Fleet) | Sand | 1[S] | 0.088 |
| Skyreburn Bay (Water of Fleet) | Salt marsh | 1[S] | 0.077 |
| Kirkcudbright | Salt marsh | 2[S] | 0.072 |
| Cutters Pool | Winkle bed | 4[S] | 0.087 |
| Rascarrel Bay | Sand | 2[S] | 0.085 |
| Gardenburn | Sediment | 2[S] | 0.091 |
| Palnackie Harbour | Sediment | 2[S] | 0.079 |
| Kippford - Slipway | Sand | 2[S] | 0.10 |
| Kippford - Merse | Salt marsh | 2[S] | 0.091 |
| Kirkconnell Marsh | Salt marsh | 2[S] | 0.099 |
| Southerness | Winkle bed | 2[S] | 0.071 |
| | | | |
| **Wales** | | | |
| Rhyl | Salt marsh | 2 | 0.086 |
| Llandudno | Sand and shingle | 2 | 0.093 |
| Caerhun | Salt marsh | 1 | 0.086 |
| Caerhun | Grass and salt marsh | 1 | 0.083 |
| Llanfairfechan | Sand and shells | 2 | 0.083 |
| | | | |
| **Northern Ireland** | | | |
| Lisahally | Mud | 1[N] | 0.066 |
| Donnybrewer | Shingle | 1[N] | 0.054 |
| Carrichue | Mud | 1[N] | 0.061 |
| Bellerena | Mud | 1[N] | 0.056 |
| Benone | Sand | 1[N] | 0.053 |
| Castlerock | Sand | 1[N] | 0.055 |
| Portstewart | Sand | 1[N] | 0.053 |
| Portrush, Blue Pool | Sand | 1[N] | 0.054 |
| Portrush, White Rocks | Sand | 1[N] | 0.055 |
| Portballintrae | Sand | 1[N] | 0.051 |
| Giant's Causeway | Sand | 1[N] | 0.054 |
| Ballycastle | Sand | 1[N] | 0.058 |
| Cushendun | Sand | 1[N] | 0.054 |
| Cushendall | Sand and stones | 1[N] | 0.061 |
| Red Bay | Sand | 1[N] | 0.065 |
| Carnlough | Sand | 1[N] | 0.053 |
| Glenarm | Sand | 1[N] | 0.052 |
| Half Way House | Sand | 1[N] | 0.058 |
| Ballygally | Sand | 1[N] | 0.051 |
| Drains Bay | Sand | 1[N] | 0.052 |
| Larne | Sand | 1[N] | 0.055 |
| Whitehead | Sand | 1[N] | 0.055 |
| Carrickfergus | Sand | 1[N] | 0.056 |
| Jordanstown | Sand | 1[N] | 0.058 |
| Helen's Bay | Sand | 1[N] | 0.060 |
| Groomsport | Sand | 1[N] | 0.068 |
| Millisle | Sand | 1[N] | 0.067 |
| Ballywalter | Sand | 1[N] | 0.066 |

**Table 2.9 continued**

| Location | Ground type | No. of sampling observations | Mean gamma dose rate in air at 1m, μGy $h^{-1}$ |
|---|---|---|---|
| **Northern Ireland continued** | | | |
| Ballyhalbert | Sand | 1[N] | 0.068 |
| Cloghy | Sand | 1[N] | 0.059 |
| Portaferry | Shingle and stones | 1[N] | 0.090 |
| Kircubbin | Sand | 1[N] | 0.085 |
| Greyabbey | Sand | 1[N] | 0.087 |
| Ards Maltings | Mud | 1[N] | 0.075 |
| Island Hill | Mud | 1[N] | 0.075 |
| Nicky's Point | Mud | 1[N] | 0.077 |
| Strangford | Shingle and stones | 1[N] | 0.10 |
| Kilclief | Sand | 1[N] | 0.074 |
| Ardglass | Mud | 1[N] | 0.080 |
| Killough | Mud | 1[N] | 0.082 |
| Ringmore Point | Sand | 1[N] | 0.069 |
| Tyrella | Sand | 1[N] | 0.080 |
| Dundrum | Sand | 1[N] | 0.078 |
| Newcastle | Sand | 1[N] | 0.095 |
| Annalong | Sand | 1[N] | 0.11 |
| Cranfield Bay | Sand | 1[N] | 0.085 |
| Mill Bay | Sand | 1[N] | 0.11 |
| Greencastle | Sand | 1[N] | 0.086 |
| Rostrevor | Sand | 1[N] | 0.11 |
| Narrow Water | Mud | 1[N] | 0.093 |

[S] *Measurements labelled "S" are made on behalf of the Scottish Environment Protection Agency*
[N] *Measurements labelled "N" are made on behalf of the Northern Ireland Environment Agency*
*All other measurements are made on behalf of the Environment Agency*

**Table 2.10 Beta radiation dose rates on contact with fishing gear on vessels operating off Sellafield, 2016**

| Vessel or location | Type of gear | No. of sampling observations | Mean beta dose rate in tissue, mSv h-1 |
|---|---|---|---|
| 101 | Nets | 1 | <0.075 |
| 106 | Nets | 1 | 0.078 |
| 114 | Nets | 1 | <0.084 |
| 115 | Nets | 1 | <0.077 |

**Table 2.11 Beta radiation dose rates over intertidal areas of the Cumbrian coast, 2016**

| Location | Ground type | No. of sampling observations | Mean beta dose rate in tissue, mSv $h^{-1}$ |
|---|---|---|---|
| Whitehaven – outer harbour | Sand | 3 | 0.15 |
| Whitehaven – outer harbour | Sand and stones | 1 | 0.16 |
| St Bees | Sand | 4 | 0.15 |
| Sellafield beach, N of discharge point | Sand | 2 | 0.13 |
| Sellafield beach, N of discharge point | Sand and shingle | 1 | 0.13 |
| Ravenglass – Raven Villa | Salt marsh | 4 | 0.10 |
| Tarn Bay | Sand | 4 | 0.11 |

**Table 2.12 Concentrations of radionuclides in aquatic plants from the Cumbrian coast and further afield, 2016**

| Location | Material | No. of sampling observ-ations | Mean radioactivity concentration (fresh), Bq kg$^{-1}$ | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $^{60}$Co | $^{65}$Zn | $^{90}$Sr | $^{95}$Zr | $^{95}$Nb | $^{99}$Tc | $^{106}$Ru | $^{110m}$Ag | $^{125}$Sb |
| **Cumbria** | | | | | | | | | | | |
| Silloth | Seaweed | 2 | <0.52 | | | <0.64 | <0.34 | 130 | <3.0 | <0.50 | <1.9 |
| Harrington Harbour | Seaweed | 2 | <0.58 | | | <0.69 | <0.35 | 140 | <3.3 | <0.53 | <1.9 |
| St Bees[b] | Seaweed | 2 | <0.68 | | 0.39 | <0.81 | <0.43 | 600 | <3.9 | <0.64 | <2.2 |
| Sellafield[c] | Seaweed | 2 | <0.69 | | <0.39 | <0.84 | <0.41 | 870 | <3.9 | <0.63 | <2.3 |
| Ravenglass | Samphire | 1[F] | <0.07 | <0.15 | | <0.22 | <0.28 | 0.30 | <0.55 | <0.08 | <0.14 |
| Ravenglass[d] | Seaweed | 2 | <0.71 | | <0.56 | <0.84 | <0.43 | 190 | <3.7 | <0.66 | <2.2 |
| **Lancashire** | | | | | | | | | | | |
| Half Moon Bay | Seaweed | 2 | <0.61 | | | <0.82 | <0.41 | 180 | <3.5 | <0.59 | <2.1 |
| Marshside Sands | Samphire | 1[F] | <0.04 | <0.11 | | <0.14 | <0.15 | 0.064 | <0.34 | <0.06 | <0.09 |
| **Scotland** | | | | | | | | | | | |
| Aberdeen | *Fucus vesiculosus* | 1[S] | <0.10 | <0.24 | | <0.34 | <0.45 | 18 | <0.70 | <0.10 | <0.19 |
| Lerwick | *Fucus vesiculosus* | 1[S] | <0.10 | <0.31 | | <0.43 | <0.62 | 3.0 | <0.92 | <0.13 | <0.24 |
| Kinlochbervie | *Fucus vesiculosus* | 2[S] | <0.10 | <0.23 | | <0.31 | <0.43 | 16 | <0.67 | <0.11 | <0.18 |
| Lewis | *Fucus vesiculosus* | 1[S] | <0.10 | <0.21 | | <0.42 | <0.85 | 22 | <0.66 | <0.11 | <0.19 |
| Islay | *Fucus vesiculosus* | 1[S] | <0.10 | <0.29 | | <0.51 | <0.86 | 47 | <0.90 | <0.14 | <0.24 |
| Campbeltown | *Fucus vesiculosus* | 1[S] | <0.10 | <0.25 | | <0.45 | <0.89 | 43 | <0.68 | <0.12 | <0.18 |
| Port William | *Fucus vesiculosus* | 4[S] | <0.10 | <0.16 | | <0.21 | <0.29 | 82 | <0.43 | <0.10 | <0.13 |
| Garlieston | *Fucus vesiculosus* | 4[S] | <0.10 | <0.21 | | <0.31 | <0.45 | 41 | <0.62 | <0.12 | <0.17 |
| Auchencairn | *Fucus vesiculosus* | 4[S] | <0.10 | <0.20 | | <0.21 | <0.31 | 170 | <0.64 | <0.13 | <0.19 |
| **Wales** | | | | | | | | | | | |
| Cemaes Bay | Seaweed | 2 | <0.60 | | | <0.74 | <0.39 | 15 | <3.4 | <0.60 | <2.1 |
| Porthmadog | Seaweed | 2 | <0.39 | | | <1.0 | <0.27 | <1.7 | <2.9 | <0.44 | <1.5 |
| Lavernock Point | Seaweed | 2 | <0.57 | | | <0.73 | <0.39 | 1.2 | <3.6 | <0.57 | <2.0 |
| Fishguard | Seaweed | 2 | <0.50 | | | <0.90 | <0.34 | 5.8 | <3.7 | <0.60 | <2.0 |
| **Northern Ireland** | | | | | | | | | | | |
| Portrush | *Fucus* spp. | 4[N] | <0.05 | <0.13 | | <0.11 | <0.10 | | <0.39 | <0.07 | <0.11 |
| Portaferry[a] | *Rhodymenia* spp. | 4[N] | <0.07 | <0.20 | | <0.24 | <0.32 | 0.29 | <0.56 | <0.10 | <0.14 |
| Ardglass | *Fucus vesiculosus* | 4[N] | <0.15 | <0.43 | | <0.83 | <1.7 | 29 | <1.3 | <0.24 | <0.33 |
| Carlingford Lough | *Ascophyllum nodosum* | 1[N] | <0.08 | <0.21 | | <0.28 | <0.31 | | <0.64 | <0.11 | <0.16 |
| Carlingford Lough | *Fucus* spp. | 3[N] | <0.06 | <0.19 | | <0.31 | <0.63 | 83 | <0.54 | <0.10 | <0.15 |

**Table 2.12 continued**

| Location | Material | No. of sampling observ-ations | Mean radioactivity concentration (fresh), Bq kg$^{-1}$ | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | $^{129}$I | $^{134}$Cs | $^{137}$Cs | $^{144}$Ce | $^{155}$Eu | $^{238}$Pu | $^{239}$Pu + $^{240}$Pu | $^{241}$Am |
| **Cumbria** | | | | | | | | | | |
| Silloth | Seaweed | 2 | 1.9 | <0.45 | 2.8 | <1.6 | | | | 2.4 |
| Harrington Harbour | Seaweed | 2 | 2.3 | <0.49 | 1.8 | <1.5 | | | | 1.8 |
| St Bees[b] | Seaweed | 2 | 6.3 | <0.56 | 2.2 | <1.7 | | 0.88 | 4.5 | 2.1 |
| Sellafield[c] | Seaweed | 2 | 7.2 | <0.55 | 2.9 | <1.7 | | 1.5 | 6.8 | 3.7 |
| Ravenglass | Samphire | 1[F] | | <0.06 | 0.64 | <0.25 | <0.09 | | | 1.5 |
| Ravenglass[d] | Seaweed | 2 | 3.7 | <0.56 | 3.0 | <1.6 | | 1.4 | 7.1 | 11 |
| **Lancashire** | | | | | | | | | | |
| Half Moon Bay | Seaweed | 2 | 2.3 | <0.54 | 2.1 | <1.5 | | | | <0.81 |
| Marshside Sands | Samphire | 1[F] | | <0.04 | 0.12 | <0.16 | <0.06 | | | <0.03 |
| **Scotland** | | | | | | | | | | |
| Aberdeen | *Fucus vesiculosus* | 1[S] | | <0.10 | <0.10 | <0.44 | <0.18 | | | <0.12 |
| Lerwick | *Fucus vesiculosus* | 1[S] | | <0.11 | <0.10 | <0.53 | <0.22 | | | <0.14 |
| Kinlochbervie | *Fucus vesiculosus* | 2[S] | | <0.10 | <0.10 | <0.40 | <0.17 | | | <0.12 |
| Lewis | *Fucus vesiculosus* | 1[S] | | <0.10 | 0.14 | <0.46 | <0.18 | | | <0.11 |
| Islay | *Fucus vesiculosus* | 1[S] | | <0.10 | <0.10 | <0.53 | <0.21 | | | <0.13 |
| Campbeltown | *Fucus vesiculosus* | 1[S] | | <0.10 | 0.35 | <0.63 | <0.28 | | | <0.30 |
| Port William | *Fucus vesiculosus* | 4[S] | | <0.10 | 0.53 | <0.28 | <0.13 | | | 1.2 |
| Garlieston | *Fucus vesiculosus* | 4[S] | | <0.10 | 4.9 | <0.41 | <0.17 | | | 11 |
| Auchencairn | *Fucus vesiculosus* | 4[S] | | <0.10 | 1.3 | <0.42 | <0.18 | | | 1.8 |
| **Wales** | | | | | | | | | | |
| Cemaes Bay | Seaweed | 2 | | <0.52 | <0.44 | <1.4 | | | | <0.44 |
| Porthmadog | Seaweed | 2 | | <0.39 | <0.54 | <1.4 | | | | <0.40 |
| Lavernock Point | Seaweed | 2 | | <0.47 | <0.42 | <1.5 | <0.70 | | | <0.48 |
| Fishguard | Seaweed | 2 | | <0.46 | <0.38 | <1.8 | | | | <0.51 |
| **Northern Ireland** | | | | | | | | | | |
| Portrush | *Fucus* spp. | 4[N] | | <0.05 | 0.12 | <0.24 | <0.12 | | | <0.14 |
| Portaferry[a] | *Rhodymenia* spp. | 4[N] | | <0.07 | 0.46 | <0.25 | <0.11 | 0.070 | 0.41 | 0.84 |
| Ardglass | *Fucus vesiculosus* | 4[N] | | <0.16 | 0.38 | <0.69 | <0.26 | | | <0.30 |
| Carlingford Lough | *Ascophyllum nodosum* | 1[N] | | <0.08 | 0.27 | <0.36 | <0.17 | | | <0.21 |
| Carlingford Lough | *Fucus* spp. | 3[N] | | <0.08 | 0.25 | <0.36 | <0.17 | | | <0.18 |

[a] *$^{242}$Cm and $^{243+244}$Cm were not detected by the method used*
[b] *The concentrations of $^{14}$C was <32 Bq kg$^{-1}$*
[c] *The concentrations of $^{14}$C was 21 Bq kg$^{-1}$*
[d] *The concentrations of $^{14}$C was 19 Bq kg$^{-1}$*
[F] *Measurements labelled "F" are made on behalf of the Food Standards Agency*
[N] *Measurements labelled "N" are made on behalf of the Northern Ireland Environment Agency*
[S] *Measurements labelled "S" are made on behalf of the Scottish Environment Protection Agency*
*All other measurements are made on behalf of the Environment Agency*

## Table 2.13 Concentrations of radionuclides in terrestrial food and the environment near Ravenglass, 2016

| Material and selection[a] | | No. of sampling observations[c] | Mean radioactivity concentration (fresh)[b], Bq kg$^{-1}$ | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Organic $^{3}$H | $^{3}$H | $^{14}$C | $^{60}$Co | $^{90}$Sr | $^{95}$Nb | $^{95}$Zr | $^{99}$Tc |
| Milk | | 3 | | <2.4 | 17 | <0.06 | <0.035 | <0.07 | <0.11 | <0.015 |
| Milk | max | | | | | | 0.053 | <0.08 | <0.12 | |
| Beef kidney | | 1 | | <4.5 | 8.6 | <0.04 | <0.064 | <0.04 | <0.11 | <0.087 |
| Beef liver | | 1 | | <4.0 | 30 | <0.05 | <0.042 | <0.46 | <0.14 | <0.088 |
| Beef muscle | | 1 | | 13 | 34 | <0.05 | <0.046 | <0.10 | <0.11 | <0.084 |
| Blackberries | | 1 | <2.4 | <2.4 | 15 | <0.03 | 0.076 | <0.11 | <0.15 | |
| Sheep muscle | | 2 | | <7.4 | 32 | <0.05 | <0.045 | <0.12 | <0.15 | <0.087 |
| Sheep muscle | max | | | <11 | 47 | <0.06 | | <0.15 | | <0.088 |
| Sheep offal | | 2 | | <7.2 | 27 | <0.03 | <0.047 | <0.05 | <0.08 | <0.093 |
| Sheep offal | max | | | <11 | 28 | <0.05 | <0.050 | <0.06 | <0.09 | <0.10 |

| Material and selection[a] | | No. of sampling observations[c] | Mean radioactivity concentration (fresh)[b], Bq kg$^{-1}$ | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | $^{106}$Ru | $^{125}$Sb | $^{129}$I | $^{134}$Cs | $^{137}$Cs | Total Cs | $^{144}$Ce |
| Milk | | 3 | <0.47 | <0.14 | <0.0055 | <0.07 | <0.10 | | <0.33 |
| Milk | max | | <0.49 | | <0.0068 | | <0.12 | | <0.34 |
| Beef kidney | | 1 | <0.29 | <0.10 | <0.017 | <0.03 | 0.08 | 0.10 | <0.34 |
| Beef liver | | 1 | <0.48 | <0.06 | <0.021 | <0.02 | <0.06 | 0.12 | <0.35 |
| Beef muscle | | 1 | <0.32 | <0.09 | <0.020 | <0.04 | 0.17 | 0.23 | <0.23 |
| Blackberries | | 1 | <0.62 | <0.16 | <0.041 | <0.09 | <0.08 | 0.052 | <0.40 |
| Sheep muscle | | 2 | <0.64 | <0.17 | <0.015 | <0.06 | 4.2 | 3.6 | <0.34 |
| Sheep muscle | max | | <0.71 | <0.21 | | <0.07 | 6.6 | 5.2 | <0.37 |
| Sheep offal | | 2 | <0.31 | <0.11 | <0.022 | <0.05 | 1.3 | 1.4 | <0.26 |
| Sheep offal | max | | <0.39 | <0.12 | <0.026 | | 1.6 | 1.7 | <0.32 |

| Material and selection[a] | | No. of sampling observations[c] | Mean radioactivity concentration (fresh)[b], Bq kg$^{-1}$ | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | $^{234}$U | $^{235}$U | $^{238}$U | $^{238}$Pu | $^{239}$Pu + $^{240}$Pu | $^{241}$Pu | $^{241}$Am |
| Milk | | 3 | | | | <0.000040 | <0.000025 | <0.11 | <0.000016 |
| Milk | max | | | | | <0.000093 | <0.000047 | <0.13 | 0.000023 |
| Beef kidney | | 1 | 0.0017 | <0.00052 | <0.00073 | <0.000047 | 0.000077 | <0.30 | 0.00020 |
| Beef liver | | 1 | | | | <0.000089 | 0.00016 | <0.22 | 0.00024 |
| Beef muscle | | 1 | | | | <0.000034 | 0.000027 | <0.22 | 0.00011 |
| Blackberries | | 1 | | | | 0.000092 | 0.00085 | <0.21 | 0.00140 |
| Sheep muscle | | 2 | | | | <0.000055 | 0.00015 | <0.20 | 0.00034 |
| Sheep muscle | max | | | | | <0.000057 | 0.00018 | <0.22 | 0.00036 |
| Sheep offal | | 2 | | | | <0.000082 | 0.00070 | <0.35 | 0.00056 |
| Sheep offal | max | | | | | <0.00012 | 0.00093 | <0.49 | 0.00084 |

[a] *Data are arithmetic means unless stated as 'max' in this column. 'Max' data are selected to be maxima. If no 'max' value is given the mean value is the most appropriate for dose assessments*

[b] *Except for milk where units are Bq l$^{-1}$*

[c] *The number of farms from which milk is sampled. The number of analyses is greater than this and depends on the bulking regime*

## Table 2.14 Concentrations of radionuclides in surface waters from West Cumbria, 2016

| Location | No. of sampling observations | Mean radioactivity concentration, Bq $l^{-1}$ | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | $^{3}H$ | $^{60}Co$ | $^{90}Sr$ | $^{134}Cs$ | $^{137}Cs$ | $^{238}Pu$ | $^{239}Pu$ + $^{240}Pu$ | Gross alpha | Gross beta |
| Ehen Spit beach[a] | 4 | 220 | <0.30 | <0.017 | <0.29 | <0.31 | <0.0018 | 0.0036 | <2.8 | 14 |
| River Ehen (100m downstream of sewer outfall) | 4 | <7.9 | <0.27 | <0.12 | <0.28 | <0.22 | <0.0018 | <0.0016 | <0.21 | <0.58 |
| River Ehen (upstream of site and tidal confluence) | 4 | <3.5 | <0.24 | <0.012 | <0.25 | <0.20 | <0.0022 | <0.0011 | <0.029 | <0.062 |
| River Calder (downstream) | 4 | <3.6 | <0.26 | <0.032 | <0.26 | <0.21 | <0.0018 | <0.0011 | <0.026 | <0.16 |
| River Calder (upstream) | 4 | <3.5 | <0.24 | <0.011 | <0.27 | <0.20 | <0.0016 | <0.0011 | <0.021 | 0.069 |
| Wast Water | 1 | <3.5 | <0.23 | | | <0.18 | | | <0.023 | <0.031 |
| Ennerdale Water | 1 | <3.4 | <0.11 | | <0.12 | <0.09 | | | <0.020 | <0.016 |
| Sellafield Tarn[b] | 1 | <6.1 | | <0.012 | | <0.19 | <0.0015 | <0.0017 | | |
| Devoke Water | 1 | <2.8 | <0.09 | | <0.10 | <0.08 | | | <0.025 | <0.016 |
| Thirlmere | 1 | <3.0 | <0.32 | | | <0.23 | | | <0.021 | <0.029 |

[a] *The concentration of $^{99}Tc$ was <0.64 Bq $l^{-1}$*
[b] *The concentration of $^{99}Tc$ was <0.086 Bq $l^{-1}$*

## Table 2.15 Concentrations of radionuclides in road drain sediments from Whitehaven and Seascale, 2016

| Location | No. of sampling observations | Mean radioactivity concentration (dry), Bq $kg^{-1}$ | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | $^{60}Co$ | $^{90}Sr$ | $^{134}Cs$ | $^{137}Cs$ | $^{238}Pu$ | $^{239}Pu$ + $^{240}Pu$ | $^{241}Am$ |
| Seascale SS 204 | 1 | <1.5 | <2.0 | <1.5 | 94 | 2.0 | 16 | 21 |
| Seascale SS 233 | 1 | <1.5 | <2.0 | <1.5 | 94 | 2.9 | 23 | 21 |
| Seascale SS 209 | 1 | <0.43 | <2.0 | <0.41 | 16 | 2.8 | 17 | 21 |
| Seascale SS 232 | 1 | <0.37 | <2.0 | <0.37 | 34 | 4.7 | 27 | 34 |
| Seascale SS 231 | 1 | <1.5 | 2.5 | <1.4 | 23 | 5.6 | 33 | 43 |

## Table 2.16 Doses from artificial radionuclides in the Irish Sea, 2007-2016

| Group | Exposure, mSv per year | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 |
| Northern Ireland | 0.015 | 0.017 | 0.012 | 0.010 | 0.010 | 0.011 | 0.010 | 0.009 | 0.009 | 0.011 |
| Dumfries and Galloway | 0.060 | 0.047 | 0.047 | 0.040 | 0.040 | 0.046 | 0.044 | 0.045 | 0.038 | 0.044 |
| Whitehaven | 0.009 | 0.009 | 0.011 | 0.010 | 0.010 | 0.013 | 0.010 | 0.012 | 0.017 | 0.016 |
| Sellafield (5 year average consumption) | 0.24 | 0.23 | 0.20 | 0.18 | 0.15 | 0.14 | 0.12 | 0.089 | 0.084 | 0.083 |
| Morecambe Bay | 0.037 | 0.042 | 0.041 | 0.046 | 0.034 | 0.034 | 0.036 | 0.032 | 0.031 | 0.024 |
| North Wales | 0.014 | 0.018 | 0.015 | 0.013 | 0.014 | 0.014 | 0.013 | 0.018 | 0.014 | 0.015 |

## Table 2.17 Individual radiation exposures, Sellafield, 2016

| Representative person[a] | Exposure, mSv per year | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Total | Seafood (nuclear industry discharges)[h] | Seafood (other discharges)[i] | Other local food | External radiation from intertidal areas, river banks or fishing gear[j] | Intakes of sediment and water | Gaseous plume related pathways | Direct radiation from site |
| ***Total dose* – maximum effect of all sources** | | | | | | | | |
| **Adult mollusc consumers** | **0.41[e]** | **0.055** | **0.34** | **–** | **0.019** | **–** | **–** | **–** |
| ***Total dose* – maximum effect of gaseous release and direct radiation sources** | | | | | | | | |
| **Local child inhabitants (0–0.25km)** | **0.008[b]** | **–** | **–** | **<0.005** | **<0.005** | **–** | **<0.005** | **0.005** |
| ***Total dose* – maximum effect of liquid release source** | | | | | | | | |
| **Adult mollusc consumers** | **0.41[e]** | **0.055** | **0.34** | **–** | **0.019** | **–** | **–** | **–** |
| **Source specfic doses** | | | | | | | | |
| **Seafood consumers** | | | | | | | | |
| Local seafood consumers (habits averaged 2012–16) | 0.43[f] | 0.051 | 0.35 | – | 0.032 | – | – | – |
| Local seafood consumers (habits for 2016) | 0.51[g] | 0.056 | 0.43 | – | 0.028 | – | – | – |
| Whitehaven seafood consumers | 0.016 | 0.016 | – | – | – | – | – | – |
| Dumfries and Galloway seafood and wildfowl consumers | 0.044 | 0.030 | – | – | 0.014 | – | – | – |
| Morecambe Bay seafood consumers | 0.024 | 0.007 | – | – | 0.017 | – | – | – |
| Northern Ireland seafood consumers | 0.011 | 0.009 | – | – | <0.005 | – | – | – |
| North Wales seafood consumers | 0.015 | 0.008 | – | – | 0.007 | – | – | – |
| **Other groups** | | | | | | | | |
| Ravenglass Estuary, marsh users | 0.011 | – | – | – | 0.009 | <0.005 | – | – |
| Fishermen handling nets or pots[c] | 0.087 | – | – | – | 0.087 | – | – | – |
| Bait diggers and shellfish collectors[c] | 0.064 | – | – | – | 0.064 | – | – | – |
| Ribble Estuary houseboats | 0.038 | – | – | – | 0.038 | – | – | – |
| Barrow Houseboats | 0.081 | – | – | – | 0.081 | – | – | – |
| Local infant consumers of locally grown food at Ravenglass | 0.019[b] | – | – | 0.019 | – | – | – | – |
| Local infant consumers of locally grown food at LLWR near Drigg | 0.007[b] | – | – | 0.007 | – | – | – | – |
| Infant inhabitants and consumers of locally grown food | 0.013[b] | – | – | 0.013 | – | – | <0.005 | – |
| **Groups with average consumption or exposure** | | | | | | | | |
| Average seafood consumer in Cumbria | <0.005 | <0.005 | – | – | – | – | – | – |
| Average consumer of locally grown food[d] | <0.005 | – | – | <0.005 | – | – | – | – |
| Typical visitor to Cumbria | <0.005 | <0.005 | <0.005 | – | <0.005 | – | – | – |
| **Recreational user of beaches** | | | | | | | | |
| Dumfries and Galloway | 0.008 | – | – | – | 0.008 | – | – | – |
| North Cumbria | 0.012 | – | – | – | 0.012 | – | – | – |
| Sellafield | 0.012 | – | – | – | 0.012 | – | – | – |
| Lancashire | 0.008 | – | – | – | 0.008 | – | – | – |
| North Wales | 0.010 | – | – | – | 0.010 | – | – | – |
| **Recreational user of mud/saltmarsh areas** | | | | | | | | |
| Dumfries and Galloway | <0.005 | – | – | – | <0.005 | – | – | – |
| North Cumbria | <0.005 | – | – | – | <0.005 | – | – | – |
| Sellafield | 0.014 | – | – | – | 0.014 | – | – | – |
| Lancashire | 0.006 | – | – | – | 0.006 | – | – | – |
| North Wales | 0.005 | – | – | – | 0.005 | – | – | – |

[a] *The* total dose *is the dose which accounts for all sources including gaseous and liquid discharges and direct radiation. The* total dose *for the representative person with the highest dose is presented. Other dose values are presented for specific sources, either liquid discharges or gaseous discharges, and their associated pathways. They serve as a check on the validity of the* total dose *assessment. The representative person is an adult unless otherwise stated*

[b] *Includes a component due to natural sources of radionuclides*

[c] *Exposure to skin for comparison with the 50 mSv dose limit*

[d] *Only the adult age group is considered for this assessment*

[e] *The dose due to nuclear industry discharges was 0.074 mSv*

[f] *The dose due to nuclear industry discharges was 0.083 mSv*

[g] *The dose due to nuclear industry discharges was 0.084 mSv*

[h] *May include a small contribution from LLWR near Drigg*

[i] *Enhanced naturally occuring radionuclides from Whitehaven*

[j] *Doses (*total dose *and source specific doses) only include estimates of anthropogenic inputs (by substracting background and cosmic sources from measured gamma dose rates)*

# 3. Research establishments

This section considers the results of monitoring, under the responsibility of the Environment Agency, FSA, FSS and SEPA, near research establishments that hold nuclear site licences.

NDA has ownership of the majority of such sites, with licensed nuclear sites at Harwell and Winfrith in England, and Dounreay in Scotland. Previously Harwell, Winfrith and Dounreay sites were operated by UKAEA. In 2009, Research Sites Restoration Limited (RSRL) and Dounreay Site Restoration Limited (DSRL) (both wholly-owned subsidiaries of UKAEA) became the site licence companies for Harwell and Winfrith, and Dounreay respectively. UKAEA Limited itself was sold to Babcock International Group plc, including its subsidiary companies DSRL and RSRL, as a preliminary to NDA starting the Dounreay Parent Body Organisation (PBO) competition.

In 2012, Babcock Dounreay Partnership, subsequently renamed as the Cavendish Dounreay Partnership, was awarded the contract to manage the decommissioning and clean-up of the Dounreay site, and became the PBO for Dounreay. In September 2014, NDA formally appointed Cavendish Fluor Partnership as the new PBO for RSRL (and Magnox Limited).

In 2014, ONR received an application to re-license the Harwell and Winfrith sites into a single site licence company alongside the ten Magnox sites. In 2015, Harwell and Winfrith sites, previously operated by RSRL, merged to be part of Magnox Limited.

All the nuclear licensed sites have reactors that are at different stages of decommissioning. Discharges of radioactive waste are largely related to decommissioning and decontamination operations and the nuclear related research that is undertaken. Some of this work is carried out by tenants, or contractors, such as Nuvia Limited.

Regular monitoring of the environment was undertaken in relation to all sites, which included the effects of discharges from neighbouring sites and tenants where appropriate, e.g. the Vulcan Naval Reactor Test Establishment (NRTE) adjacent to the Dounreay site.

In 2016, gaseous and liquid discharges were below regulated limits for each of the research establishments (see Appendix 2, Tables A2.1 and A2.2). Solid waste transfers in 2016 from nuclear establishments in Scotland (Dounreay) are also given in Appendix 2 (Table A2.4).

## Key points

- *Total doses* for the representative person were less than 6 per cent of the dose limit, for sites that were assessed

### Dounreay, Highland

- *Total dose* for the representative person increased in 2016

### Harwell, Oxfordshire

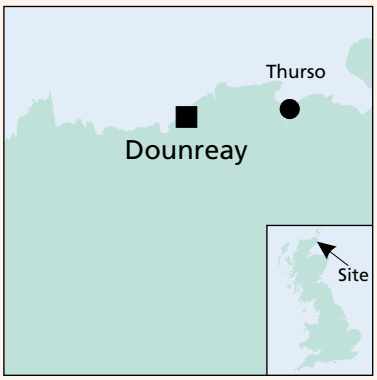
- *Total dose* for the representative person decreased in 2016
- Liquid discharges to the sewer were the lowest reported values in 2016

### Winfrith, Dorset

- *Total dose* for the representative person increased in 2016
- Liquid discharges of tritium (inner pipeline) decreased in 2016

Other minor research sites considered in this section are the non-nuclear site at Culham, Oxfordshire and the Imperial College Reactor Centre near Ascot, Berkshire.

## 3.1 Dounreay, Highland




The Dounreay site was opened in 1955 to develop research reactors. Three reactors were built on the site; the Prototype Fast Reactor, the Dounreay Fast Reactor and the Dounreay Materials Test Reactor. All three are now closed and undergoing decommissioning. It is currently expected that final active remediation of the site will be achieved by the interim end state date between 2030 and 2033 (NDA, 2017).

From 2005, NDA became responsible for the UK's civil nuclear liabilities which included those at UKAEA Dounreay, and UKAEA became a contractor to NDA. Consequently, the three existing radioactive waste disposal authorisations were transferred from UKAEA to a new site licence

company (Dounreay Site Restoration Limited, DSRL), before DSRL took over the site management contract. In 2012, Babcock Dounreay Partnership, which was subsequently renamed as the Cavendish Dounreay Partnership, was awarded the contract to manage the decommissioning and clean-up of the Dounreay site, and became the PBO for Dounreay.

In 2013, SEPA granted DSRL's authorisation for a Low Level Radioactive Waste disposal facility adjacent to the site. The facility began accepting waste for disposal in April 2015.

In May 2016, DSRL notified SEPA of the identification of the release of unmonitored krypton-85 gaseous discharges through the authorised discharge outlet at the DFR facility. Although the presence of the DFR Reactor Gas Blanket (RGB) pressure balancing system was known to DSRL, DSRL failed to evaluate krypton-85 discharges from the DFR RGB pressure balancing system and leakage from the reactor and failed to include these within the records for the krypton-85 discharges from the DFR facility. As a result, SEPA sent a Final Warning Letter to DSRL in relation to the site's arrangements for the evaluation of krypton-85 discharges. Details of the revised reported discharges of krypton-85 from the DFR facility, which takes account of DSRL's estimate of the additional krypton-85 discharges from DFR, are provided in the RIFE 22 errata document.

In July 2016, DSRL reported to SEPA that bowing/distortion of a lid on a Half-Height ISO (HHISO) container had been noted during routine operations. DSRL undertook an investigation which identified issues around an area of voidage/ullage between the top of the grouted waste mass and the HHISO container lid. As a result, SEPA requested from DSRL a review of its grouting practices, taking cognisance of national and international best practice and an assessment of the implications of the voidage in terms of settlement, stability and the mechanical loading on the container lids. While this programme of work is ongoing DSRL ceased all disposals to the LLW disposal facility adjacent to the site.

In September 2016, DSRL notified SEPA of the identification of water ingress into the Wet Silo (ILW storage facility). The source of the water was identified and isolated by DSRL. SEPA investigated the circumstances of DSRL's actions in response to the water ingress, DSRL's arrangements for the evaluation of the compliance implications of the event and the circumstances surrounding the maintenance of a pump at the wet silo facility. As a result, SEPA sent a Final Warning Letter to DSRL in relation to the site's arrangements for the management of the wet silo storage facility and its maintenance and inspection arrangements.

In 2016, radioactive waste discharges from Dounreay were made by DSRL under an authorisation granted by SEPA. The quantities of both gaseous and liquid discharges were generally similar to those releases in 2016 (Appendix 2, Tables A2.1 and A2.2). Solid waste transfers from Dounreay in 2016 are also given in Appendix 2 (Table A2.4).

The most recent habits survey was conducted in 2013 (Papworth *et al*., 2014).

## Doses to the public

The *total dose* from all pathways and sources of radiation was 0.058 mSv in 2016 (Table 3.1), or less than 6 per cent of the dose limit, and up from 0.010 mSv in 2015. In 2016, the representative person was an adult consuming game meat at high-rates, and was a change from that in 2015 (adult spending time over sediments). The increase in *total dose* was mostly due to the inclusion of the caesium-137 concentration in game (venison) in 2016 (sample not collected in 2015), the activity most likely from historical releases.

The trend in *total dose* over the period 2004 – 2016 is given in Figure 3.1. The variations in the earlier years were due to changes in caesium-137 concentrations in game meat and the type of game sampled, but *total doses* were low. A change in *total dose* between 2013 – 2015 was mostly due to the contribution of goats' milk not being included in the assessment (which has been assessed prior to 2013), as milk samples have not been available in most recent years. The significant contributor that increased dose in 2016 was the inclusion of the concentration of caesium-137 found in venison (game), which had not been sampled in recent years.

Source specific assessments for external pathways (for Geo occupants, who regularly visit Oigin's Geo, consumers of terrestrial foodstuffs and fishermen), give exposures of less than the *total dose* in 2016 (Table 3.1). In 2016, the dose to a consumer of terrestrial foodstuffs was 0.043 mSv or approximately 4 per cent of the dose limit for members of the public of 1 mSv. As in previous years, adults were identified as the most exposed age group. The reason for the increase in dose (from 0.014 mSv in 2015) is the same as that contributing to the maximum *total dose*. The dose to a consumer of fish and shellfish, including external exposure from occupancy over local beaches, was 0.013 mSv. The small increase in dose from 0.011 mSv (in 2015) was due to higher gamma dose rates over sand in 2016.

## Gaseous discharges and terrestrial monitoring

DSRL is authorised by SEPA to discharge radioactive gaseous wastes to the local environment via stacks to the atmosphere. The discharges also include a minor contribution from the adjoining reactor site (Vulcan NRTE), which is operated by the MoD's Defence Equipment and Support organisation. Monitoring conducted in 2016 included the sampling of air, freshwater, grass, soil

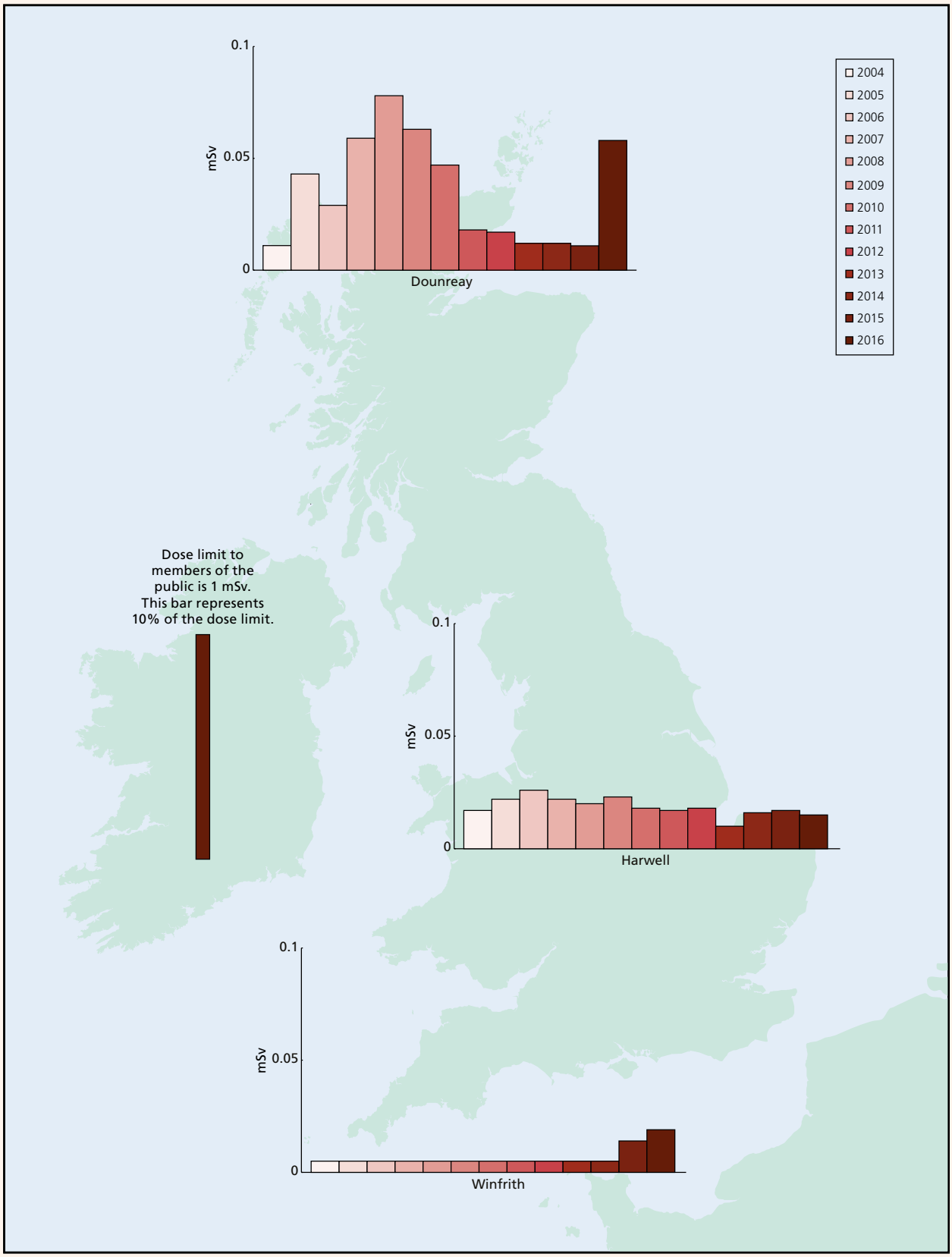



**Figure 3.1.** *Total dose* at research establishments, 2004–2016
(Small doses less than or equal to 0.005 mSv are recorded as being 0.005 mSv)

and locally grown terrestrial foods including meat and vegetables as well as wild foods. As there are no dairy cattle herds in the Dounreay area, no milk samples were collected from cattle. Goats' milk samples (which have been analysed in previous years) were not sampled, as no milk sample was available in 2016. The sampling locations for the terrestrial (and marine) monitoring programmes are shown in Figure 3.2 (Dounreay) and Figure 3.3 (north of Scotland). The results for terrestrial samples and radioactivity in air are given in Tables 3.2(a) and (c) and generally show low concentrations of radioactivity. In 2016, low concentrations of caesium-137, strontium-90, cobalt-60, antimony-125, uranium, plutonium and americium-241 are reported in some samples (many reported as less than values). Additional monitoring for caesium-137 in a venison sample was carried out in 2016 to determine the typical background concentration in the vicinity of the site. The caesium-137 concentration in venison was 160 Bq $kg^{-1}$ and more elevated than those enhanced concentrations measured in other game in previous years (venison: 69 Bq $kg^{-1}$ in 2009, and rabbit: 110 Bq $kg^{-1}$ in 2008). The variation of caesium-137 concentrations in the terrestrial environment in the Dounreay area will have been affected by fallout from weapons testing in the 1960s and from the Chernobyl reactor accident in 1986. The caesium-137 concentration in a honey sample (38 Bq $kg^{-1}$) was also positively detected again in 2016, which is higher than the maximum concentration in 2015 (7 Bq $kg^{-1}$) but similar to the maximum value reported in 2014 (33 Bq $kg^{-1}$). The variability in caesium-137 concentrations between years was likely due to the collection of honey from different sources (i.e. different types of produced honey samples). SEPA will keep this issue under review. Activity concentrations in air samples at locations near to the site are reported as less than values.

## Liquid waste discharges and aquatic monitoring

Low level liquid waste is routed via a Low Level Liquid Effluent Treatment Plant (LLLETP). The effluent is discharged to sea (Pentland Firth) via a pipeline terminating 600 metres offshore at a depth of about 24 metres. The discharges also include groundwater pumped from the Dounreay Shaft, surface water runoff, leachate from the low level solid waste disposal facility, and a minor contribution from the adjoining reactor site (Vulcan NRTE).

Routine marine monitoring included sampling of seafood, around the Dounreay outfall in the North Atlantic, and other materials further afield from the outfall, as well as the measurement of beta and gamma dose rates. Seafood samples from within the zone covered by a FEPA* Order are collected under consent granted in 1997 by the Scottish Office and revised in 2011 by FSA in Scotland (now FSS).

Crabs were sampled from the outfall area, together with mussels and winkles from areas along the coastline. Additionally, seawater, sediment and seaweed were sampled as indicator materials. The results for marine samples, and gamma and beta dose rates, are given in Tables 3.2(a) and (b). Activity concentrations were generally low in 2016 and generally similar to those in recent years. Technetium-99 concentrations in seaweed remained at the expected levels for this distance from Sellafield and were similar to those in 2015. Figure 3.3 also gives time trend information for technetium-99 concentrations (from Sellafield) in seaweed at Sandside Bay (location shown in Figure 3.2), Kinlochbervie and Burwick. They show an overall decline in concentrations over the period at all three locations. Generally, gamma dose rates were similar in 2016 (in comparison to 2015), although higher dose rates were measured over sand at Strathy Sands and Dunnet Bay. Beta dose rate measurements are reported as less than values (Table 3.2(b)).

During 2016, DSRL continued vehicle-based monitoring of local public beaches for radioactive fragments in compliance with the requirements of the authorisation granted by SEPA. In 2016, 8 fragments were recovered from Sandside Bay and 8 from the Dounreay foreshore. The caesium-137 activity measured in the fragments recovered from Sandside Bay ranged between 1.4 kBq and 53 kBq (similar to ranges observed in recent years). In November 2016, a fragment was recovered from Murkle Beach that had a measured caesium-137 activity of 21 kBq. During beach monitoring on the west foreshore, the presence of caesium-137 contamination was detected on two stones in February 2016 and August 2016. Both stones were recovered and brought onto the Dounreay site. It is believed that the contamination on the stones is associated with residual historical contamination from the Castlegate Seep.

In December 2016, one fragment was discovered and recovered from the Dounreay foreshore due to the measurement of americium-241. Unlike fragments normally detected and removed, the presence of caesium-137 contamination was not detected in this fragment by gamma-ray spectrometry. Further examination and analysis is being carried out to establish the radiological and non-radiological composition to assist in identifying the likely source of the fragment.

The previously conducted offshore survey work provided data on repopulation rates of particles to areas of the seabed previously cleared of particles. This work has improved the understanding of particle movements in the marine environment. The Dounreay Particles Advisory Group (DPAG) completed its work following the production

* *The FEPA Order was made in 1997 following the discovery of fragments of irradiated nuclear fuel on the seabed near Dounreay, by UKAEA, and prohibits the harvesting of seafoods within a 2 km radius of the discharge pipeline.*

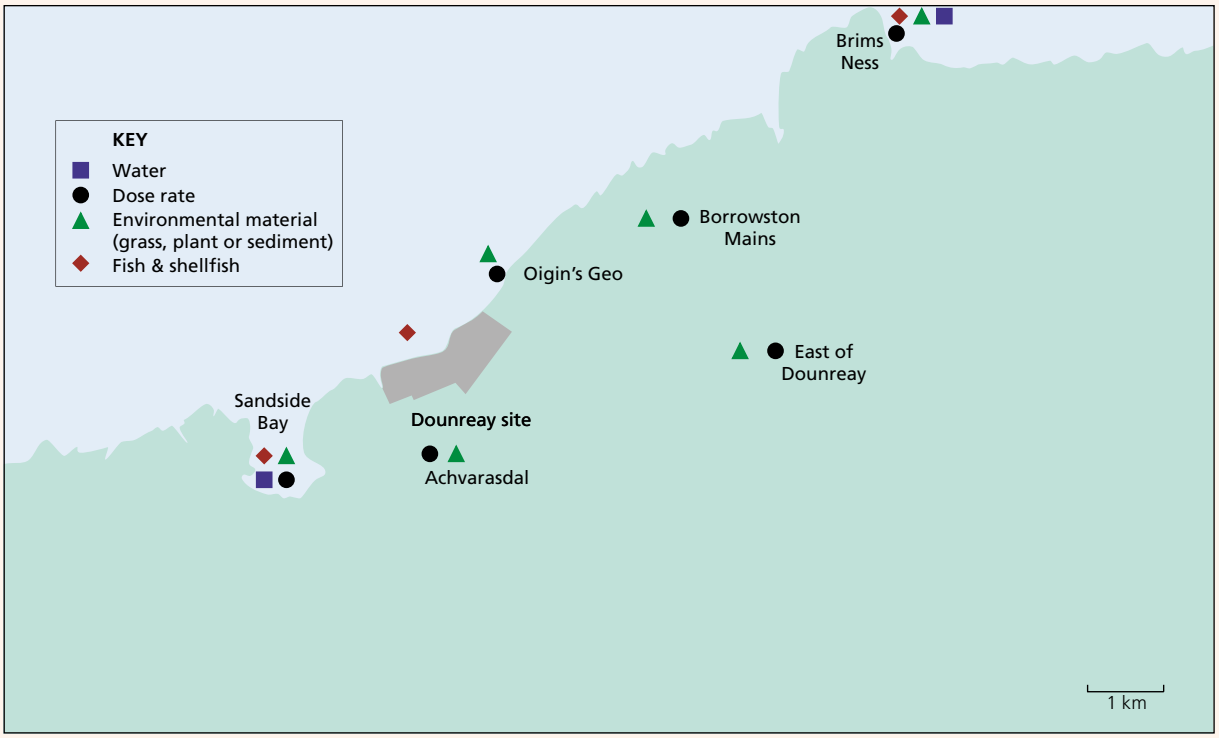



**Figure 3.2.** Monitoring locations at Dounreay, 2016 (not including farms)

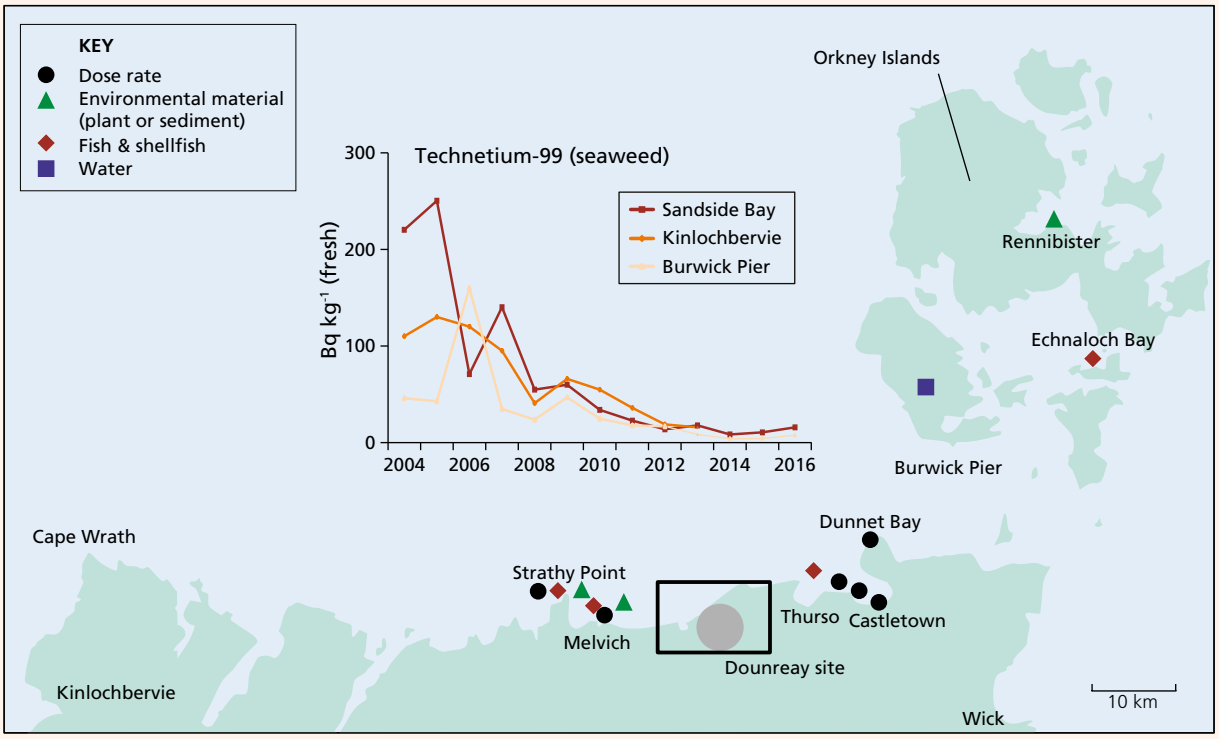
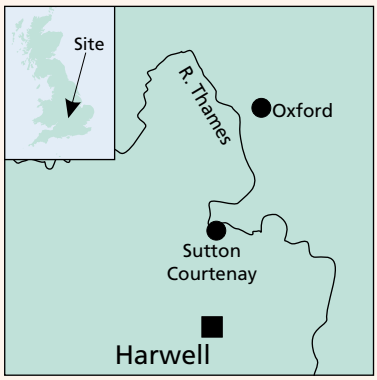



**Figure 3.3.** Monitoring locations and concentrations of technetium-99 in seaweed in the north of Scotland, 2016 (not including farms). The rectangle around the Dounreay site is the area presented in figure 3.2.

of its Fourth Report (*DPAG, 2008). Since the work of DPAG was concluded, the Particles Retrieval Advisory Group (Dounreay) (PRAG (D)) has published reports in March 2010 and March 2011 (PRAG (D), 2010; 2011). In March 2016, PRAG (D) published a further report into the retrieval of offshore particles. This was produced following an extensive research and monitoring programme in 2012 (PRAG (D), 2016). The report considers the extent and effectiveness of the offshore recovery programme to reduce the numbers of particles. The report concludes that any noticeable change in the rate or radioactive content of the particles arriving on the nearest public beach (Sandside Bay) will take a number of years to assess and recommends that in the interim the monitoring of beach local beaches should continue.

In 2007, FSA reviewed the Dounreay FEPA Order. A risk assessment, that was peer-reviewed by PHE, indicated that the food chain risk was very small (FSA, 2009). The FEPA Order was reviewed with regard to ongoing work to remove radioactive particles from the seabed and the food chain risk. In 2009, FSA in Scotland (now FSS) announced that the FEPA Order would remain in place, and be reviewed again when the seabed remediation work was complete.

## 3.2 Harwell, Oxfordshire




The site at Harwell was established in 1946 as Britain's first Atomic Energy Research Establishment and is situated approximately 5 km southwest of the town of Didcot. Since April 2015, the Harwell site has been operated by Magnox Limited on behalf of the NDA. The Harwell nuclear licensed site forms part of Harwell Campus, a science, innovation and business campus. The nuclear licensed site originally accommodated five research reactors of various types. Two of the reactors have been completely removed, and the fuel has been removed from the remaining three reactors. Decommissioning at the Harwell site is well underway. It is expected that all primary facilities and reactor decommissioning on the site will be completed by 2027. Final site clearance is expected to be achieved by 2064 (NDA, 2017). The most recent habits survey was conducted in 2015 (Clyne *et al.*, 2016b).

* *DPAG was set up in 2000, and PRAG (D) thereafter, to provide independent advice to SEPA and UKAEA on issues relating to the Dounreay fragments.*

### Doses to the public

The *total dose* from all pathways and sources of radiation was 0.015 mSv in 2016 (Table 3.1), which was less than 2 per cent of the dose limit, and down from 0.017 mSv in 2015. The small decrease in *total dose* (from 2015) was attributed to a lower estimate of direct radiation from the site in 2016. The dominant contribution to this dose was direct radiation from the site and the representative person was adults living near to the site (as in 2015). The trend in *total dose* over the period 2004 – 2016 is given in Figure 3.1. The *total doses* remained broadly similar from year to year, and were low.

Source specific assessments for a high-rate consumer of terrestrial foods, and for an angler, give exposures that were less than the *total dose* (Table 3.1).

### Gaseous discharges and terrestrial monitoring

Gaseous wastes are discharged via stacks to the local environment. As in previous years, discharges of radioactive wastes continued at very low rates in 2016. The monitoring programme sampled milk, fruit and grass. Sampling locations at Harwell and in other parts of the Thames catchment are shown in Figure 3.4. The results of the terrestrial monitoring programme in 2016 are shown in Table 3.3(a). The results for tritium analyses in terrestrial samples are reported as less than values.

### Liquid waste discharges and aquatic monitoring

Regulated discharges from Harwell are discharged to sewers serving the Didcot STW; treated effluent subsequently enters the River Thames at Long Wittenham. Discharges to the River Thames at Sutton Courtenay ceased in 2013, thereafter the decommissioning of the treated waste effluent discharge point was completed in 2014 by RSRL. Discharges of surface water effluent from the Harwell site are made via the Lydebank Brook, north of the site, which is a permitted route. Cobalt-60 and caesium-137 discharges from the site in 2016 were the lowest releases for many years; all values of discharges from the stream were less than 1 per cent of the limit in 2016. Figure 3.5 shows trends of discharges over time (2000 – 2016) for cobalt-60 and caesium-137. There was an overall reduction in the discharges over the whole period, particularly for cobalt-60.

The aquatic monitoring programme is directed at consumers of freshwater fish and occupancy close to the liquid discharge point. Tritium and cobalt-60 concentrations in all aquatic samples, and caesium-137 concentrations in fish and freshwater, are reported as less than values. The concentrations of all radionuclides in flounder from the lower reaches of the Thames are reported as less

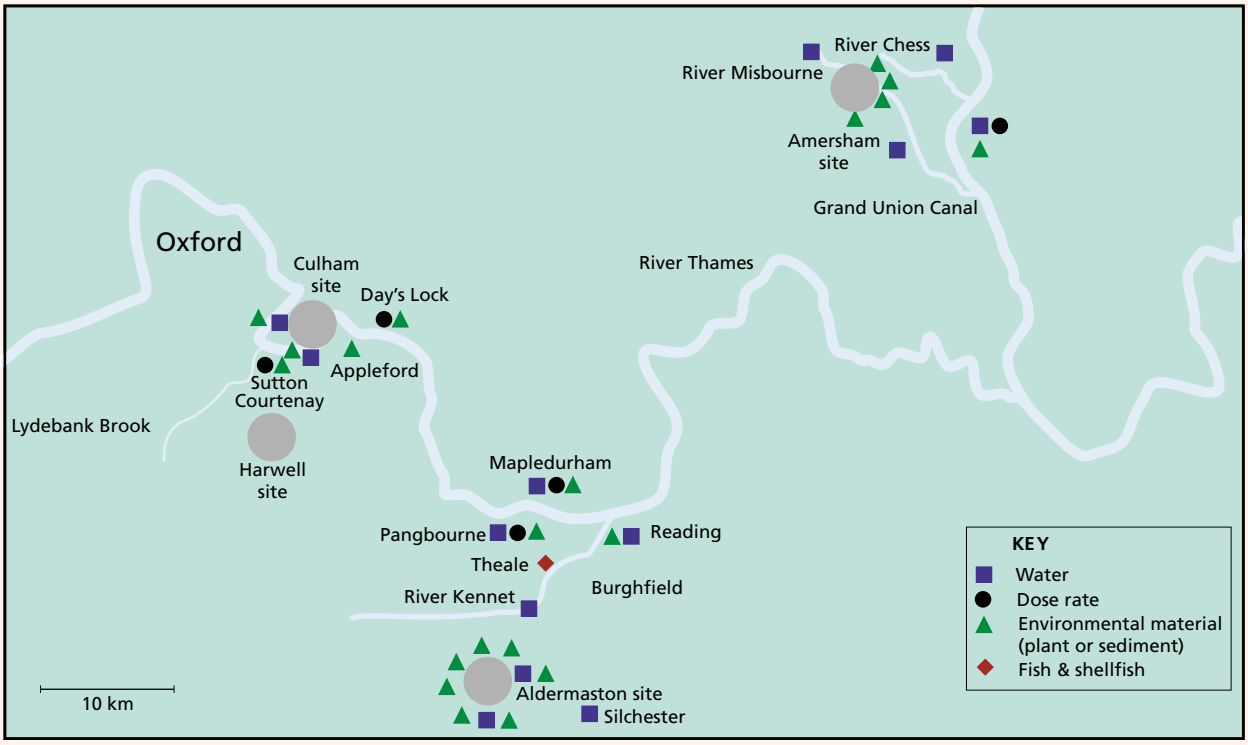



**Figure 3.4.** Monitoring locations at Thames sites, 2016 (not including farms)

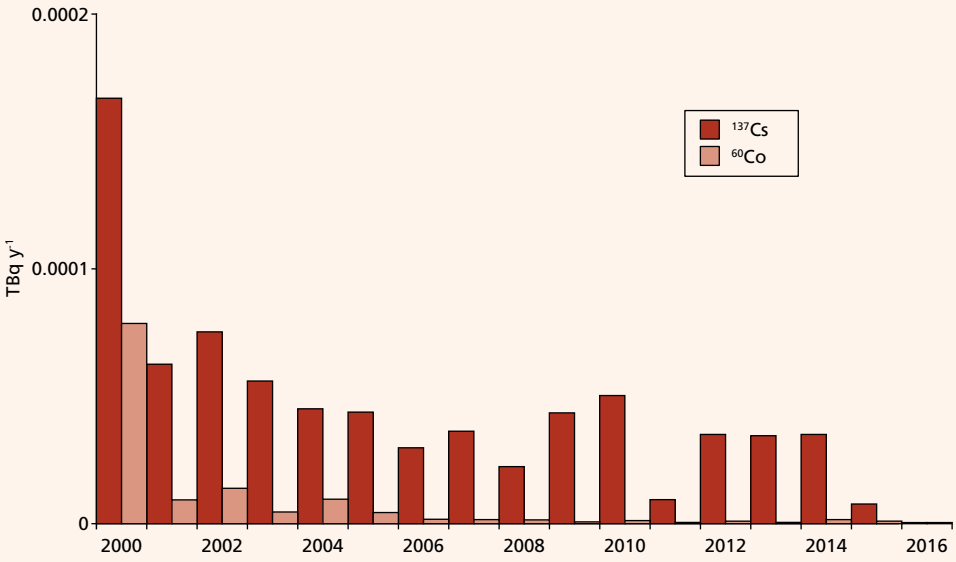
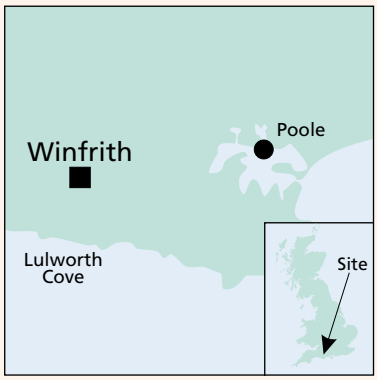



**Figure 3.5.** Trends in liquid discharges of caesium-137 and cobalt-60 from Harwell, Oxfordshire 2000-2016

than values (or close to the less than value). Caesium-137 concentrations in sediments continued to be enhanced above background levels in 2016, but were small in terms of any radiological effect. In 2016, sediments were not analysed for iodine-125 (undertaken in 2015 and positively detected). Concentrations of transuranic elements in sediments are mostly reported as less than values. In 2016, gamma dose rates (where comparisons can be made) were generally lower than those in 2015.

## 3.3 Winfrith, Dorset




The Winfrith site is located near Winfrith Newburgh. It was established by in 1957 as an experimental reactor research and development site. Since April 2015, the Winfrith site has been operated by Magnox Limited on behalf of the NDA. During various times there have been nine research and development reactors. The last operational reactor at Winfrith closed in 1995. Seven of the reactors have been decommissioned and dismantled. It is expected that final decommissioning of both remaining reactors (which commenced in 2014) will be completed by 2023. It is currently expected that final remediation of the site will be achieved by the interim end state date between 2022 and 2023 (NDA, 2017). The most recent habits survey undertaken for Winfrith was in 2003 (McTaggart *et al*., 2004b).

### Doses to the public

In 2016, the *total dose* from all pathways and sources of radiation was 0.019 mSv (Table 3.1), or less than 2 per cent of the dose limit, and up from 0.014 mSv in 2015. The representative person was adults living near the site (as in 2015). The increase in *total dose* was due to a higher estimate of direct radiation from the site in 2016. Trends in *total doses* in the area of the south coast (and the Severn Estuary) over time are shown in Figure 6.1. At Winfrith, *total doses* remained broadly similar from year to year (up to 2014) and were generally very low. The relative increases in recent years were due to higher estimates of direct radiation from the site.

Source specific assessments for a high-rate consumer of locally grown food, and of fish and shellfish, give exposures that were less than 0.005 mSv in 2016 (Table 3.1).

### Gaseous discharges and terrestrial monitoring

Gaseous radioactive waste is discharged via various stacks to the local environment. As in previous years, discharges of radioactive wastes continued at very low rates in 2016. The focus of the terrestrial sampling was for the content of tritium and carbon-14 in milk and crops. Local freshwater samples were also analysed. Sampling locations at Winfrith are shown in Figure 3.6. Data for 2016 are given in Table 3.4(a). Results for terrestrial samples provide little indication of an effect due to gaseous discharges. Carbon-14 was detected in locally produced milk, just above the expected background concentration. Low concentrations of tritium were found in surface water to the north of the site, similar to those in previous years. In all cases, tritium, gross alpha and gross beta concentrations in water were below the investigation levels for drinking water in the European Directive 2013/51.

### Liquid waste discharges and aquatic monitoring

Liquid wastes are disposed via a pipeline to deep water in Weymouth Bay. Discharges of tritium (inner pipeline) decreased in 2016, in comparison to releases in 2015. Figure 3.7 shows trends of liquid discharges over time (2000 – 2016) for tritium and alpha emitting radionuclides. Over the period, alpha-emitting radionuclide discharges have generally decreased since the peak in 2003 (although discharges peaked again in 2013). In comparison, tritium discharges have varied more between years, with periodic peaks in releases, due to operations at Traebe-Inutec (a tenant on the site). Discharges of alpha-emitting radionuclides from Winfrith (inner pipeline) were the less than 1 per cent of the annual limit (as in 2015).

Analyses of seafood and marine indicator materials and measurements of external radiation over muddy intertidal areas were conducted. Data for 2016 are given in Tables 3.4(a) and (b). Concentrations of radionuclides in the marine environment largely continued at the low levels found in recent years. Gamma dose rates were difficult to distinguish from natural background.

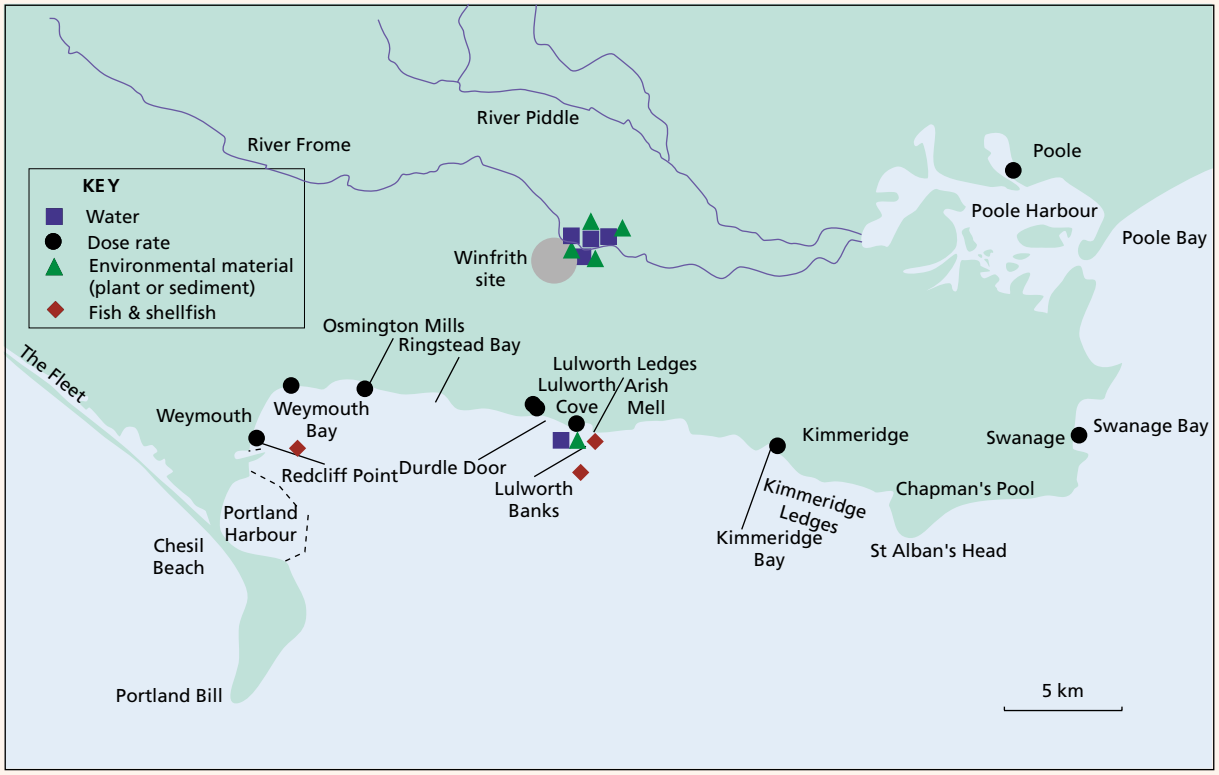



**Figure 3.6.** Monitoring locations at Winfrith, 2016 (not including farms)

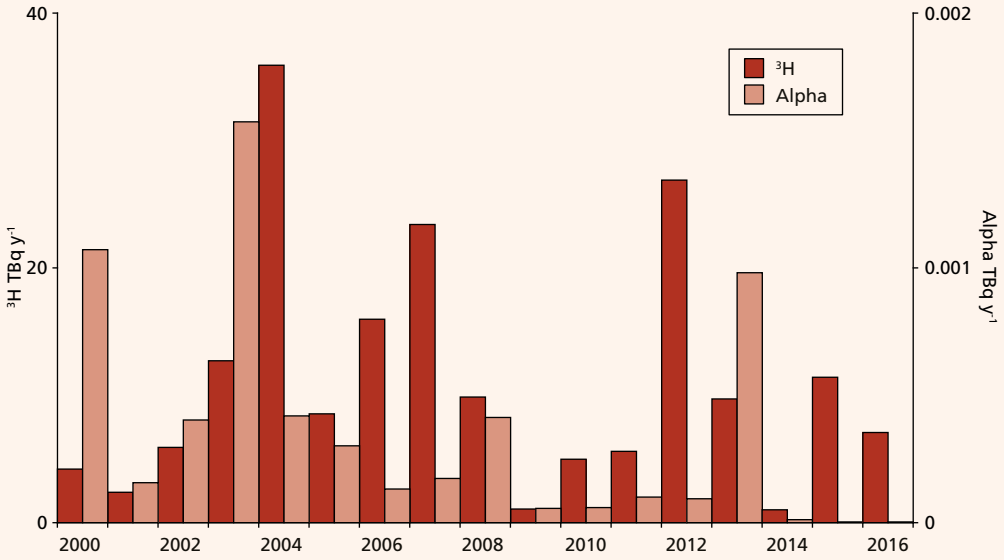
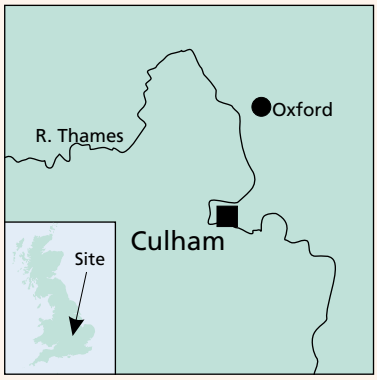



**Figure 3.7.** Trends in liquid discharges of tritium and alpha emitting radionuclides from Winfrith, Dorset 2000-2016

## 3.4 Minor sites

Two minor sites are monitored using a small sampling programme of environmental materials. The results, given in the following sections, show that there was no detected impact on the environment in 2016 due to operation of these sites.

### 3.4.1 Culham, Oxfordshire




Culham Centre for Fusion Energy (CCFE), based at the Culham Science Centre, is the UK's national laboratory for fusion research. CCFE hosts and is responsible for the operation of an experimental fusion reactor, the Joint European Torus (JET), via a contract between the European Commission and UKAEA. Although not currently designated, NDA understands that the intention of Government is to designate that part of the Culham Site occupied by JET facilities as an NDA site at an appropriate time after JET operation ceases. NDA would then take responsibility for the decommissioning programme that is expected to take 10 years to complete. The length of future operations is uncertain, but the assumption is that operations will continue until 2018 and the facility is then decommissioned (DECC and NDA, 2014).

*Total dose* is not determined at this site, in this report, because an integrated habits survey has not been undertaken. The source specific dose, from using the River Thames directly as drinking water downstream of the discharge point at Culham in 2016, was estimated to be much less than 0.005 mSv (Table 3.1).

Monitoring of soil and grass around Culham and of sediment and water from the River Thames was undertaken in 2016. Locations and data are shown in Figure 3.4 and Table 3.5, respectively. Historically, the main effect of the site's operation was the increased tritium concentrations found in grass collected near the site perimeter. As in recent years, tritium concentrations in all samples are reported as less than values. Overall, no effects due to site operation were detected. The caesium-137 concentration in the downstream sediment (77 Bq $kg^{-1}$) was higher in 2016, in comparison to those in recent years. Caesium-137 concentrations in the River Thames sediment are not attributable to Culham but were due to past discharges from Harwell, nuclear weapons testing fallout from the 1950s and 1960s and the Chernobyl reactor accident in 1986.

### 3.4.2 Imperial College Reactor Centre, Ascot, Berkshire

The licensed reactor at Imperial College is a minor site with very low radioactive discharges, and is monitored using a small sampling programme for environmental materials.

The Reactor Centre provided facilities for the University and other organisations for research and commercial purposes. The reactor was permanently shut down in 2012 and de-fuelled in 2014. The aim is that the reactor will be dismantled with eventual de-licensing of the site by 2021. In 2015, Imperial College applied to the ONR for consent to carry out the decommissioning of the reactor. ONR undertook a public consultation on the submitted environmental statement and a decision to grant consent was issued in July 2015 (ONR, 2015a). In November 2015, ONR reported the assessment findings of the decommissioning Safety Case (submitted by Imperial College) and concluded that the licensee has adequately identified the major hazards and performed an adequate assessment of the risks associated with each stage of the decommissioning programme to enable the site to move into decommissioning (ONR, 2015b).

As in previous years, gaseous and aqueous discharges were very low in 2016 (Appendix 2). Monitoring of the environmental effects involved the analysis of grass and crop (potato) samples by gamma-ray spectrometry on behalf of the Food Standards Agency. Activity concentrations in both samples, from radioactive discharges, are reported as less than values.

## Table 3.1 Individual doses – research sites, 2016

| Site | Representative person[a] | Exposure, mSv per year | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Total | Fish and Shellfish | Other local food | External radiation from intertidal areas, river banks or fishing gear[d] | Intakes of sediment and water | Gaseous plume related pathways | Direct radiation from site |
| Culham | | | | | | | | |
| Source specific dose | Drinkers of river water | <0.005 | – | – | – | <0.005 | – | – |
| Dounreay | | | | | | | | |
| ***Total dose* – all sources** | **Adult game meat consumers** | **0.058** | **<0.005** | **0.058** | **–** | **–** | **–** | **–** |
| Source specific doses | Seafood consumers | 0.013 | <0.005 | – | 0.013 | – | – | – |
| | Geo occupants[b] | <0.005 | – | – | <0.005 | – | – | – |
| | Inhabitants and consumers of locally grown food | 0.043 | – | 0.043 | – | – | <0.005 | – |
| Harwell | | | | | | | | |
| ***Total dose* – all sources** | **Local adult inhabitants (0–0.25km)** | **0.015[c]** | **–** | **–** | **–** | **–** | **<0.005** | **0.015** |
| Source specific doses | Anglers | <0.005 | <0.005 | – | <0.005 | – | – | – |
| | Infant inhabitants and consumers of locally grown food | <0.005[c] | – | <0.005 | – | – | <0.005 | – |
| Winfrith | | | | | | | | |
| ***Total dose* – all sources** | **Local adult inhabitants (0.5–1km)** | **0.019** | **<0.005** | **<0.005** | **<0.005** | **–** | **<0.005** | **0.019** |
| Source specific doses | Seafood consumers | <0.005 | <0.005 | – | <0.005 | – | – | – |
| | Infant inhabitants and consumers of locally grown food | <0.005 | – | <0.005 | – | – | <0.005 | – |

[a] *The* total dose *is the dose which accounts for all sources including gaseous and liquid discharges and direct radiation. The* total dose *for the representative person with the highest dose is presented. Other dose values are presented for specific sources, either liquid discharges or gaseous discharges, and their associated pathways. They serve as a check on the validity of the* total dose *assessment. The representative person is an adult unless otherwise stated*

[b] *People who visit Oigin's Geo, a coastal feature to the east of Dounreay*

[c] *includes a component due to natural sources of radionuclides*

[d] *Doses (*total dose *and source specific doses) only include estimates of anthropogenic inputs (by substracting background and cosmic sources from measured gamma dose rates)*

## Table 3.2(a) Concentrations of radionuclides in food and the environment near Dounreay, 2016

| Material | Location | No. of sampling observ-ations | Mean radioactivity concentration (fresh)[a], Bq kg$^{-1}$ | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | $^{3}$H | $^{60}$Co | $^{65}$Zn | $^{90}$Sr | $^{95}$Nb | $^{99}$Tc | $^{125}$Sb | $^{137}$Cs |
| **Marine samples** | | | | | | | | | | |
| Cod | Scrabster | 2 | | <0.10 | <0.26 | | <0.71 | | <0.23 | <0.27 |
| Crabs | Pipeline | 2 | | <0.10 | <0.17 | | <0.41 | <0.36 | <0.15 | <0.10 |
| Crabs | Strathy | 2 | | <0.10 | <0.15 | | <0.30 | | <0.14 | <0.10 |
| Crabs | Melvich Bay | 2 | | <0.10 | <0.19 | | <0.40 | 0.24 | <0.16 | <0.10 |
| Winkles | Brims Ness | 4 | | <0.10 | <0.19 | <0.10 | <0.50 | | <0.18 | <0.11 |
| Winkles | Sandside Bay | 4 | | <0.12 | <0.27 | <0.10 | <0.61 | 0.83 | <0.24 | <0.12 |
| Mussels | Echnaloch Bay | 4 | | <0.10 | <0.19 | | <0.44 | 1.2 | <0.19 | <0.10 |
| *Fucus vesiculosus* | Brims Ness | 4 | | <0.10 | <0.21 | | <0.46 | | <0.17 | <0.10 |
| *Fucus vesiculosus* | Sandside Bay | 4 | | <0.10 | <0.23 | | <0.55 | 16 | <0.18 | <0.12 |
| *Fucus vesiculosus* | Burwick Pier | 4 | | <0.10 | <0.23 | | <0.42 | 7.7 | <0.18 | <0.15 |
| Sediment | Oigin's Geo | 2 | | <0.10 | <0.36 | | <0.40 | | <0.39 | 11 |
| Sediment | Brims Ness | 1 | | <0.10 | <0.19 | | <0.27 | | <0.15 | 1.0 |
| Sediment | Sandside Bay | 1 | | <0.10 | <0.10 | | <0.15 | | <0.12 | 1.7 |
| Sediment | Melvich Bay | 1 | | <0.10 | <0.22 | | <0.45 | | <0.16 | 1.3 |
| Sediment | Strathy | 1 | | <0.10 | <0.16 | | <0.31 | | <0.12 | 0.70 |
| Sediment | Rennibister | 1 | | <0.10 | <0.29 | | <0.43 | | <0.22 | 13 |
| Seawater | Brims Ness | 2 | <3.0 | <0.10 | <0.12 | | <0.18 | | <0.13 | <0.10 |
| Seawater | Sandside Bay | 2 | <3.0 | <0.10 | <0.12 | | <0.16 | | <0.12 | <0.10 |
| Spume | Oigin's Geo | 2 | | <0.87 | <2.4 | | <9.1 | | <2.3 | 11 |

| Material | Location | No. of sampling observ-ations | Mean radioactivity concentration (fresh)[a], Bq kg$^{-1}$ | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | $^{154}$Eu | $^{155}$Eu | $^{238}$Pu | $^{240}$Pu | $^{241}$Am | Gross alpha | Gross beta |
| **Marine samples** | | | | | | | | | |
| Cod | Scrabster | 2 | <0.11 | <0.19 | 0.0041 | 0.00038 | 0.0013 | | |
| Crabs | Pipeline | 2 | <0.10 | <0.13 | 0.013 | 0.042 | 0.078 | 0.71 | 140 |
| Crabs | Strathy | 2 | <0.10 | <0.12 | 0.0014 | 0.012 | 0.0077 | | |
| Crabs | Melvich Bay | 2 | <0.10 | <0.14 | 0.0015 | 0.011 | 0.042 | | |
| Winkles | Brims Ness | 4 | <0.11 | <0.13 | 0.029 | 0.18 | 0.21 | | |
| Winkles | Sandside Bay | 4 | <0.13 | <0.20 | 0.026 | 0.11 | 0.11 | | |
| Mussels | Echnaloch Bay | 4 | <0.11 | <0.15 | | 0.038 | 0.022 | | |
| *Fucus vesiculosus* | Brims Ness | 4 | <0.11 | <0.16 | | | <0.13 | 3.6 | 360 |
| *Fucus vesiculosus* | Sandside Bay | 4 | <0.11 | <0.19 | | | <0.23 | 5.9 | 450 |
| *Fucus vesiculosus* | Burwick Pier | 4 | <0.10 | <0.17 | | | <0.11 | | |
| Sediment | Oigin's Geo | 2 | <0.21 | 1.9 | 0.87 | 4.1 | 3.0 | | |
| Sediment | Brims Ness | 1 | <0.10 | <0.28 | 2.1 | 9.6 | 17 | | |
| Sediment | Sandside Bay | 1 | 0.19 | <0.12 | 3.1 | 14 | 16 | | |
| Sediment | Melvich Bay | 1 | <0.16 | <0.25 | 0.076 | 1.1 | 0.85 | | |
| Sediment | Strathy | 1 | <0.13 | <0.20 | 0.15 | 0.82 | 0.63 | | |
| Sediment | Rennibister | 1 | <0.17 | 1.1 | 0.13 | 0.75 | <0.22 | | |
| Seawater | Brims Ness | 2 | <0.10 | <0.12 | | | <0.10 | | |
| Seawater | Sandside Bay | 2 | <0.10 | <0.11 | | | <0.10 | | |
| Spume | Oigin's Geo | 2 | <1.0 | <1.7 | 0.30 | 1.6 | 1.8 | | |

## Table 3.2(a) continued

| Material | Location or selection[b] | No. of sampling observ-ations | Mean radioactivity concentration (fresh)[a], Bq kg$^{-1}$ | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | $^{3}$H | $^{90}$Sr | $^{95}$Nb | $^{125}$Sb | $^{129}$I | $^{137}$Cs | $^{155}$Eu |
| **Terrestrial samples** | | | | | | | | | |
| Beef muscle | | 1 | <5.0 | <0.10 | <0.26 | <0.11 | <0.05 | <0.05 | |
| Beef offal | | 1 | <5.0 | <0.10 | <0.23 | <0.11 | <0.05 | <0.05 | |
| Broccoli | | 1 | <5.0 | 0.21 | <0.12 | <0.06 | <0.05 | 0.13 | |
| Cabbage | | 1 | <5.0 | <0.10 | <0.22 | <0.10 | <0.05 | <0.05 | |
| Cauliflower | | 1 | <5.0 | 0.10 | <0.18 | <0.76 | <0.05 | 0.10 | |
| Eggs | | 1 | <5.0 | <0.10 | <0.07 | <0.11 | <0.05 | <0.05 | |
| Honey | | 1 | <5.0 | <0.10 | <0.30 | <0.22 | <0.11 | 38 | |
| Lamb muscle | | 1 | <5.0 | <0.10 | <0.24 | <0.11 | <0.05 | 0.11 | |
| Leeks | | 1 | <5.0 | <0.10 | <0.18 | <0.11 | <0.05 | <0.05 | |
| Potatoes | | 1 | <5.0 | <0.10 | <0.20 | <0.08 | <0.05 | <0.05 | |
| Rosehips | | 1 | <5.0 | 0.73 | <0.25 | <0.13 | <0.10 | 0.48 | |
| Turnips | | 1 | <5.0 | <0.10 | <0.07 | <0.04 | <0.05 | <0.05 | |
| Venison | | 1 | <5.0 | <0.10 | <0.48 | <0.30 | <0.06 | 160 | |
| Wild mushrooms | | 1 | <5.0 | 0.19 | <0.21 | <0.12 | <0.05 | 7.7 | |
| Grass | | 6 | <5.0 | <0.38 | <0.37 | | <0.07 | <0.23 | |
| Grass | max | | | 0.99 | <0.82 | | <0.10 | 0.71 | |
| Soil | | 6 | <5.0 | 1.6 | <0.31 | 0.38 | <0.07 | 17 | <1.6 |
| Soil | max | | | 2.8 | 0.79 | 0.51 | <0.15 | 29 | 2.2 |
| Freshwater | Loch Calder | 1 | <1.0 | | <0.01 | | | <0.01 | |
| Freshwater | Loch Shurrery | 1 | <1.0 | | <0.01 | | | <0.01 | |
| Freshwater | Loch Baligill | 1 | <1.0 | | <0.01 | | | <0.01 | |
| Freshwater | Heldale Water | 1 | <1.0 | | <0.01 | | | <0.01 | |

| Material | Location or selection[b] | No. of sampling observ-ations | Mean radioactivity concentration (fresh)[a], Bq kg$^{-1}$ | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | $^{234}$U | $^{235}$U | $^{238}$U | $^{238}$Pu | $^{239}$Pu + $^{240}$Pu | $^{241}$Am | Gross alpha | Gross beta |
| **Terrestrial samples** | | | | | | | | | | |
| Beef muscle | | 1 | <0.050 | <0.050 | <0.050 | <0.050 | <0.050 | <0.050 | | |
| Beef offal | | 1 | <0.050 | <0.050 | <0.050 | <0.050 | <0.050 | 0.10 | | |
| Broccoli | | 1 | | | | <0.050 | <0.050 | <0.050 | | |
| Cabbage | | 1 | | | | <0.050 | <0.050 | <0.050 | | |
| Cauliflower | | 1 | | | | <0.050 | <0.050 | 0.050 | | |
| Eggs | | 1 | | | | <0.050 | 0.060 | 0.15 | | |
| Honey | | 1 | | | | <0.050 | <0.050 | <0.050 | | |
| Lamb muscle | | 1 | <0.050 | <0.050 | <0.050 | <0.050 | <0.050 | <0.050 | | |
| Leeks | | 1 | | | | <0.050 | <0.050 | <0.11 | | |
| Potatoes | | 1 | | | | <0.050 | <0.050 | <0.050 | | |
| Rosehips | | 1 | | | | | <0.050 | 0.050 | | |
| Turnips | | 1 | | | | <0.050 | <0.050 | 0.050 | | |
| Venison | | 1 | | | | <0.050 | <0.050 | <0.050 | | |
| Wild mushrooms | | 1 | | | | <0.050 | <0.050 | <0.050 | | |
| Grass | | 6 | <0.34 | <0.050 | <0.34 | <0.050 | <0.050 | <0.050 | | |
| Grass | max | | 0.55 | | 1.1 | | | | | |
| Soil | | 6 | 30 | 1.6 | 28 | <0.057 | 0.32 | 0.22 | | |
| Soil | max | | 50 | 3.3 | 45 | <0.090 | 0.47 | 0.33 | | |
| Freshwater | Loch Calder | 1 | | | | | | <0.01 | <0.010 | 0.044 |
| Freshwater | Loch Shurrery | 1 | | | | | | <0.01 | 0.013 | 0.030 |
| Freshwater | Loch Baligill | 1 | | | | | | <0.01 | 0.019 | 0.070 |
| Freshwater | Heldale Water | 1 | | | | | | <0.01 | <0.010 | 0.065 |

[a] *Except for seawater and freshwater where units are Bq l$^{-1}$, and for soil and sediment where dry concentrations apply*

[b] *Data are arithmetic means unless stated as 'Max' in this column. 'Max' data are selected to be maxima. If no 'max' value is given the mean value is the most appropriate for dose assessments*

## Table 3.2(b) Monitoring of radiation dose rates near Dounreay, 2016

| Location | Material or ground type | No. of sampling observations | µGy $h^{-1}$ |
|---|---|---|---|
| **Mean gamma dose rates at 1m over substrate** | | | |
| Sandside Bay | Sand | 2 | 0.060 |
| Sandside Bay | Winkle bed | 2 | 0.11 |
| Oigin's Geo | Rocks | 2 | 0.15 |
| Brims Ness | Stones and rocks | 2 | 0.10 |
| Melvich | Salt marsh | 2 | 0.070 |
| Melvich Sands | Salt marsh | 1 | 0.063 |
| Melvich Sands | Sand | 1 | 0.060 |
| Strathy Sands | Sand | 2 | 0.063 |
| Thurso riverbank | Seaweed | 2 | 0.082 |
| Achvarasdal | Grass | 2 | 0.082 |
| Thurso Park | Grass | 2 | 0.075 |
| Borrowston Mains | Grass | 2 | 0.083 |
| East of Dounreay | Grass | 2 | 0.089 |
| Castletown Harbour | Sand | 2 | 0.075 |
| Dunnet Bay | Sand | 2 | 0.066 |
| **Mean beta dose rates** | | | µSv $h^{-1}$ |
| Sandside Bay | Sand | 2 | <1.0 |
| Oigin's Geo | Stones | 2 | <1.0 |
| Thurso riverbank | Sediment | 2 | <1.0 |
| Castletown Harbour | Sand | 1 | <1.0 |
| Castletown Harbour | Lobster pots | 1 | <1.0 |

## Table 3.2(c) Radioactivity in air near Dounreay, 2016

| Location | No. of sampling observations | Mean radioactivity concentration, mBq $m^{-3}$ | | |
|---|---|---|---|---|
| | | $^{137}Cs$ | Gross alpha | Gross beta |
| Shebster | 12 | <0.010 | <0.0084 | <0.20 |
| Reay | 11 | <0.010 | <0.011 | <0.20 |
| Balmore | 12 | <0.010 | <0.011 | <0.20 |

## Table 3.3(a) Concentrations of radionuclides in food and the environment near Harwell, 2016

| Material | Location | No. of sampling observations | Mean radioactivity concentration (fresh)[a], Bq kg$^{-1}$ | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $^{3}$H | $^{60}$Co | $^{131}$I | $^{137}$Cs | $^{238}$Pu | $^{239}$Pu + $^{240}$Pu | $^{241}$Am | Gross alpha | Gross beta |
| **Freshwater samples** | | | | | | | | | | | |
| Flounder | Woolwich Reach | 1 | <25 | <0.04 | * | 0.05 | | | <0.04 | | |
| Sediment | Bank of River Thames (Sutton Courtenay) | 1[E] | | <1.1 | | 2.7 | <0.49 | 0.91 | <0.59 | 130 | 200 |
| Sediment | Bank of River Thames (Day's Lock) | 2[E] | | <0.34 | | 5.2 | <0.35 | <0.30 | <0.39 | 170 | 280 |
| Freshwater | Day's Lock | 4[E] | <4.5 | <0.29 | | <0.23 | | | | <0.048 | <0.23 |
| Freshwater | River Thames (Long Wittenham) | 4[E] | <3.5 | <0.21 | | <0.18 | | | | <0.050 | 0.37 |

| Material | Location or selection[b] | No. of sampling observations[c] | Mean radioactivity concentration (fresh)[a], Bq kg$^{-1}$ | |
|---|---|---|---|---|
| | | | Organic $^{3}$H | $^{3}$H |
| **Terrestrial samples** | | | | |
| Milk | | 2 | <3.8 | <3.8 |
| Milk | max | | <4.2 | <4.2 |
| Strawberries | | 1 | <3.3 | <3.3 |
| Grass | | 1 | <2.5 | <2.5 |

* *Not detected by the method used*

[a] *Except for milk where units are Bq l$^{-1}$, and for sediment where dry concentrations apply*

[b] *Data are arithmetic means unless stated as 'max' in this column. 'Max' data are selected to be maxima. If no 'max' value is given the mean value is the most appropriate for dose assessments*

[c] *The number of farms from which milk is sampled. The number of analyses is greater than this and depends on the bulking regime*

[E] *Measurements labelled "E" are made on behalf of the Environment Agency, all other measurements are made on behalf of the Food Standards Agency*

## Table 3.3(b) Monitoring of radiation dose rates near Harwell, 2016

| Location | Ground type | No. of sampling observations | µGy h$^{-1}$ |
|---|---|---|---|
| **Mean gamma dose rates at 1m over substrate** | | | |
| Sutton Courtenay | Grass and mud | 3 | 0.070 |
| Day's Lock | Grass and mud | 2 | 0.065 |
| Day's Lock | Grass | 1 | 0.062 |

## Table 3.4(a) Concentrations of radionuclides in food and the environment near Winfrith, 2016

| Material | Location | No. of sampling observ-ations | Mean radioactivity concentration (fresh)[a], Bq kg$^{-1}$ | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $^{14}$C | $^{60}$Co | $^{99}$Tc | $^{137}$Cs | $^{238}$Pu | $^{239}$Pu + $^{240}$Pu | $^{241}$Am | $^{242}$Cm | $^{243}$Cm + $^{244}$Cm | Gross alpha | Gross beta |
| **Marine samples** | | | | | | | | | | | | | |
| Plaice | Weymouth Bay | 1 | | <0.05 | | <0.05 | | | <0.05 | | | | |
| Crabs | Lulworth Banks | 1 | 32 | <0.08 | | <0.07 | | | <0.21 | | | | |
| Scallops | Lulworth Ledges | 1 | | <0.04 | | <0.04 | 0.00030 | 0.0026 | 0.00060 | 0.000098 | 0.000048 | | |
| Seaweed | Lulworth Cove | 1[E] | | <0.65 | 2.8 | <0.43 | | | <0.43 | | | | |
| Seaweed | Bognor Rock | 2[E] | | <0.51 | <0.36 | <0.38 | | | <0.48 | | | | |
| Seawater | Lulworth Cove | 1[E] | | <0.33 | | <0.25 | | | <0.26 | | | <2.4 | <5.0 |

| Material | Location or selection[b] | No. of sampling observations[c] | Mean radioactivity concentration (fresh)[a], Bq kg$^{-1}$ | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Organic $^{3}$H | $^{3}$H | $^{14}$C | $^{137}$Cs | Gross alpha | Gross beta |
| **Terrestrial samples** | | | | | | | | |
| Milk | | 2 | <2.5 | <2.5 | 20 | <0.07 | | |
| Milk | max | | | | 21 | | | |
| Broad beans | | 1 | <2.4 | <2.4 | 16 | <0.12 | | |
| Grass | | 1 | <3.3 | <3.3 | 3.8 | <0.05 | | |
| Grass | Near Newburgh Farm Cottages | 1[E] | | 17 | 23 | <0.76 | <2.2 | 230 |
| Grass | Adjacent to railway | 1[E] | | 68 | 23 | <4.3 | <1.9 | 190 |
| Sediment | North of site (Stream A) | 1[E] | | | | 0.84 | <110 | <150 |
| Sediment | R Frome (upstream) | 1[E] | | | | 1.3 | <96 | <110 |
| Sediment | R Frome (downstream) | 1[E] | | | | 1.6 | <130 | <97 |
| Sediment | R Win, East of site | 1[E] | | | | <0.17 | <94 | <110 |
| Freshwater | North of site (Stream A) | 2[E] | | 11 | | <0.20 | <0.056 | 0.14 |
| Freshwater | R Frome (upstream) | 2[E] | | <3.4 | | <0.18 | <0.033 | <0.064 |
| Freshwater | R Frome (downstream) | 2[E] | | <3.4 | | <0.23 | <0.035 | <0.080 |
| Freshwater | R Win, East of site | 2[E] | | <3.2 | | <0.21 | <0.029 | 0.14 |

[a] *Except for milk and freshwater where units are Bq l$^{-1}$, and for sediment where dry concentrations apply*
[b] *Data are arithmetic means unless stated as 'max' in this column. 'Max' data are selected to be maxima. If no 'max' value is given the mean value is the most appropriate for dose assessments*
[c] *The number of farms from which milk is sampled. The number of analyses is greater than this and depends on the bulking regime*
[E] *Measurements labelled "E" are made on behalf of the Environment Agency, all other measurements are made on behalf of the Food Standards Agency*

## Table 3.4(b) Monitoring of radiation dose rates near Winfrith, 2016

| Location | Ground type | No. of sampling observations | µGy h$^{-1}$ |
|---|---|---|---|
| **Mean gamma dose rates at 1m over substrate** | | | |
| Weymouth Bay | Pebbles | 1 | 0.049 |
| Osmington Mills | Pebbles and sand | 1 | 0.070 |
| Durdle Door | Pebbles | 1 | 0.048 |
| Lulworth Cove | Pebbles and sand | 1 | 0.067 |
| Kimmeridge Bay | Pebbles and rock | 1 | 0.077 |
| Swanage Bay | Sand | 1 | 0.055 |
| Poole Harbour | Pebbles and sand | 1 | 0.048 |

**Table 3.5 Concentrations of radionuclides in the environment near Culham, 2016**

| Material | Location | No. of sampling observations | Mean radioactivity concentration (fresh)[a], Bq kg$^{-1}$ | | | | |
|---|---|---|---|---|---|---|---|
| | | | $^{3}$H | $^{14}$C | $^{137}$Cs | Gross alpha | Gross beta |
| Freshwater | River Thames (upstream) | 2 | <4.1 | | <0.20 | <0.050 | 0.32 |
| Freshwater | River Thames (downstream) | 2 | <4.1 | | <0.18 | <0.12 | 0.34 |
| Grass | 0.6 km East of site perimeter | 1 | <12 | 9.9 | <1.2 | | 200 |
| Sediment | River Thames (upstream) | 2 | | | 7.2 | | |
| Sediment | River Thames (downstream) | 2 | | | 77 | | |
| Soil | 1 km East of site perimeter | 1 | <4.5 | 9.4 | 3.8 | | 490 |

[a] *Except for freshwater where units are Bq l$^{-1}$, and for sediment and soil where dry concentrations apply*

# 4. Nuclear power stations

## Key points

- *Total doses* for the representative person were less than 4 per cent of the dose limit for all sites assessed

### Berkeley, Gloucestershire and Oldbury, South Gloucestershire

- *Total dose* for the representative person increased in 2016
- Gaseous discharges of tritium decreased and carbon-14 increased from Berkeley, and liquid discharges of tritium decreased from Oldbury, in 2016

### Bradwell, Essex

- *Total dose* for the representative person increased in 2016
- Gaseous and liquid discharges of tritium increased in 2016
- Enhanced monitoring continued in 2016

### Chapelcross, Dumfries and Galloway

- *Total dose* for the representative person increased in 2016

### Dungeness, Kent

- *Total dose* for the representative person increased in 2016
- Gaseous and liquid discharges of sulphur-35, increased from Dungeness B in 2016

### Hartlepool, County Durham

- *Total dose* for the representative person decreased in 2016
- Liquid discharges of tritium and sulphur-35 increased in 2016

### Heysham, Lancashire

- *Total dose* for the representative person decreased in 2016
- Gaseous discharges of carbon-14 and sulphur-35 increased at Heysham 1, and argon-41 decreased at Heysham 2, liquid discharges of tritium, sulphur-35 and "other radionuclides" increased from Heysham 1 and "other radionuclides" increased from Heysham 2, in 2016

### Hinkley Point, Somerset

- *Total dose* for the representative person decreased in 2016
- Liquid discharges of "other radionuclides" decreased from Hinkley Point B in 2016

### Hunterston, North Ayrshire

- *Total dose* for the representative person decreased in 2016
- Gaseous discharges of "all other radionuclides" increased, liquid discharges of alpha and plutonium-241 increased, from Hunterston A, in 2016

### Sizewell, Suffolk

- Gaseous discharges of carbon-14 decreased, liquid discharges of "other radionuclides" increased, from Sizewell A in 2016

### Torness, East Lothian

- A verification visit (Article 35 of the Euratom Treaty) of the environmental monitoring arrangements was under taken in 2016

### Trawsfynydd, Gwynedd

- *Total dose* for the representative person increased in 2016

### Wylfa, Isle of Anglesey

- *Total dose* for the representative person decreased in 2016
- Gaseous discharges of carbon-14 and sulphur-35 decreased, and liquid discharges of tritium decreased, in 2016

This section considers the results of environment and food monitoring, under the responsibility of the Environment Agency, FSA, FSS, NRW and SEPA, from nuclear power stations. There is a total of 19 nuclear power stations at 14 locations, nine in England (Berkeley, Oldbury, Bradwell, Calder Hall, Dungeness, Hartlepool, Heysham, Hinkley Point and Sizewell), three in Scotland (Chapelcross, Hunterston and Torness) and two in Wales (Trawsfynydd and Wylfa). Some of these stations are being decommissioned.

Eleven of the 19 nuclear power stations are older Magnox power stations, owned by NDA. NDA (set up under the Energy Act 2004) is a non-departmental public body (sponsored by BEIS), with a remit to secure the decommissioning and clean-up of the UK's civil public sector nuclear licensed sites. All Magnox stations are in the process of de-fuelling or decommissioning. In March 2017, NDA published a business plan which summarises the programme of work at each of the sites during 2017/20 (NDA, 2017).

In March 2014, NDA announced that the Cavendish Fluor Partnership, a joint venture between Cavendish Nuclear (a wholly-owned subsidiary of Babcock International Group plc) and Fluor Corporation, had been selected to take ownership of Magnox Limited. In 2013, Magnox Limited managed ten nuclear sites and was owned and operated by Energy Solutions on behalf of NDA. In 2014, NDA formally appointed Cavendish Fluor Partnership as the new PBO for and Magnox Limited (and RSRL). In 2014, ONR received an application to relicense the ten Magnox sites into a single site licence company alongside the Harwell and Winfrith sites. As of 1st April 2015, Harwell and Winfrith sites, previously operated by RSRL, merged to be part of Magnox Limited. Concurrently the EPR 2010 radioactive substances permits (now EPR 16) for each site were also transferred to Magnox Limited.

Calder Hall is being decommissioned; it is operated by Sellafield Limited and discharges from this Magnox power station are considered in Section 2 because it is located at Sellafield.

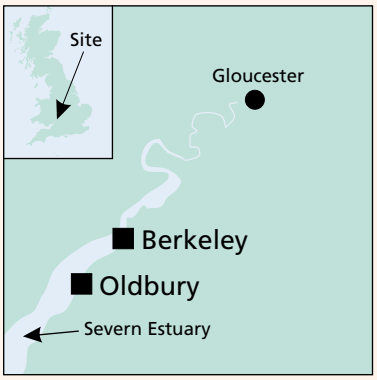
Seven AGR power stations and one Pressurised Water Reactor (PWR) power station were owned and operated by EDF Energy Nuclear Generation Limited in 2016; these are Dungeness B, Hartlepool, Heysham 1 and 2, Hinkley Point B and Sizewell B Power Stations in England, and Hunterston B and Torness Power Stations in Scotland. All these power stations generated electricity during 2016.

Gaseous and liquid discharges from each of the power stations are regulated by the Environment Agency and NRW in England and Wales, respectively and by SEPA in Scotland. In 2016, gaseous and liquid discharges were below regulated limits for each of the power stations (see Appendix 2, Tables A2.1 and A2.2). Solid waste transfers in 2016 from nuclear establishments in Scotland (Chapelcross, Hunterston A, Hunterston B and Torness) are also given in Appendix 2 (Table A2.4). Independent monitoring of the environment around each of the power stations is conducted by the FSA and the Environment Agency in England and Wales, and by SEPA in Scotland. In Wales, this is conducted on behalf of NRW and the Welsh Government.

The sites in this Section are grouped according to their location in England, Scotland or Wales.

# ENGLAND

## 4.1 Berkeley, Gloucestershire and Oldbury, South Gloucestershire




Berkeley and Oldbury are both Magnox power stations. Berkeley Power Station is situated on the eastern bank of the **River Severn** and was powered by two Magnox reactors. Berkeley was the first commercial power station in the UK to enter into decommissioning. It ceased electricity generation in 1989 and de-fuelling was completed in 1992. Decommissioning is still in progress and radioactive wastes are still generated by these operations. The Berkeley site will enter the Care and Maintenance phase by the year 2021. Thereafter, the current plan is to de-license the Berkeley site (released from regulatory control). Final site clearance is expected to commence in 2070 and be achieved by 2079 (NDA, 2017).

Oldbury Power Station is located on the south bank of the River Severn close to the village of Oldbury-on-Severn and has two Magnox reactors. Electricity generation started in 1967 and ceased in 2012. De-fuelling was completed in 2016 and the site is now focusing on the retrieval, processing, storage and dispatch of waste. The Oldbury site will enter the Care and Maintenance phase by the year 2027. Thereafter, the current plan is to de-license the Oldbury site (released from regulatory control). Final site clearance is expected to commence in 2092 and be achieved by 2101 (NDA, 2017).

Berkeley and Oldbury sites are considered together for the purposes of environmental monitoring because the effects from both sites contribute to the same area. The most recent habits survey was undertaken in 2014 (Clyne *et al.*, 2015).

### Doses to the public

The *total dose* from all pathways and sources of radiation is assessed to have been 0.006 mSv in 2016 (Table 4.1), which was less than 1 per cent of the dose limit, and up from less than 0.005 mSv in 2015. In 2016, the representative person was infants (1 year-old) consuming milk at high-rates. The trend in the *total dose* over the period 2004 – 2016 is given in Figure 4.1. Any longer-term variations in *total doses* with time are attributable to changes in the contribution from direct radiation from the site.

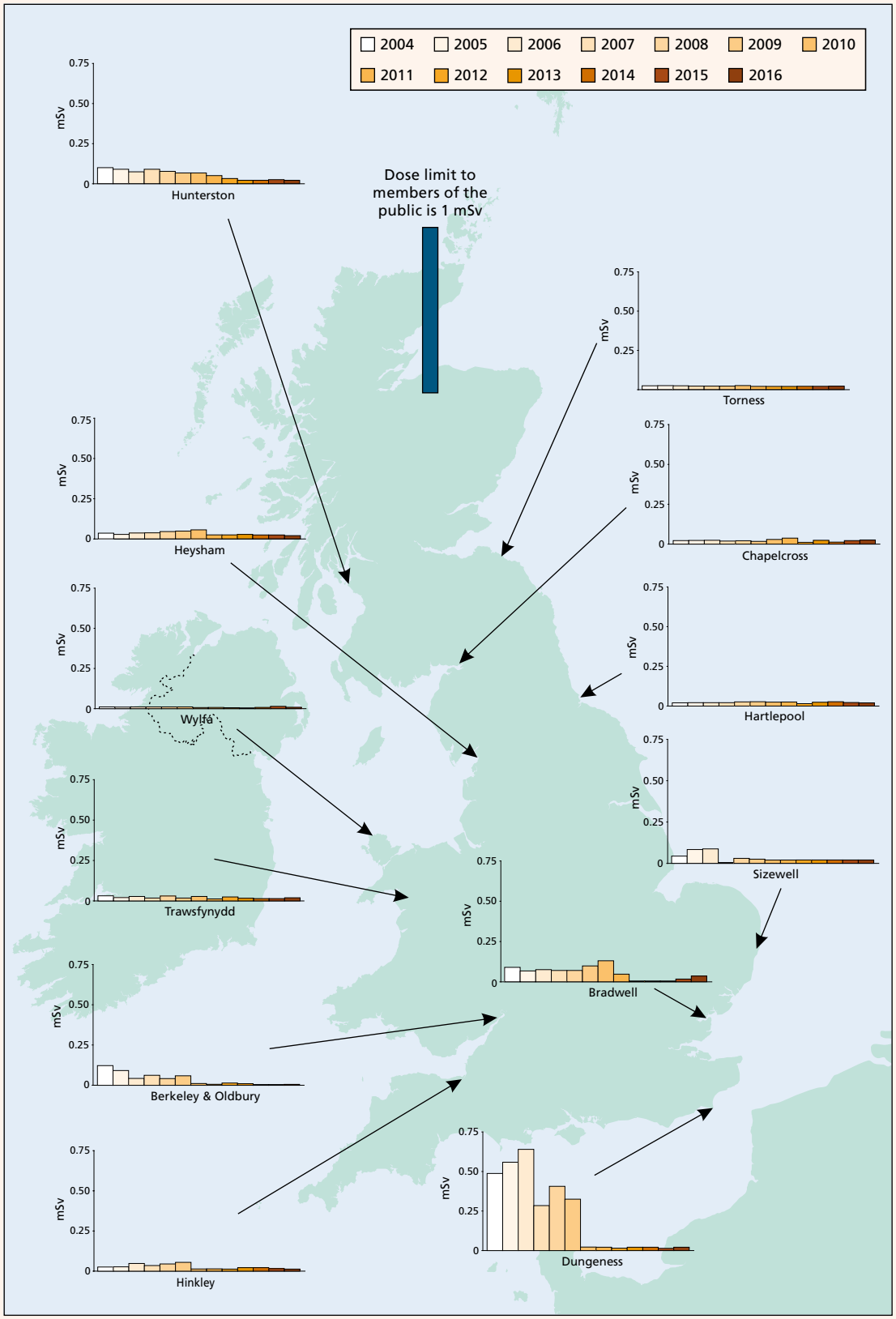



**Figure 4.1.** *Total dose* at nuclear power stations, 2004-2016
(Small doses less than or equal to 0.005 mSv are recorded as being 0.005 mSv)

The source specific assessments for a high-rate consumer of fish and shellfish, and for houseboat dwellers in the vicinity of the Berkeley and Oldbury sites, give exposures that were less than the *total dose* (Table 4.1). The dose to a consumer of fish and shellfish includes external gamma radiation, a component due to the tritium historically originating from the GE Healthcare Limited plant at Cardiff, and a component of the dose resulting from an increased tritium dose coefficient (see Appendix 1). The dose to a high-rate consumer of locally grown foods was estimated to be 0.006 mSv. The small increase in dose (from 0.005 mSv in 2015) was due to higher carbon-14 concentrations in milk in 2016. The estimated dose for houseboat dwellers was less than 0.031 mSv in 2016, and up from 0.006 mSv in 2015. The higher value in 2016 was due to an increase in the gamma dose rates from sediments at Sharpness, in comparison to those in 2015. The estimate for this pathway is determined as a cautious value (and therefore not included in the *total dose* assessment), because gamma dose rate measurements used were not necessarily representative of the types of ground type and houseboat location (as identified in the habits survey).

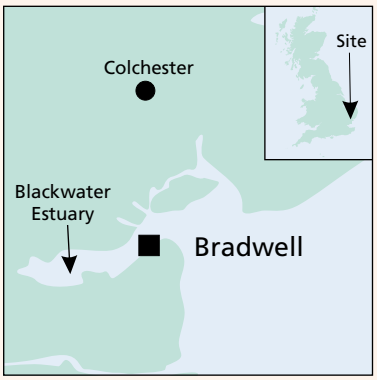
## Gaseous discharges and terrestrial monitoring

The Berkeley and Oldbury sites discharge gaseous radioactive wastes via separate stacks to the atmosphere. Discharges of tritium decreased and carbon-14 increased at Berkeley in 2016, in comparison to releases in 2015. The focus of the terrestrial sampling was for the content of tritium, carbon-14 and sulphur-35 in milk and crops. Local freshwater samples were also analysed. Data for 2016 are given in Table 4.2(a). Sulphur-35 was detected at very low levels in two terrestrial food samples (potatoes and barley). Carbon-14 concentrations in foodstuffs (milk) increased in 2016 by small amounts in comparison to those in 2015. Tritium, gross alpha and gross beta concentrations in surface water were below the investigation levels for drinking water in the European Directive 2013/51.

## Liquid waste discharges and aquatic monitoring

Liquid radioactive wastes are discharged to the Severn Estuary. Discharges of tritium decreased from Oldbury in 2016, in comparison to releases in 2015. Analyses of seafood and marine indicator materials and measurements of external radiation were conducted over muddy intertidal areas. Measurements of tritium in seafood were made to monitor the additional local effects of historical discharges from the GE Healthcare Limited radiopharmaceutical plant in Cardiff (see Section 6). Data for 2016 are given in Tables 4.2(a) and (b). Most of the artificial radioactivity detected was due to caesium-137, representing the combined effect of discharges from the sites, other nuclear establishments discharging into the Bristol Channel and weapons testing, and possibly a small Sellafield-derived component. There is limited evidence to suggest that caesium-137 concentrations in sediment have been generally decreasing over the last decade (Figure 4.2). The tritium concentrations in fish and seawater (the latter sample not analysed for tritium in recent years) are reported as a less than values. In previous years, the levels of tritium in seafood have been relatively high and were likely to be mainly due to historical discharges from GE Healthcare Limited, Cardiff. Very small concentrations of other radionuclides were detected but, taken together, were of low radiological significance. Gamma dose rates were generally similar (where comparisons can be made), although rates at Sharpness increased by small amounts, in comparison to those in 2015.

## 4.2 Bradwell, Essex




The Bradwell site is located on the south side of the Blackwater Estuary. This Magnox power station ceased electricity production in 2002 after 40 years of operation, and de-fuelling was completed in 2006. The focus for the site is the completion of decommissioning projects. The site is following an accelerated decommissioning programme and is now more than halfway through a programme of work. Bradwell should become the first Magnox site in England to enter the Care and Maintenance phase, which is expected to last for around 70 years. The Bradwell site will enter the Care and Maintenance phase between 2018 and 2020. Thereafter, the plan is for final site clearance to commence in 2083 and be achieved by 2092 (NDA, 2017).

During 2014, the Environment Agency carried out a review of their own environmental monitoring programme, which concluded that the Bradwell programme was consistent with the published technical guidance (Environment Agency, FSA and SEPA, 2010). However, in response to requests from local stakeholders to enhance the environmental monitoring, whilst treatment of Intermediate Level Waste (Fuel Element Debris) was being carried out, the Environment Agency expanded the size of their environmental monitoring programme. These enhancements to the environmental monitoring started at the beginning of 2015 and continued during 2016. This monitoring is only planned to remain in place whilst this waste treatment is being carried out; thereafter it will then revert to the baseline monitoring programme.

The most recent habits survey was undertaken in 2015 (Clyne *et al.*, 2016a).

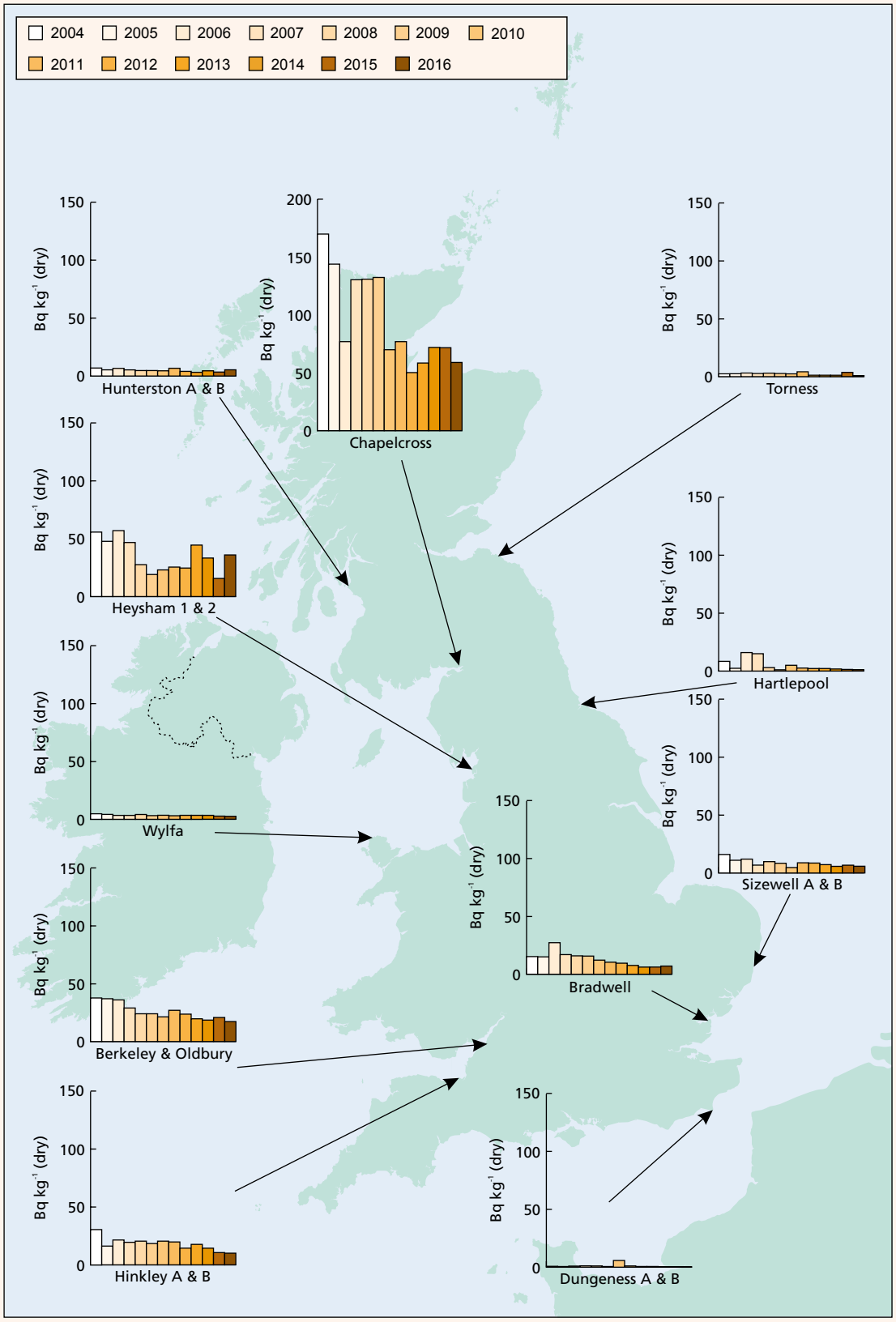



**Figure 4.2.** Caesium-137 concentration in marine sediments near nuclear power stations between 2004-2016

## Doses to the public

The *total dose* from all pathways and sources of radiation was 0.036 mSv in 2016 (Table 4.1), which was less than 4 per cent of the dose limit for members of the public of 1 mSv, and up from 0.017 mSv in 2015. The representative person was prenatal children of local inhabitants (as in 2015). The increase in *total dose* was due to a higher estimate of direct radiation from the site in 2016. The trend in *total dose* over the period 2004 – 2016 is given in Figure 4.1. Any significant variations in *total dose* with time were attributed to changes in the estimate of direct radiation.

The source specific assessments for a high-rate consumer of locally grown foods, and of fish and shellfish give exposures that were less than the *total dose* in 2016 (Table 4.1). The dose to a high-rate consumer of locally grown foods was estimated to be 0.006 mSv. The small increase in dose (from 0.005 mSv in 2015) was due to higher carbon-14 concentrations in milk in 2016. As in 2015, an additional source specific assessment was undertaken in 2016 to determine the external exposure based on the enhanced monitoring. The estimated dose was also less than 0.005 mSv. This estimate is determined as a cautious value (using maximising assumptions for gamma dose rates and occupancy rates) and therefore not included in the *total dose* assessment.

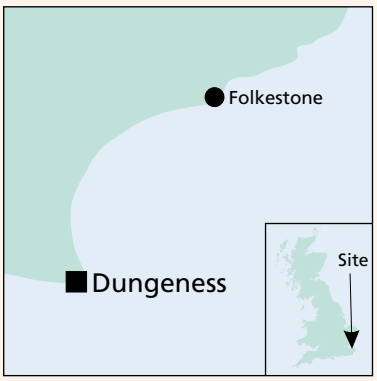
## Gaseous discharges and terrestrial monitoring

This power station is permitted to discharge gaseous wastes to the local environment via stacks to the atmosphere. Discharges of tritium increased in 2016, in comparison to releases in 2015. Terrestrial sampling is similar to that for other power stations including analyses of milk and crop samples for tritium, carbon-14 and sulphur-35. Samples of water are also taken from a coastal ditch. As in 2015, a number of grass samples were also collected and analysed, to enhance the environmental monitoring programme. Data for 2016 are given in Table 4.3(a). Activity concentrations were low in terrestrial samples. Carbon-14 was detected in locally produced milk at concentrations above the expected background concentration and increased by small amounts in comparison to those in 2015. Tritium was positively detected at a very low concentration in one local food sample (cabbage). In grass samples, tritium, carbon-14 and caesium-137 concentrations are all reported as less than values. In 2016, strontium-90 (not analysed in recent years) was detected at a low level in a coastal ditch sample. Surface water (public supply) samples were not taken in 2016. As in previous years, the gross beta activities in water from the coastal ditch continued to be enhanced above background levels, and these were in excess of the WHO screening level for drinking water (1 Bq $l^{-1}$). Tritium concentrations in coastal ditches were similar to those in recent years, with positively detected values substantially below the EU reference level for tritium of 100 Bq $l^{-1}$. The water in the ditches is not known to be used as a source of drinking water.

## Liquid waste discharges and aquatic monitoring

Liquid wastes are discharged into the River Blackwater estuary. Discharges of tritium increased by a small amount in 2016, in comparison to releases in 2015. Aquatic sampling was directed at consumption of locally caught fish and shellfish and external exposure over intertidal sediments. Seaweeds were also analysed as an environmental indicator material. As in 2015, a number of additional sediment and seawater samples were also collected and analysed, and measurement of gamma dose rates, to enhance the environmental monitoring programme at Bradwell. The locations of the enhanced programme in 2016, together with routine annual survey monitoring, are shown in Figure 4.3. Data for 2016 are given in Tables 4.3(a) and (b). Low concentrations of artificial radionuclides were detected in aquatic materials as a result of discharges from the station, discharges from Sellafield and weapons testing. In seawater samples, tritium, caesium-137 and americium-241 concentrations are all reported as less than values. Due to the low concentrations detected, it is generally difficult to attribute the results to a particular source; however, concentrations (including those for the 2016 enhanced sediment monitoring) were generally similar in magnitude to those results reported in recent years. There is an overall decline in caesium-137 concentrations in sediments over the last decade (Figure 4.2), and the activity concentration in 2016 was generally similar to recent years, including the lowest reported value in 2014. The technetium-99 detected in seaweeds at Bradwell was likely to be due to the long distance transfer of Sellafield derived activity. Gamma dose rates on beaches, and those taken for the enhanced monitoring in 2016, were difficult to distinguish from natural background.

## 4.3 Dungeness, Kent




The Dungeness power stations are located on the south Kent coast between Folkestone and Rye. There are two separate A and B nuclear power stations on neighbouring sites; the A station was powered by two Magnox reactors and the B station has two AGRs. Discharges are made via separate and adjacent outfalls and stacks, but for the

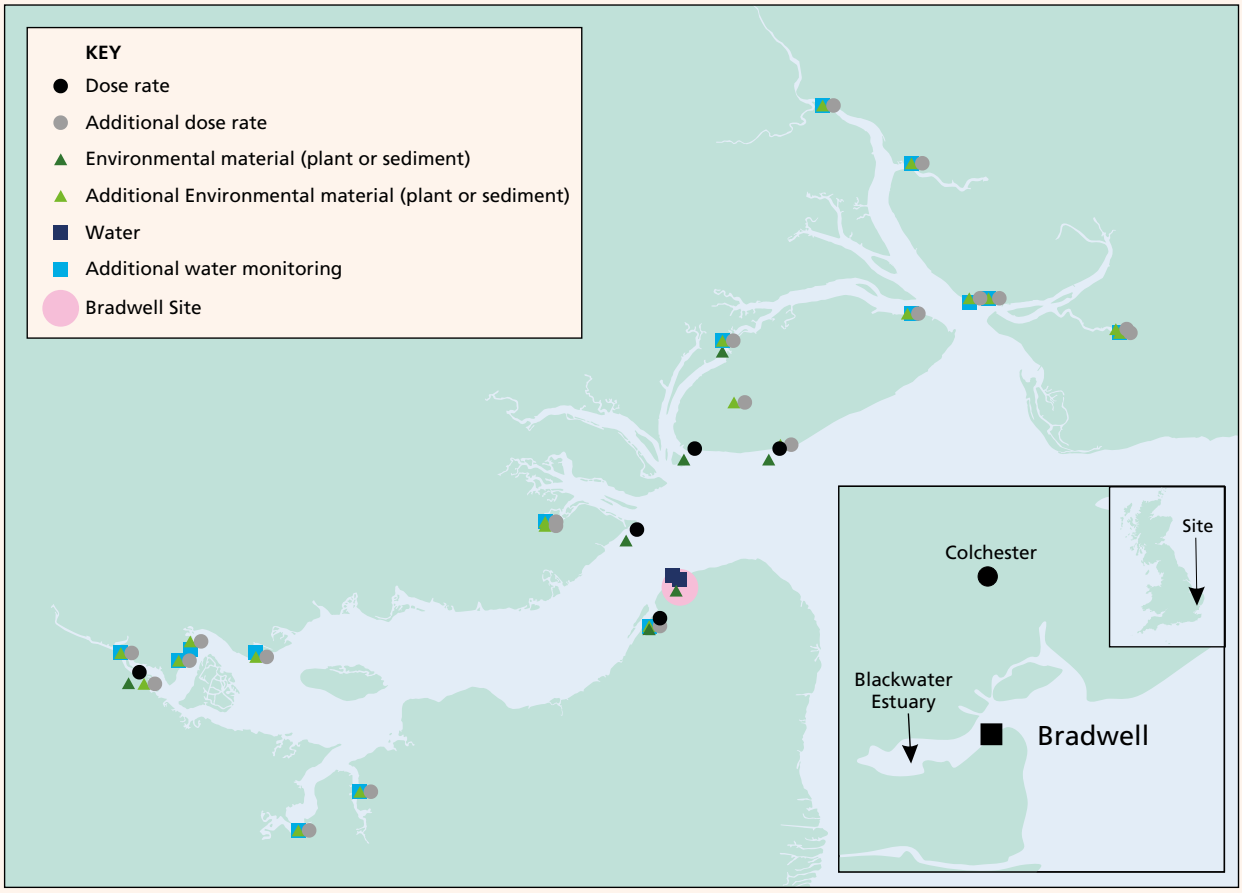



**Figure 4.3.** Aquatic monitoring locations (routine and enhanced) at Bradwell, 2016

purposes of environmental monitoring these are considered together. Dungeness A ceased generating electricity in 2006. De-fuelling of both Magnox reactors was completed in 2012. The Dungeness A site will enter the Care and Maintenance phase by the year 2025. Final site clearance is expected to commence in 2087 and be achieved by 2097 (NDA, 2017). Dungeness B is expected to continue electricity generation until 2028. EDF Energy must continue to demonstrate that the station complies with the Safety Cases which are reviewed by ONR to enable continued operation to 2028. The most recent habits survey was undertaken in 2010 (Clyne *et al.*, 2011b).

## Doses to the public

In 2016, the *total dose* from all pathways and sources of radiation was 0.021 mSv (Table 4.1), or approximately 2 per cent of the dose limit of 1 mSv, and up from 0.014 mSv in 2015. The increase in *total dose* was attributed to a higher estimate of direct radiation from the site in 2016. As in recent years, this is almost entirely due to direct radiation from the site. The representative person was adults living near to the site. The trend in *total dose* over the period 2004 – 2016 is given in Figure 4.1. *Total doses* ranged between 0.014 and 0.63 mSv over the time period and were dominated by direct radiation. Following the shut-down of the Magnox reactors in 2006, this dose has significantly declined.

Source specific assessments for a high-rate consumer of locally grown foodstuffs, for a local bait digger (who consumes large quantities of fish and shellfish and spends long periods of time in the location being assessed), and for a houseboat occupant give exposures that were less than the *total dose* (Table 4.1). The dose to a high-rate consumer of locally grown foods was estimated to be 0.010 mSv. The increase in dose from 0.005 mSv (in 2015) was mostly due to higher carbon-14 concentrations in milk in 2016. The dose to a local bait digger was estimated to be less than 0.005 mSv. The decrease in dose (from 0.006 mSv in 2015) was due to a combination of lower dose rates (at Pilot Sands) and a lower reported less than value for americium-241 in fish, in comparison to those in 2015. The dose to a houseboat dweller from external exposure was 0.009 mSv. The reason for the small increase in dose (from < 0.005 mSv in 2015) was mostly because the gamma dose rate was slightly higher at Rye Bay (over sand and shingle) in 2016.

## Gaseous discharges and terrestrial monitoring

Discharges of sulphur-35 from Dungeness B increased in 2016, in comparison to releases in 2015. The focus of the terrestrial sampling was analyses of tritium, carbon-14 and sulphur-35 in milk and crops. The results of monitoring for 2016 are given in Tables 4.4(a). Activity

concentrations in many terrestrial foods are reported as less than values (or close to the less than value). As in previous years, sulphur-35 was positively detected at a very low concentration in one local food sample (potatoes). Carbon-14 was detected in locally produced milk at concentrations above the expected background concentration and increased by small amounts in comparison to those in 2015. Tritium, gross alpha and gross beta concentrations in freshwater were below the investigation levels for drinking water in the European Directive 2013/51.

## Liquid waste discharges and aquatic monitoring

Discharges of sulphur-35 increased from Dungeness B in 2016, in comparison to releases in 2015. Marine monitoring included gamma dose rate measurements, and analysis of seafood and sediments. The results of monitoring for 2016 are given in Tables 4.4(a) and (b). Caesium-137 concentrations in seafood and marine materials are attributable to discharges from the stations and to weapon test fallout with a long distance contribution from Sellafield and La Hague. Due to the low concentrations detected, it is generally difficult to attribute the results to a particular source. The low concentrations of transuranic nuclides in scallops were typical of levels expected at sites remote from Sellafield. No tritium was detected in seafood in 2016. Caesium-137 concentrations in sediment have remained low over the last decade (Figure 4.2) and reported as less than values in 2016; the apparent increase in 2010 was due to the inclusion of a value (< 5.8 Bq $kg^{-1}$) which was reported as a less than value. Strontium-90 concentrations (not analysed in recent years) in all sediments are all reported as less than values. Gamma dose rates were generally difficult to distinguish from the natural background, although the dose rates decreased by small amounts at Pilot Sands, in comparison to those in 2015.

## 4.4 Hartlepool, County Durham


Hartlepool Power Station is situated on the mouth of the Tees estuary, on the north east coast of England. This station, which is powered by twin AGRs, began operation in 1983. It is estimated that power generation will continue until 2024. The most recent habits survey was undertaken in 2014 (Garrod *et al.*, 2015).

## Doses to the public

The *total dose* from all pathways and sources of radiation was 0.020 mSv in 2016 (Table 4.1), which was 2 per cent of the dose limit, and down from 0.022 mSv in 2015. The small decrease in *total dose* was mostly attributed to lower dose rates over sediment in 2016, in comparison to those in 2015. The representative person was adults spending time living near to the site whose dose was from direct radiation (from the site) and external exposure from activity in sand and sediment on local beaches. The trend in *total dose* over the period 2004 – 2016 is given in Figure 4.1. *Total doses* remained broadly similar from year to year, and were low.

Source specific assessments for both high-rate consumers of locally grown foodstuffs, and of fish and shellfish, give exposures that were less than the *total dose* (Table 4.1). The dose to a local fish and shellfish consumer, including external radiation but excluding naturally occurring radionuclides, was 0.018 mSv. The dose in 2015 was 0.020 mSv, and the reason for the small decrease is because the gamma dose rates were slightly lower over sand in 2016.

Since 2012, a source specific assessment has been undertaken to determine the exposure from naturally occurring radionuclides, as a consequence of the reported polonium-210 concentrations in mollusc samples. As in previous years, winkle samples collected in 2016 for South Gare (inside the Tees Estuary entrance) consisted of a mixture, including some winkles from the estuary entrance near Paddy's Hole. The area in the close proximity to Paddy's Hole was unlikely to sustain a high-rate consumption of winkles, as it is an extremely localised area which contains oil and other wastes. In addition, the most recent habits survey undertaken in 2014 did not identify any consumption of molluscs from Paddy's Hole. However, in the event that some of these molluscs were a constituent of the diet of a high-rate consumer of fish and shellfish, the dose from naturally occurring radionuclides was considered. In 2016, the polonium-210 (and lead-210) concentration was not enhanced above background, and therefore no additional exposure contributed to the dose, in addition to that from artificial radionuclides. This estimate assumes that the median concentrations for naturally occurring radionuclides at background (Appendix 1, Table X4.1) be subtracted from the total concentrations as measured in 2016.

## Gaseous discharges and terrestrial monitoring

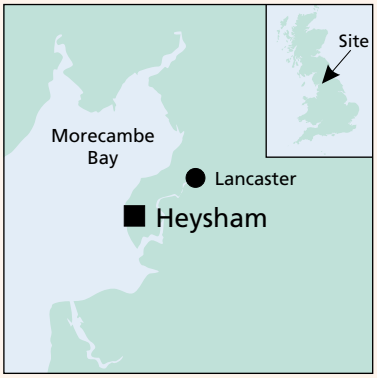
Gaseous radioactive waste is discharged via stacks to the local environment. Analyses of tritium, carbon-14, sulphur-35 and gamma emitters were made in milk and crop samples. Samples of water were also taken from a borehole. Data for 2016 are given in Table 4.5(a). The effects of gaseous disposals from the site were not easily

detectable in foodstuffs, although small enhancements of sulphur-35 concentrations (reported as just above the less than value) were measured one food sample (wheat), whilst the carbon-14 concentration in another sample (potatoes) was enhanced above expected background, in 2016. Carbon-14 was detected in locally produced milk at concentrations close to the expected background value. Tritium, gross alpha and gross beta concentrations in freshwater were below the investigation levels for drinking water in the European Directive 2013/51.

## Liquid waste discharges and aquatic monitoring

Regulated discharges of radioactive liquid effluent are made to Hartlepool Bay with a minor component being discharged directly to the River Tees. Discharges of tritium and sulphur-35 increased in 2016, in comparison to those in 2015. Results of the aquatic monitoring programme conducted in 2016 are shown in Tables 4.5(a) and (b). As in previous years, small enhancements of carbon-14 concentrations, above the expected background, were observed in seafood samples. Enhancements are most likely to be due to carbon-14 discharges from a nearby non-nuclear site since carbon-14 discharges from the power station are low. Technetium-99 analysis in seaweed is used as a specific indication of the far-field effects of disposals to sea from Sellafield. Concentrations in seaweed were low and much less than the peak observed in 1998 (see also Figure 2.9). They are less than 1 per cent of the equivalent concentrations near Sellafield. As in recent years, iodine-131 was positively detected in seaweed samples collected around the mouth of the River Tees Estuary in 2016. The detected values, as in previous years, are believed to originate from the therapeutic use of this radionuclide in a local hospital. Detectable concentrations of radiocaesium and transuranics were mainly due to disposals from Sellafield and to weapon test fallout. However, caesium-137 concentrations in sediment have remained low for a number of years (Figure 4.2). In 2016, the reported polonium-210 and lead-210 concentrations in winkles from South Gare (consisting of a mixture including some winkles collected from the estuary entrance near Paddy's Hole) were values expected due to natural sources. The polonium-210 concentration (7.9 Bq $kg^{-1}$) was lower in comparison to those concentrations in recent years (enhanced above background). Overall, gamma dose rates in 2016 were generally similar over sediment, although the dose rates over sand (Seaton Carew and Carr House) decreased by small amounts, in comparison to those in 2015.

## 4.5 Heysham, Lancashire




Heysham Power Station is situated on the Lancashire coast to the south of Morecambe and near the port of Heysham. This establishment comprises two separate nuclear power stations, both powered by two AGRs. It is estimated that Heysham 1 and 2 will continue to generate electricity until at least 2024 and 2030, respectively. Disposals of radioactive waste from both stations are made under permit via separate outfalls to Morecambe Bay and via stacks, but for the purposes of environmental monitoring both stations are considered together.

In July 2016, a habits survey was conducted to determine the consumption and occupancy rates by members of the public (Garrod *et al*., 2017). Small decreases in the fish, mollusc and crustacean consumption rates have been observed, together with a small increase in the occupancy rate over salt marsh, in comparison with those of the previous survey in 2011. Revised figures for consumption rates, together with occupancy rates, are provided in Appendix 1 (Table X2.2).

## Doses to the public

The *total dose* from all pathways and sources of radiation was 0.019 mSv in 2016 (Table 4.1), or less than 2 per cent of the dose limit for members of the public, and down from 0.023 mSv in 2015. In 2016, the representative person was adults who spent a large amount of time over sediments, and was a change from that in 2015 (adults consuming molluscs). The decrease in *total dose*, and change in the representative person (from 2015), was mostly due to both a reduction of the mollusc consumption rate (from the revised habits) and lower concentrations of plutonium radionuclides and americium-241 in molluscs, in 2016 (in comparison to those in 2015). The trend in *total dose* over the period 2004 – 2016 is given in Figure 4.1. Any changes in *total doses* from 2004 – 2010 were attributable to environmental variability (in measurements of gamma dose rates); thereafter (2011 – 2015) relatively lower *total doses* were estimated due to lower occupancy rates over local beaches.

Source specific assessments for high-rate terrestrial food consumption, and from external exposure for turf cutting over salt marsh, give exposures that were less than the *total dose* (Table 4.1). The estimated doses from terrestrial food consumption, and turf cutting over salt marsh, in 2016 were 0.007 mSv (< 0.005 mSv in 2015)

and 0.010 mSv (0.016 mSv in 2015), respectively. The change in the dose from turf cutting over salt marsh was attributed to a revision of habits information in 2016, using revised locations, differing from the assessment in 2015. The dose to a local fisherman, who was considered to consume a large amount of seafood and was exposed to external radiation over intertidal areas, was 0.024 mSv in 2016, which was approximately 2 per cent of the dose limit for members of the public of 1 mSv (Table 4.1). The dose in 2015 was 0.031 mSv. The decrease in dose in 2016 was due to a combination of reasons; a reduction of the mollusc consumption rate (from the revised habits), lower gamma dose rates, and lower concentrations of plutonium radionuclides and americium-241 in molluscs, in 2016 (in comparison to those in 2015).

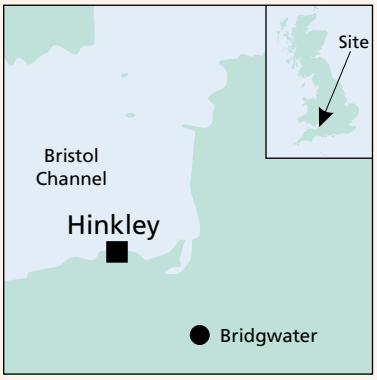
## Gaseous discharges and terrestrial monitoring

In 2016, discharges of carbon-14 and sulphur-35 increased at Heysham 1, and argon-41 decreased at Heysham 2, in comparison to releases in 2015. These increased discharges at Heysham 1 were due to an increase in power generation during 2016 (in comparison to 2015). The monitoring programme for the effects of gaseous disposals was similar to that for other power stations. Data for 2016 are given in Table 4.6(a). The effects of gaseous disposals were generally difficult to detect in 2015. Carbon-14 was detected in locally produced milk at concentrations above the expected background concentration and increased by small amounts in comparison to those in 2015. Iodine-129 was positively detected in seaweed (reported as just above the less than value) in 2016. As in 2015 (but unlike in previous years), the maximum caesium-137 concentration in milk was positively detected in 2016. Small enhancements of concentrations of sulphur-35 were measured in one food sample (reported as just above the less than value) and grass, but activities of cobalt-60 were all reported as less than values.

## Liquid waste discharges and aquatic monitoring

In 2016, discharges of tritium, sulphur-35 and "other radionuclides" increased from Heysham 1 and "other radionuclides" increased from Heysham 2, in comparison to releases in 2015. These increased discharges at Heysham 1 were due to an increase in power generation during 2016 (in comparison to 2015). The monitoring programme for the effects of liquid disposals included sampling of fish, shellfish, sediment, seawater and measurements of gamma dose rates and for completeness the data considered in this section include all of those for Morecambe Bay. A substantial part of the programme is in place in order to monitor the effects of Sellafield disposals. The results for 2016 are given in Tables 4.6(a) and (b). In general, similar levels to those for 2015 were observed and the effect of liquid disposals from Heysham was difficult to detect above the Sellafield background. Concentrations of tritium in flounder, shrimps and mussels were not sufficiently high to demonstrate that any originated as a result of discharges from Heysham. Plutonium radionuclides and americium-241 concentrations in winkles were slightly lower in 2016 (in comparison to those in 2015). Concentrations of technetium-99 in marine samples remained at levels typical of recent years, caused by discharges from Sellafield. In 2016, strontium-90 concentrations were detected at low levels (reported as close to, or just above, the less than value) in food samples. Gamma dose rates over intertidal sediment in 2016 were slightly lower in comparison to those in 2015.

## 4.6 Hinkley Point, Somerset




The Hinkley Point Power Station sites are situated on the Somerset coast, west of the River Parrett estuary. There are two separate A and B stations that include two Magnox reactors and two AGRs, respectively. Hinkley Point A started electricity generation in 1965 and ceased in 2000. This station completed de-fuelling in 2004 and is undergoing decommissioning. The Hinkley Point A site will enter the Care and Maintenance phase by the year 2027. Final site clearance is expected to commence in 2081 and be achieved by 2090 (NDA, 2017). It is estimated that power generation will continue at Hinkley Point B until at least 2023. A single environmental monitoring programme covers the effects of the two power stations.

In 2013, the Environment Agency issued three environmental permits for the new nuclear power station at Hinkley Point C covering (i) disposal and discharge of radioactive wastes, (ii) operation of standby power supply systems using diesel generators and (iii) discharge cooling water and liquid effluents into the Bristol Channel. Also in 2013, the Secretary of State for Energy and Climate Change (now part of BEIS) granted a planning consent order to EDF Energy to build and operate Hinkley Point C and associated development. The decision follows the submission of EDF Energy's application to the Infrastructure Planning Commission (now the Planning Inspectorate) in 2011. More information can be found at: **www.environment-agency.gov.uk/hinkleypoint**.

In 2014, ONR published its assessment of a Pre-Construction Safety Report submitted by NNB GenCo Limited for the Hinkley Point C licensed site: **www.onr.org.uk/hinkley-point-c/assessment-reports.htm#preconstruction**.

In July 2016, EDF's Board of Directors made the final investment decision to build two reactors at Hinkley Point C. Thereafter in September 2016, following a review of the Hinkley Point C project, the UK Government announced its decision to proceed with the first new nuclear power station for a generation. Final contracts signed for Hinkley Point C were signed by EDF, the UK Government and China General Nuclear (CGN) in late September 2016. In March 2017, ONR granted its first consent for the start of construction of a twin EPR nuclear power station at Hinkley Point C. The consent covers the placement of the structural concrete for the first nuclear safety-related structure, the 'technical galleries' at the Hinkley Point C site. The technical galleries are a series of underground reinforced concrete structures to be located beneath the site and some above-ground structures, connecting services such as cooling water and electricity.

The most recent habits survey was conducted in 2010 (Clyne *et al.*, 2011a).

## Doses to the public

In 2016, the *total dose* from all pathways and sources of radiation was 0.013 mSv (Table 4.1), or approximately 1 per cent of the dose limit, and down from 0.016 mSv in 2015. The representative person was adults who spent a large amount of time over sediments was the representative person. The apparent decrease in *total dose* was mostly because gamma dose rates were measured on different ground types (at Stolford) from one year to the next. The trend in *total dose* over the period 2004 – 2016 is given in Figure 4.1. The decrease in *total dose* in 2011 (and continued thereafter) was attributed to relatively lower gamma dose rates over local beaches.

A source specific assessment for a high-rate consumer of locally grown food gives an exposure that was less than the *total dose* (Table 4.1). The dose to this consumer was 0.011 mSv in 2016. The increase in dose (from < 0.005 mSv in 2015) was mostly due to as mostly due to higher carbon-14 concentrations in milk in 2016. The dose to a local fisherman, who consumed a large amount of seafood and was exposed to external radiation over intertidal areas, was 0.018 mSv in 2016, which was less than 2 per cent of the dose limit for members of the public of 1 mSv. The reason for the apparent decrease in dose (from 0.023 mSv in 2015) is the same as that contributing to the maximum *total dose*. This dose estimate also includes the effects of discharges (historical) of tritium and carbon-14 from the GE Healthcare Limited plant at Cardiff and uses an increased tritium dose coefficient (see Appendix 1).

## Gaseous discharges and terrestrial monitoring

Gaseous radioactive waste is discharged via separate stacks to the local environment. Analyses of milk and crops were undertaken to measure activity concentrations of tritium, carbon-14, sulphur-35 and gamma emitters. Local reservoir water samples were also taken and analysed. Data for 2016 are given in Table 4.7(a). Activity concentrations of tritium and gamma emitters (including caesium-137) in terrestrial materials are reported as less than values. Sulphur-35 from Hinkley Point B was detected at low concentrations in some of the food samples (excluding milk). Carbon-14 was detected in locally produced milk at concentrations above the expected background concentration and increased by small amounts in comparison to those in 2015. Carbon-14 was also detected in blackberries (not collected in 2015) above the expected background value in 2016. Tritium, gross alpha and gross beta concentrations in reservoir water were below the investigation levels for drinking water in the European Directive 2013/51.

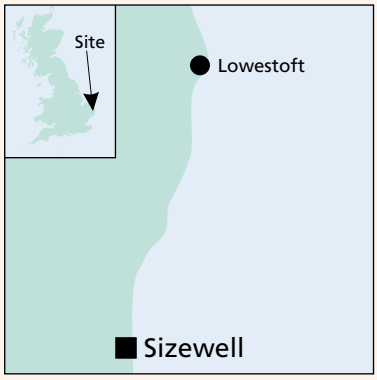
## Liquid waste discharges and aquatic monitoring

Regulated discharges of radioactive liquid effluent from both power stations are made via separate outfalls into the Bristol Channel. Discharges of "other radionuclides" decreased from Hinkley Point A in 2016, in comparison to releases in 2015. Analyses of seafood and marine indicator materials and measurements of external radiation were conducted over intertidal areas. Measurements of tritium and carbon-14 are made primarily to establish the local effects of historical discharges from the GE Healthcare Limited plant at Cardiff.

The environmental results for 2016 are given in Tables 4.7 (a) and (b). Activity concentrations observed in seafood and other materials from the Bristol Channel were generally similar to those in recent years. In 2016, tritium concentrations in fish and shellfish were lower, in comparison to recent years, mostly reported as less than values. Concentrations of other radionuclides in the aquatic environment represent the combined effect of releases from these stations, plus other establishments that discharge into the Bristol Channel. Other contributors to the aquatic environment are Sellafield, weapons testing and Chernobyl fallout. Due to the low concentrations detected, it is generally difficult to attribute the results to a particular source. The concentrations of transuranic nuclides in seafoods were of negligible radiological significance. There is now limited evidence to suggest that caesium-137 concentrations in sediment have been generally decreasing over the most recent years (Figure 4.2). Overall, gamma dose rates over intertidal sediment in 2016 were generally similar (where comparisons can be made) in comparison to those in 2015.

In 2016, the Environment Agency carried out additional environmental sampling and analyses (including particle size analysis) of sediments from the River Parrett, in response to concerns raised by the Stop Hinkley Group. Their main concern was that radioactivity discharged from Hinkley Point was accumulating and concentrating in fine sediments in the inter-tidal zone of the River Parrett, particularly near Bridgwater. A total of 5 locations were chosen, and sampling was undertaken in March and August 2016. The results showed lower activity concentrations of both naturally occurring (potassium-40) and man-made radioactivity (caesium-137) further upstream in the River Parrett. This is reflective of the larger average particle size and decreasing influence of finer marine sediments with increasing distance from the mouth of the river. The additional sampling results were also consistent with existing data derived from the routine monitoring programme at Hinkley Point.

## 4.7 Sizewell, Suffolk




The two Sizewell Power Stations are located on the Suffolk coast, near Leiston. Sizewell A is a Magnox twin reactor site. Sizewell B, powered by one reactor, is the only commercial PWR power station in the UK. The B station began operation in 1995 and it is estimated that it will end power generation by 2035. Sizewell A power station ceased electricity generation in 2006. De-fuelling commenced in 2007 and was completed in 2014. The Sizewell A site will enter the Care and Maintenance phase by the year 2027. Final site clearance is expected to commence in 2088 and be achieved by 2097 (NDA, 2017). The most recent habits survey was conducted in 2015 (Garrod *et al*., 2016).

### Doses to the public

The *total dose* from all pathways and sources was 0.021 mSv in 2016 (Table 4.1) or approximately 2 per cent of the dose limit, and unchanged from 2015. As in recent years, the dominant contribution to *total dose* was from direct radiation and the representative person was adults living in the vicinity of the site. Dose from this pathway has reduced by a factor of three since Sizewell A ceased generation in 2006. The trend in *total dose* over the period 2004 – 2016 is given in Figure 4.1. The *total dose* declined at the end of 2006, following the closure of the Magnox reactors at Sizewell A, thereafter any variations were due to the change in the contribution from direct radiation from the site.

Source specific assessments for both a high-rate consumer of locally grown foodstuffs, and of fish and shellfish, and of external exposure for houseboat occupancy, give exposures that were less than the *total dose* in 2016 (Table 4.1). The dose to a consumer of locally grown foods was 0.006 mSv. The increase in dose from less than 0.005 mSv (in 2015) was mostly due to higher carbon-14 concentrations in milk in 2016.

### Gaseous discharges and terrestrial monitoring

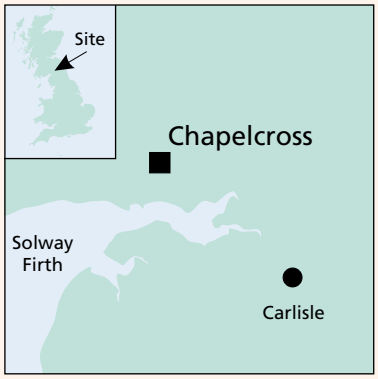
Gaseous wastes are discharged via separate stacks to the local environment. Gaseous discharges of carbon-14 decreased by a small amount from Sizewell A in 2016, in comparison to those in 2015. The results of the terrestrial monitoring in 2016 are shown in Table 4.8 (a). Gamma-ray spectrometry and analysis of tritium, carbon-14 and sulphur-35 in milk and crops generally showed very low concentrations of artificial radionuclides near the power stations in 2016. Carbon-14 was detected in locally produced milk at concentrations above the expected background concentration and increased by small amounts in comparison to those in 2015. Sulphur-35 was positively detected at a very low concentration in one food sample (wheat) in 2016. Tritium concentrations in local freshwater were all low, including those measured at the Leisure Park (positively detected in previous years). Tritium, gross alpha and gross beta concentrations in surface water were below the investigation levels for drinking water in the European Directive 2013/51.

### Liquid waste discharges and aquatic monitoring

Regulated discharges of radioactive liquid effluent are made via outfalls to the North Sea. Discharges of "other radionuclides" increased by a small amount from Sizewell A in 2016, in comparison to those in 2015. In the aquatic programme, analysis of seafood, sediment, and seawater, and measurements of gamma dose rates were conducted in intertidal areas. Data for 2016 are given in Tables 4.8(a) and (b). Concentrations of artificial radionuclides were low and mainly due to the distant effects of Sellafield discharges and to weapons testing. Tritium concentrations in seafood are all reported as less than values. Caesium-137 concentrations in sediment have remained low over the last decade (Figure 4.2). Overall, gamma radiation dose rates over intertidal areas were difficult to distinguish from the natural background, although the dose rates at Southwold Harbour decreased in comparison to those in 2015 (most likely due to natural variation).

## SCOTLAND

## 4.8 Chapelcross, Dumfries and Galloway




Chapelcross was Scotland's first commercial nuclear power station and has four Magnox reactors located near the town of Annan in Dumfries and Galloway. After 45 years of continuous operation, electricity generation ceased in 2004 and the station has been undergoing decommissioning. De-fuelling of the reactors began in 2008 and was completed during 2013. The major hazards remaining on the site will now be addressed early during decommissioning. The site will enter the Care and Maintenance phase by the year 2028. The current plan is for the site to be de-licensed (released from regulatory control). Final site clearance is expected to commence in 2085 and be achieved by 2095 (NDA, 2017).

Habits surveys have been undertaken to investigate aquatic and terrestrial exposure pathways. The most recent habits survey for Chapelcross was conducted in 2015 (Tyler *et al.*, 2017). In 2012, a habits survey was also conducted to determine the consumption and occupancy rates by members of the public on the Dumfries and Galloway coast (Garrod *et al.*, 2013a). The results of this survey are used to determine the potential exposure pathways relating to permitted liquid discharges from the Sellafield nuclear licensed site in Cumbria (see Section 2.3.1).

### Doses to the public

The *total dose* from all pathways and sources of radiation is assessed to have been 0.026 mSv in 2016 (Table 4.1), which was less than 3 per cent of the dose limit, and up from 0.022 mSv in 2015. In 2016 (as in 2015), the representative person was infants consuming milk at high-rates. The increase in *total dose* (from 2015) was mostly due to a higher maximum carbon-14 concentration in milk in 2016. The trend in *total dose* over the period 2004 – 2016 is given in Figure 4.1. *Total doses* remained broadly similar from year to year, and were low.

Source specific assessments for a high-rate consumer of locally grown food, for a seafood (crustaceans) consumer and for a salmon and wildfowl consumer, give exposures that were less than the *total dose* in 2016 (Table 4.1). The dose for the terrestrial food consumer was estimated to be 0.018 mSv in 2016. The reason for the small increase in dose (from 0.017 mSv in 2015) is the same as that contributing to the maximum *total dose*. The dose for the salmon, mollusc and wildfowl consumer was 0.009 mSv in 2016, and unchanged from 2015.

A consideration of the discharges from Chapelcross indicates that they contribute a very small fraction of the dose to the local population from seafood consumption and occupancy over salt marsh; the greater proportion of the dose can be attributed to the discharges from Sellafield.

### Gaseous discharges and terrestrial monitoring

Gaseous radioactive waste is discharged via stacks to the local environment. Terrestrial monitoring consisted of the analysis of a variety of foods, including milk, fruit, crops and game, as well as grass, soil and freshwater samples, for a range of radionuclides. Air samples at three locations were also monitored to investigate the inhalation pathway.

The results of terrestrial food and air monitoring in 2016 are given in Tables 4.9(a) and (c). The activity concentrations of radionuclides in milk and grass were generally similar to those observed in previous years. However, the maximum carbon-14 concentration in milk was slightly higher than default values used to represent background levels in 2016. Sulphur-35 and americium-241 concentrations in all terrestrial food samples are reported as less than values. In previous years, the tritium results in terrestrial samples have shown the effects of discharges from Chapelcross. In 2016 (and 2015), tritium concentrations over the range of food samples are all reported as less than values, whilst most other samples are reported as just above or as less than values. As in recent years, the level of tritium was measured above the detection limit in one freshwater sample (Gullielands Burn). Activity concentrations in air samples at locations near to the site are reported as less than values (Table 4.9(c)). Solid waste transfers in 2016 are also given in Appendix 2 (Table A2.4).

### Liquid waste discharges and aquatic monitoring

Radioactive liquid effluents are discharged to the Solway Firth. Samples of seawater and *Fucus vesiculosus*, as environmental indicators, were collected in addition to seafood, sediments and dose rates. Data for 2016 are given in Tables 4.9(a) and (b). Concentrations of artificial radionuclides in marine materials in the Chapelcross vicinity are mostly due to the effects of Sellafield discharges and are consistent with values expected at this distance from Sellafield. Concentrations of most radionuclides remained at similar levels to those detected in recent years. Low concentrations of cobalt-60, europium-154 and europium-155 were positively detected (reported as just above the less than value) in sediment samples. As

in previous years, concentrations of caesium-137 and plutonium radionuclides were enhanced in sediment samples taken close to the pipeline in 2016. Technetium-99 concentrations in seaweed were higher, by small amounts, in comparison to those in 2015, whilst concentrations in fish (flounder) are reported as less than values in 2016. Concentrations of caesium-137 in sediments, largely due to Sellafield, are generally in decline over the last decade (Figure 4.2). In 2016, gamma dose rates (where comparisons can be made) were generally similar to those in 2015; albeit with minor variations. Measurements of the contact beta dose rate on stake nets are reported as less than values in 2016.

Between 1992 and 2009, a number of particles were found at the end of the discharge outfall consisting of lime-scale originating from deposits within the pipeline. Magnox Limited continues to monitor this area frequently and no particles were found during 2016 (as for the interim years). The relining of the pipeline and grouting at strategic points, which was undertaken in 2009/2010, has reduced the potential for particles to be released.

## 4.9 Hunterston, North Ayrshire


Hunterston Power Station is located on the Ayrshire coast near West Kilbride. At this location, there are two separate nuclear power stations - Hunterston A and Hunterston B.

Hunterston A was powered by twin Magnox reactors until it ceased electricity production in 1990 and is now being decommissioned by Magnox Limited. De-fuelling was completed in 1995. Decommissioning activities continue to focus on two key areas, these are: the ongoing draining and cleaning of the cartridge (nuclear fuel) cooling pond; and making progress towards ensuring that all higher activity waste is stored in a passively safe manner. The site will enter the Care and Maintenance phase between 2022 and 2023. Current plans are for the Hunterston A site to be de-licensed (released from regulatory control) with final site clearance to commence in 2071 and be achieved by 2080 (NDA, 2017).

The majority of the radioactivity in liquid effluent discharged from the Hunterston A site over the last few years has arisen from the cartridge cooling pond. The draining of the cartridge cooling pond is now largely complete. Key remaining tasks are to transfer and safely package radioactive sludges from the pond floor and to remove the surface layer of concrete from the pond floors.

Whilst discharges of effluent from the cooling pond are coming to an end there was an increase in the amount of radioactivity discharged in 2016, compared to 2015. This increase is related to the management of water from the radioactive sludges.

In terms of safe management of legacy higher activity waste, Magnox Limited are in the process of constructing and commissioning two new facilities at Hunterston A; the solid intermediate level waste encapsulation plant (SILWE) and the wet intermediate level waste recovery and encapsulation plant (WILREP). The legacy higher activity waste, which is present at the Hunterston A site, will be processed through these facilities and made passively safe by encapsulating it in a grout mixture. The encapsulated waste will then be transferred to the Intermediate Level Radioactive Waste Store (ILWS) for storage. WILWREP underwent active commissioning in early 2017 and the first encapsulated packages of waste have been sent to the ILWS.

Hunterston B is powered by a pair of AGRs. Due to issues with the boiler tubes a number of years ago, the station is limited to approximately 80 per cent of its design output. The life of the station has been extended twice, and the current end of generation is set for 2023.

In late 2013, EDF Energy applied to SEPA to vary Hunterston B's authorisation in order to allow more flexibility in the disposal by transfer to another person of its radioactive waste. SEPA determined the application and issued a Notice of Variation in May 2016. The variation does not include any changes to the station's authorised limits for discharges to the environment.

Environmental monitoring in the area considers the effects of both Hunterston A and Hunterston B sites together. The most recent habits survey was undertaken in 2012, to determine the consumption and occupancy rates by members of the public (Rumney *et al.*, 2013).

### Doses to the public

The *total dose* from all pathways and sources of radiation is assessed to have been 0.021 mSv in 2016 (Table 4.1), which was approximately 2 per cent of the dose limit, and down from 0.025 mSv in 2015. The representative person was prenatal children exposed to direct radiation in 2016 (as opposed to infants (1 year-old) consuming milk in 2015). The apparent decrease in *total dose* in 2016, and change in the representative person, (from 2015) was due to the exclusion of americium-241 concentrations in food in the 2016 assessment. In line with the rules on use of the results for dose calculations, americium-241 was included in the 2015 assessment because detectable activity was observed in other terrestrial samples (soil and grass). The trend in *total dose* over the period 2004 – 2016 is given in Figure 4.1. The decrease in *total dose* in recent

years reflected a downward trend in the reported direct radiation.

Source specific assessments for both a high-rate consumer of locally grown food, and of local seafood, give exposures that were less than the *total dose* in 2016 (Table 4.1). The estimated dose to a terrestrial food consumer was 0.010 mSv in 2016 which was 1 per cent of the dose limit for members of the public of 1 mSv. The reason for the apparent decrease in dose from 0.019 mSv (in 2015) was the same as that contributing to the maximum *total dose*. The dose to a fish and shellfish consumer was 0.006 mSv. The reason for the small increase in dose (from < 0.005 mSv in 2015) was because the gamma dose rates were slightly higher over sand in 2016.

## Gaseous discharges and terrestrial monitoring

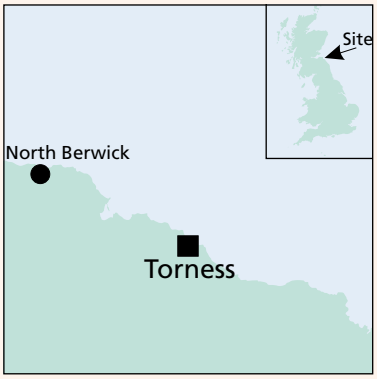
Gaseous discharges are made via separate discharge points from the Hunterston A and Hunterston B stations. Discharges of "all other radionuclides" increased from Hunterston A in 2016, in comparison to those releases in 2015. There is a substantial terrestrial monitoring programme which includes the analyses of a comprehensive range of wild and locally produced foods. In addition, air, freshwater, grass and soil are sampled to provide background information. The results of terrestrial food and air monitoring in 2016 are given in Tables 4.10(a) and (c). The concentrations of radionuclides in air, milk, crops and fruit were generally low and similar to those in previous years (where comparisons can be made). In 2016, amercium-241 concentrations in all samples are all reported as less than values. The caesium-137 concentration in honey was positively detected (close to the less than value), whilst sulphur-35 was detected at very low concentrations in food samples (lamb and wild blackberries), in 2016. As in previous years, some carbon-14 concentrations in foodstuffs were higher than the default values used to represent background levels (including milk, honey, vegetables and domestic/wild fruit). Activity concentrations in air at locations near to the site are reported as less than values (Table 4.10(c)). Solid waste transfers in 2016 are also given in Appendix 2 (Table A2.4).

## Liquid waste discharges and aquatic monitoring

Authorised liquid discharges from both Hunterston stations are made to the Firth of Clyde via the Hunterston B station's cooling water outfall. Discharges of alpha and plutonium-241 increased from Hunterston A in 2016, in comparison to those releases in 2015. The main part of the aquatic monitoring programme consists of sampling of fish and shellfish and the measurement of gamma and beta dose rates on the foreshore. Samples of sediment, seawater and seaweed are analysed as environmental indicator materials.

The results of aquatic monitoring in 2016 are shown in Tables 4.10(a) and (b). The concentrations of artificial radionuclides in the marine environment are predominantly due to Sellafield discharges, the general values being consistent with those to be expected at this distance from Sellafield. The reported concentrations of technetium-99 from Sellafield in crabs and lobsters around Hunterston continued to remain low in 2016 and were generally similar to those reported in previous years. Small concentrations (above the less than value) of activation products (manganese-54 and cobalt-60) were also detected in seaweed and in sediment (cobalt-60), which were likely to have originated from the site, but these were of negligible radiological significance. Generally, gamma dose rates in 2016 were slightly higher over sand in comparison to those in 2015. Measurements of the beta dose rates over sand are reported as less than values in 2016. Caesium-137 concentrations in sediment have remained low over the last decade (Figure 4.2).

## 4.10 Torness, East Lothian




Torness Power Station is located near Dunbar on the east coast of Scotland. This station, which is powered by two AGRs, began operation at the end of 1987 and it is currently scheduled to cease generation in 2030 (extended from 2023).

In late 2013, EDF Energy applied to SEPA to vary the authorisation for Torness in order to allow radioactive waste to be disposed of by transfer to any waste permitted person, both within the UK and overseas, and to be able to accept radioactive waste from other EDF Energy stations for the purposes of bulking up low volume wastes before final disposal. SEPA determined the application and issued a Notice of Variation in May 2016. The variation does not include any changes to the station's authorised limits for discharges to the environment.

EDF Energy is continuing with its programme to reduce carbon deposition within the reactor and has continued to inject carbonyl sulphide (COS) into both reactors during 2016. This process was started in 2011 and after the initial expected increase in sulphur-35 levels discharged to the local environment, via the liquid and gaseous routes, the levels have stabilised. In 2016, discharges of sulphur-35 to the local environment were similar to those in recent years and remained within the authorised limits. The gaseous and liquid discharges from the site are given in Appendix 2.

In October 2016, the EC conducted a verification visit of the environmental monitoring arrangements at Torness, under Article 35 of the Euratom Treaty. The verification team examined EDF's arrangements for on-site monitoring of liquid and gaseous discharges and environmental monitoring in the local area. SEPA's arrangements were also examined for environmental monitoring. The formal report is not expected until after the publication of this report; however, the initial feedback from the Commission was positive and indicated that the UK was fulfilling its monitoring obligations under Article 35 of the Euratom Treaty.

During the summer of 2016, a habits survey was conducted to determine the consumption and occupancy rates by members of the public (SEPA, in press/a). Large increases in all consumption rates (fish, crustacean and mollusc) have been observed, together with an increase in the occupancy rates over sand and mud, in comparison with those of the previous survey in 2011. Revised figures for consumption rates, together with occupancy rates, are provided in Appendix 1 (Table X2.2).

## Doses to the public

In 2016, the *total dose* from all pathways and sources of radiation was 0.021 mSv (Table 4.1) or approximately 2 per cent of the dose limit, and similar to the value of 0.020 mSv in 2015. Direct radiation was the dominant contributor to the dose. The representative person was prenatal children of local inhabitants and a change from that in 2015 (adults living near the site). The trend in *total dose* over the period 2004 – 2016 is given in Figure 4.1. *Total doses* remained broadly similar from year to year, and were low.

Source specific assessments for both a high-rate consumer of locally grown foods and of local fish and shellfish give exposures that were less than the *total dose* in 2016 (Table 4.1). The estimated dose to a terrestrial food consumer was 0.008 mSv in 2016, which was less than 1 per cent of the dose limit for members of the public of 1 mSv. The small increase in dose (from 0.006 mSv in 2015) was mostly due to higher carbon-14 concentrations in milk in 2016. The dose to a fish and shellfish consumer was less than 0.005 mSv in 2016.

## Gaseous discharges and terrestrial monitoring

A variety of foods, including milk, crops, fruit, and game as well as grass, soil and freshwater samples, were measured for a range of radionuclides. Air sampling at three locations was undertaken to investigate the inhalation pathway. The results of terrestrial food and air monitoring in 2016 are given in Tables 4.11(a) and (c). Activity concentrations in many terrestrial foods are reported as less than values (or close to the less than value). Carbon-14 concentrations in milk increased by small amounts in comparison to those in 2015. The effects of discharges from the power station were not observed for concentrations of sulphur-35 in terrestrial foods (which are reported as less than values); concentrations in environmental indicator materials were very low. Americium-241 concentrations, measured by gamma–ray spectrometry, are also reported as less than values. In 2016, tritium concentrations in local grass, soil and freshwater were all low (mostly reported as less than values), although one water sample at Hopes Reservoir was positively detected and reported as just above the less than value. Measured concentrations of radioactivity in air at locations near to the site are mostly reported as less than values (Table 4.11(c)). Cobalt-60 was detected at a very low concentration (reported as just above the less than value) in one air sample (Innerwick) in 2016. Solid waste transfers in 2016 are also given in Appendix 2 (Table A2.4).

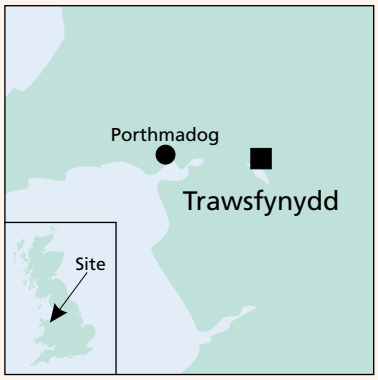
## Liquid waste discharges and aquatic monitoring

Authorised liquid radioactive wastes are made to the Firth of Forth. Seawater, sediment, seafood and seaweed (*Fucus vesiculosus*) samples were collected. Measurements were also made of gamma dose rates over intertidal areas, supported by analyses of sediment, and beta dose rates on fishing gear.

The results of the aquatic monitoring in 2016 are shown in Tables 4.11(a) and (b). Concentrations of artificial radionuclides were mainly due to the distant effects of Sellafield discharges and to weapon testing and Chernobyl fallout. In 2016, the americium-241 concentrations in *Nephrops* (from Dunbar Bay) were similar to those in 2015 (although elevated in 2014). As in recent years, a few very low concentrations of activation products were detected in environmental indicator samples. These were likely to have originated from the station. Technetium-99 concentrations in marine samples were similar to those in 2015. Overall, caesium-137 concentrations in sediments have remained low over the last decade (Figure 4.2). Gamma dose rates over intertidal areas were generally indistinguishable from natural background and were similar to those measured in recent years. Measurements of the contact beta dose rate on fishermen's pots are reported as less than values in 2016.

## WALES

## 4.11 Trawsfynydd, Gwynedd




Trawsfynydd Power Station is located inland, on the northern bank of a lake in the heart of Snowdonia National Park, North Wales and was powered by twin Magnox reactors. Trawsfynydd ceased to generate electricity in 1991. De-fuelling of the reactors was completed in 1995 and the station is being decommissioned. The focus for the site is now the completion of decommissioning projects. The Trawsfynydd site continues to prepare for entry into the Care and Maintenance phase. Final site clearance is expected to commence in 2074 and be achieved by 2083 (NDA, 2017). The most recent habits survey was undertaken in 2005 (Tipple *et al.,* 2006).

### Doses to the public

The *total dose* from all pathways and sources of radiation was 0.019 mSv in 2016 (Table 4.1), which was less than 2 per cent of the dose limit, and up from 0.014 mSv in 2015. The representative person in 2016 (as in 2015) was an infant (1 year-old) living near to the site, whose dose was from the consumption of milk at high-rates and direct radiation (from the site). The increase in *total dose* was attributed to a higher reported less than value for the americium-241 concentration in milk in 2016 (in comparison to that in 2015). The trend in *total dose* over the period 2004 – 2016 is given in Figure 4.1. *Total doses* remained broadly similar from year to year, and were low.

A source specific assessment for an angler (who consumes large quantities of fish and spends long periods of time in the location being assessed) gives an exposure that was less than the *total dose* in 2016 (Table 4.1). The dose to an angler was less than 0.005 mSv in 2016; the change in dose from 0.007 mSv (in 2015) was due to the contribution of brown trout (from caesium-137) not being included in the assessment in 2016. The observed activity concentrations in lake sediments are used as the basis for external radiation calculations in view of the difficulty in establishing the increase in measured dose rates above natural background levels. The dose to infants (1 year-old) consuming terrestrial food was 0.025 mSv, or approximately 2 per cent of the dose limit. The dose in 2015 was 0.016 mSv, and the reason for the increase in 2016 is the same as that contributing to the maximum *total dose*.

### Gaseous discharges and terrestrial monitoring

The results of the terrestrial programme, for local milk, fruit and grass samples in 2016, are shown in Table 4.12(a). Results from surveys, for activity concentrations in sheep samples, are available in earlier RIFE reports (e.g. Environment Agency, FSA, NIEA, NRW and SEPA, 2014). Concentrations of activity in all terrestrial samples were low. Carbon-14 concentrations in foodstuffs (milk) were higher than the default values used to represent background levels. As in previous years, measured activities for caesium-137 are reported as less than values (or close to the less than value). The most likely source of small amounts of caesium-137 is fallout from Chernobyl and weapon tests, though it is conceivable that a small contribution may be made by re-suspension of lake activity. In recognition of this potential mechanism, monitoring of transuranic radionuclides was also conducted in a food sample (and in animal samples in previous years). In 2016, detected activities in potatoes were low and generally similar to observations in other areas of England and Wales, where activity was attributable to weapon test fallout. There was no evidence of re-suspension of activity in sediment from the lake shore contributing to increased exposure from transuranic radionuclides in 2016.

### Liquid waste discharges and aquatic monitoring

Discharges of liquid radioactive waste are made to a freshwater lake making the power station unique in UK terms. The aquatic monitoring programme was directed at consumers of freshwater fish caught in the lake and external exposure over the lake shoreline; the important radionuclides are radiocaesium and, to a lesser extent, strontium-90. Freshwater and sediment samples are also analysed. Habits surveys have established that the species of fish regularly consumed are brown and rainbow trout. Most brown trout are indigenous to the lake but rainbow trout are introduced from a hatchery. Because of the limited period that they spend in the lake, introduced fish generally exhibit lower radiocaesium concentrations than indigenous fish.

Data for 2016 are given in Tables 4.12(a) and (b). The majority of activity concentrations in fish and sediments result from historical discharges. The concentration of caesium-137 in fish (brown trout) was the lowest reported value in 2015; a brown trout sample was not collected in 2016. Caesium-137 concentrations in rainbow trout and water samples are reported as less than values in 2016. Concentrations in the water column are predominantly maintained by processes that release activity (such as remobilisation) from near surface sediments. Low concentrations of other radionuclides including transuranics were also detected, particularly in lake sediments; in previous years' monitoring, it has been demonstrated that these concentrations increase with

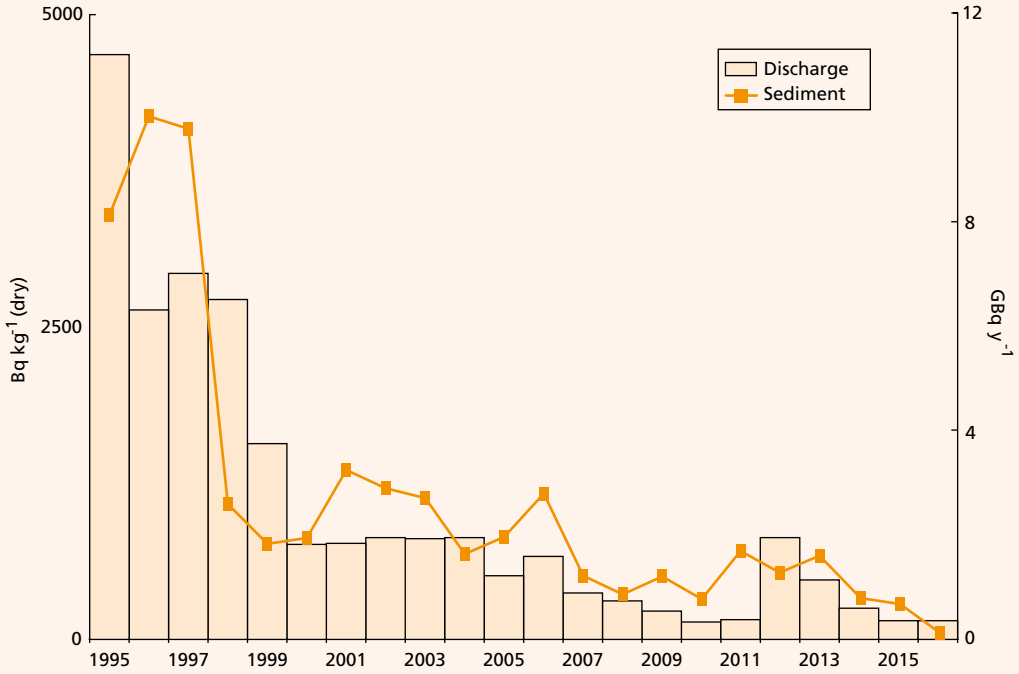
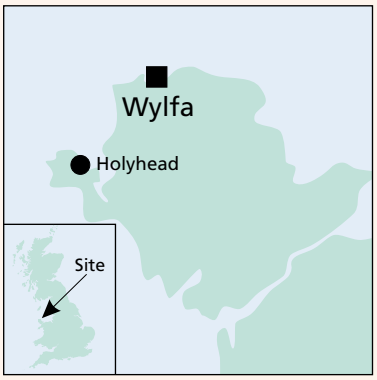



**Figure 4.4.** Caesium-137 liquid discharge from Trawsfynydd and concentration in sediment in Trawsfynydd lake, 1995-2016

depth beneath the sediment surface. Overall, caesium-137 concentrations in the lake sediments were decreased (where comparisons can be made), in comparison to those in 2015 (although no sediment sample was collected from the fish farm in 2016). Sediment concentrations of strontium-90, plutonium-239+240 and americium-241 (where comparisons can be made) in 2016 were similar to those in recent years. Strontium-90 and transuranic concentrations in fish continued to be very low in 2016 and it is the effects of caesium-137 that dominate the fish consumption and external radiation pathways.

In the lake itself, there remains clear evidence of activity concentrations from the site's liquid discharges. However, gamma dose rates found on the shoreline (where anglers fish) were difficult to distinguish from background levels, and rates in 2016 were generally similar (where comparisons can be made) to those in 2015. The predominant radionuclide was caesium-137. The time trends of concentrations of caesium-137 in sediments and discharges are shown in Figure 4.4. A substantial decline in levels was observed in the late 1990s in line with reducing discharges. In the earlier part of the last decade, the observed concentrations were mainly affected by sample variability. In the latter part of the last decade, with sustained reductions in discharges of caesium-137, there was a general progressive decrease in these concentrations in sediments. In years thereafter, there has been an overall small increase in activity concentrations, but activities generally decreasing again from the small peak in discharge in 2012, with the lowest concentrations reported in 2016.

## 4.12 Wylfa, Isle of Anglesey




Wylfa Power Station is located on the north coast of Anglesey and has two Magnox reactors (Reactor 1 and 2). It was the last and largest power station of its type to be built in the UK and commenced electricity generation in 1971 and ceased in December 2015. De-fuelling is expected to be completed in 2018. Final site clearance is expected to commence in 2096 and be achieved by 2105 (NDA, 2017). The most recent habits survey was undertaken in 2013 (Garrod *et al*., 2014).

### Doses to the public

The *total dose* from all pathways and sources of radiation was 0.008 mSv in 2016 (Table 4.1), which was less than 1 per cent of the dose limit, and down from 0.013 mSv in 2015. As in 2015, the representative person was infants (1 year-old) living near to the site in 2016. The decrease in *total dose* (from 2015) was due to a lower estimate of direct radiation from the site in 2016. The trend in *total dose* over the period 2004 – 2016 is given in Figure 4.1. *Total doses* remained broadly similar from year to year, and were generally very low.

A source specific assessment for a high-rate consumer of locally grown foods gives an exposure that was less than the *total dose* (Table 4.1). The dose to this consumer was 0.005 mSv in 2016 and the reason for the small increase (from < 0.005 mSv in 2015) was due to higher carbon-14 concentrations in milk in 2016. The dose to a high-rate consumer of fish and shellfish (including external radiation) was 0.009 mSv. The reason for the small increase in dose (from 0.007 mSv in 2015) was mostly due to a combination of higher gamma dose rates over sand, and an increase in the reported less than value for americium-241 in fish, in 2016.

## Gaseous discharges and terrestrial monitoring

Discharges of carbon-14 and sulphur-35 decreased in 2016, in comparison to releases in 2015. The focus of the terrestrial sampling was for the content of tritium, carbon-14 and sulphur-35 in milk and crops. Data for 2016 are given in Table 4.13(a). Sulphur-35 was detected at a very low concentration in food (potatoes) and grass samples. Carbon-14 was detected in locally produced milk at concentrations above the expected background concentration and increased by small amounts in comparison to those in 2015. A surface water (public supply) sample was not taken in 2016 (unlike previous years).

## Liquid waste discharges and aquatic monitoring

Discharges of tritium decreased in 2016, in comparison to releases in 2015. The monitoring programme for the effects of liquid disposals included sampling of seafood, sediment, seawater and measurements of gamma dose rates. The results of the programme in 2016 are given in Tables 4.13 (a) and (b). The data for artificial radionuclides related to the Irish Sea continue to reflect the distant effects of Sellafield discharges. The activity concentrations in 2016 were similar to those in recent years, including technetium-99 derived from Sellafield. Caesium-137 concentrations in sediment have remained low over the last decade (Figure 4.2). Where comparisons can be made (from similar ground types and locations), gamma dose rates were generally similar, although rates over sand (Cemaes Bay) increased by small amounts, in comparison to those in 2015.

## Table 4.1 Individual doses – nuclear power stations, 2016

| Site | Representative person[a] | Exposure, mSv per year | | | | | |
|---|---|---|---|---|---|---|---|
| | | Total | Fish and shellfish | Other local food | External radiation from intertidal areas or the shoreline[c] | Gaseous plume related pathways | Direct radiation from site |
| **England** | | | | | | | |
| Berkeley and Oldbury | | | | | | | |
| ***Total dose* – all sources** | **Infant milk consumers** | **0.006** | **–** | **0.006** | **–** | **–** | **–** |
| Source specific doses | Seafood consumers | <0.005 | <0.005 | – | <0.005 | – | – |
| | Houseboat occupants | 0.031 | – | – | 0.031 | – | – |
| | Infant inhabitants and consumers of locally grown food | 0.006 | – | 0.006 | – | <0.005 | – |
| Bradwell | | | | | | | |
| ***Total dose* – all sources** | **Prenatal children of local inhabitants (0 – 0.25km)** | **0.036** | **–** | **<0.005** | **–** | **<0.005** | **0.036** |
| Source specific doses | Seafood consumers | <0.005 | <0.005 | – | <0.005 | – | – |
| | Infant inhabitants and consumers of locally grown food | 0.006 | – | 0.005 | – | <0.005 | |
| Dungeness | | | | | | | |
| ***Total dose* – all sources** | **Local adult inhabitants (0–0.25km)** | **0.021** | **<0.005** | **<0.005** | **<0.005** | **<0.005** | **0.020** |
| Source specific doses | Seafood consumers | <0.005 | <0.005 | – | <0.005 | – | – |
| | Houseboat occupants | 0.009 | – | – | 0.009 | – | – |
| | Infant inhabitants and consumers of locally grown food | 0.010 | – | 0.009 | – | <0.005 | – |
| Hartlepool | | | | | | | |
| ***Total dose* – all sources** | **Local adult inhabitants (0–0.25km)** | **0.020** | **<0.005** | **–** | **0.010** | **<0.005** | **0.010** |
| Source specific doses | Seafood consumers[b] | 0.018 | <0.005 | – | 0.014 | – | – |
| | Infant inhabitants and consumers of locally grown food | <0.005 | – | <0.005 | – | <0.005 | – |
| Heysham | | | | | | | |
| ***Total dose* – all sources** | **Adult occupants over sediment** | **0.019** | **<0.005** | **<0.005** | **0.018** | **<0.005** | **<0.005** |
| Source specific doses | Seafood consumers | 0.024 | 0.007 | – | 0.017 | – | – |
| | Turf cutters | 0.010 | – | – | 0.010 | – | – |
| | Infant inhabitants and consumers of locally grown food | 0.007 | – | 0.005 | – | <0.005 | – |
| Hinkley Point | | | | | | | |
| ***Total dose* – all sources** | **Adult occupants over sediment** | **0.013** | **<0.005** | **<0.005** | **0.012** | **<0.005** | **<0.005** |
| Source specific doses | Seafood consumers | 0.018 | <0.005 | – | 0.017 | – | – |
| | Infant inhabitants and consumers of locally grown food | 0.011 | – | 0.011 | – | <0.005 | – |
| Sizewell | | | | | | | |
| ***Total dose* – all sources** | **Local adult inhabitants (0–0.25km)** | **0.021** | **<0.005** | **<0.005** | **<0.005** | **<0.005** | **0.020** |
| Source specific doses | Seafood consumers | <0.005 | <0.005 | – | <0.005 | – | – |
| | Houseboat occupants | <0.005 | – | – | <0.005 | – | – |
| | Infant inhabitants and consumers of locally grown food | 0.006 | – | 0.006 | – | <0.005 | – |

**Table 4.1 continued**

| Site | Representative person[a] | Exposure, mSv per year | | | | | |
|---|---|---|---|---|---|---|---|
| | | Total | Fish and shellfish | Other local food | External radiation from intertidal areas or the shoreline[c] | Gaseous plume related pathways | Direct radiation from site |
| **Scotland** | | | | | | | |
| Chapelcross | | | | | | | |
| ***Total dose* – all sources** | **Infant milk consumers** | **0.026** | **<0.005** | **0.026** | **<0.005** | **–** | **–** |
| Source specific doses | Salmon, mollusc and wildfowl consumers | 0.009 | 0.005 | – | <0.005 | – | – |
| | Crustacean consumers | <0.005 | <0.005 | – | – | – | – |
| | Infant inhabitants and consumers of locally grown food | 0.018 | – | 0.018 | – | <0.005 | – |
| Hunterston | | | | | | | |
| ***Total dose* – all sources** | **Prenatal children of local inhabitants (0.25–0.5km)** | **0.021** | **–** | **<0.005** | **<0.005** | **<0.005** | **0.020** |
| Source specific doses | Seafood consumers | 0.006 | <0.005 | – | <0.005 | – | – |
| | Infant inhabitants and consumers of locally grown food | 0.010 | – | 0.008 | – | <0.005 | – |
| Torness | | | | | | | |
| ***Total dose* – all sources** | **Local adult inhabitants (0.5–1km)** | **0.021** | **<0.005** | **<0.005** | **<0.005** | **<0.005** | **0.020** |
| Source specific doses | Seafood consumers | <0.005 | <0.005 | – | <0.005 | – | – |
| | Infant inhabitants and consumers of locally grown food | 0.008 | – | 0.008 | – | <0.005 | – |
| Wales | | | | | | | |
| Trawsfynydd | | | | | | | |
| ***Total dose* – all sources** | **Infant local inhabitants (0.25–0.5km)** | **0.019** | **–** | **0.013** | **–** | **<0.005** | **0.006** |
| Source specific doses | Anglers | <0.005 | <0.005 | – | <0.005 | – | – |
| | Infant inhabitants and consumers of locally grown food | 0.025 | – | 0.025 | – | <0.005 | – |
| Wylfa | | | | | | | |
| ***Total dose* – all sources** | **Infant local inhabitants (0.25–0.5km)** | **0.008** | **–** | **<0.005** | **–** | **<0.005** | **0.006** |
| Source specific doses | Seafood consumers | 0.009 | <0.005 | – | 0.007 | – | – |
| | Infant inhabitants and consumers of locally grown food | 0.005 | – | 0.005 | – | <0.005 | – |

[a] *The* total dose *is the dose which accounts for all sources including gaseous and liquid discharges and direct radiation. The* total dose *for the representative person with the highest dose is presented. Other dose values are presented for specific sources, either liquid discharges or gaseous discharges, and their associated pathways. They serve as a check on the validity of the* total dose *assessment. The representative person is an adult unless otherwise stated*

[b] *Excluding possible enhancement of naturally occurring radionuclides. See Section 4*

[c] *Doses (*total dose *and source specific doses) only include estimates of anthropogenic inputs (by substracting background and cosmic sources from measured gamma dose rates)*

## Table 4.2(a) Concentrations of radionuclides in food and the environment near Berkeley and Oldbury nuclear power stations, 2016

| Material | Location | No. of sampling observ-ations | Mean radioactivity concentration (fresh)[a], Bq kg$^{-1}$ | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | $^{3}$H | $^{14}$C | $^{99}$Tc | $^{137}$Cs | $^{238}$Pu | $^{239}$Pu + $^{240}$Pu |
| **Marine samples** | | | | | | | | |
| Salmon | Beachley | 1 | | | | 0.34 | | |
| Mullet | River Severn | 1 | <25 | | | 0.18 | | |
| Elvers | River Severn | 1 | | | | <0.12 | | |
| Shrimps | Guscar | 2 | <25 | 32 | | 0.33 | 0.00016 | 0.0010 |
| Seaweed | 2 km south west of Berkeley | 2[E] | | | <1.0 | <0.69 | | |
| Sediment | 0.5 km south of Oldbury | 2[E] | | | | 16 | | |
| Sediment | 2 km south west of Berkeley | 2[E] | | | | 20 | | |
| Sediment | Sharpness | 2[E] | | | | 17 | | |
| Sediment | Ledges | 2[E] | | | | 11 | | |
| Seawater | 2 km south west of Berkeley | 2[E] | <3.3 | | | <0.25 | | |

| Material | Location | No. of sampling observ-ations | Mean radioactivity concentration (fresh)[a], Bq kg$^{-1}$ | | | | |
|---|---|---|---|---|---|---|---|
| | | | $^{241}$Am | $^{242}$Cm | $^{243}$Cm + $^{244}$Cm | Gross alpha | Gross beta |
| **Marine samples** | | | | | | | |
| Salmon | Beachley | 1 | <0.07 | | | | |
| Mullet | River Severn | 1 | <0.19 | | | | |
| Elvers | River Severn | 1 | <0.10 | | | | |
| Shrimps | Guscar | 2 | 0.00087 | * | * | | |
| Seaweed | 2 km south west of Berkeley | 2[E] | <0.63 | | | | |
| Sediment | 0.5 km south of Oldbury | 2[E] | <0.79 | | | | |
| Sediment | 2 km south west of Berkeley | 2[E] | <0.83 | | | | |
| Sediment | Sharpness | 2[E] | <0.69 | | | | |
| Sediment | Ledges | 2[E] | <0.63 | | | | |
| Seawater | 2 km south west of Berkeley | 2[E] | <0.26 | | | <2.1 | 3.9 |

| Material | Location or selection[b] | No. of sampling observ-ations[c] | Mean radioactivity concentration (fresh)[a], Bq kg$^{-1}$ | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | $^{3}$H | $^{14}$C | $^{35}$S | $^{137}$Cs | Gross alpha | Gross beta |
| **Terrestrial samples** | | | | | | | | |
| Milk | | 4 | <3.5 | 22 | <0.27 | <0.39 | | |
| Milk | max | | <4.1 | 27 | <0.30 | <1.3 | | |
| Barley | | 1 | <5.4 | 99 | 1.3 | <0.04 | | |
| Potatoes | | 1 | <2.1 | 16 | 0.30 | <0.09 | | |
| Freshwater | Gloucester and Sharpness Canal | 2[E] | <3.1 | | <0.44 | <0.25 | <0.038 | 0.21 |

* *Not detected by the method used*

[a] *Except for milk and water where units are Bq l$^{-1}$, and for sediment where dry concentrations apply*

[b] *Data are arithmetic means unless stated as 'max' in this column. 'Max' data are selected to be maxima. If no 'max' value is given the mean value is the most appropriate for dose assessments*

[c] *The number of farms from which milk is sampled. The number of analyses is greater than this and depends on the bulking regime*

[E] *Measurements labelled "E" are made on behalf of the Environment Agency, all other measurements are made on behalf of the Food Standards Agency*

**Table 4.2(b) Monitoring of radiation dose rates near Berkeley and Oldbury nuclear power stations, 2016**

| Location | Ground type | No. of sampling observations | μGy $h^{-1}$ |
|---|---|---|---|
| **Mean gamma dose rates at 1m over substrate** | | | |
| 0.5 km south of Oldbury | Mud and salt marsh | 2 | 0.084 |
| 2 km south west of Oldbury | Mud and salt marsh | 2 | 0.080 |
| Guscar Rocks | Mud | 2 | 0.080 |
| Lydney Rocks | Mud | 2 | 0.089 |
| Sharpness | Salt marsh | 2 | 0.080 |
| Ledges | Mud | 1 | 0.091 |
| Ledges | Mud and salt marsh | 1 | 0.072 |

## Table 4.3(a) Concentrations of radionuclides in food and the environment near Bradwell nuclear power station, 2016

| Material | Location | No. of sampling observ-ations | Mean radioactivity concentration (fresh)[a], Bq kg$^{-1}$ | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $^{3}$H | $^{99}$Tc | $^{137}$Cs | $^{238}$Pu | $^{239}$Pu + $^{240}$Pu | $^{241}$Am | $^{242}$Cm | $^{243}$Cm + $^{244}$Cm | Gross alpha | Gross beta |
| **Marine samples** | | | | | | | | | | | | |
| Bass | Pipeline | 1 | | | 0.21 | | | <0.05 | | | | |
| Lobsters | West Mersea | 1 | | | <0.05 | | | <0.05 | | | | |
| Native oysters | Blackwater Estuary | 1 | | | <0.06 | 0.00024 | 0.0013 | 0.00076 | * | 0.000016 | | |
| Samphire | Tollesbury | 1 | | <0.45 | 0.25 | | | <0.06 | | | | |
| Seaweed | Waterside | 2[E] | | 1.7 | <0.45 | | | <0.50 | | | | |
| Samphire | West Mersea | 1[E] | | <0.33 | <0.86 | | | <0.70 | | | | |
| Sediment | Bradwell Pipeline | 2[E] | | | <0.42 | | | <0.31 | | | | |
| Sediment | Bradwell Marina | 2[E] | | | 2.6 | | | <0.72 | | | | |
| Sediment | Waterside | 2[E] | | | 4.4 | | | <1.0 | | | | |
| Sediment | Steeple | 2[E] | | | 6.6 | | | <0.72 | | | | |
| Sediment | Maylandsea Bay | 2[E] | | | 11 | | | <0.71 | | | | |
| Sediment | Blackwater | 2[E] | | | 7.6 | | | <0.76 | | | | |
| Sediment | N side Blackwater Estuary | 2[E] | | | 7.3 | | | <0.79 | | | | |
| Sediment | Osea Causeway | 2[E] | | | 5.1 | | | <0.41 | | | | |
| Sediment | Maldon Harbour | 2[E] | | | 15 | | | <0.94 | | | | |
| Sediment | Maldon, Waterships Down | 2[E] | | | 24 | | | <0.83 | | | | |
| Sediment | Heybridge | 2[E] | | | 9.6 | | | <0.98 | | | | |
| Sediment | Strood Channel | 2[E] | | | 9.9 | | | <1.1 | | | | |
| Sediment | Tollesbury Boatyard | 2[E] | | | 9.7 | | | <0.75 | | | | |
| Sediment | Tollesbury saltwater pool | 2[E] | | | <9.6 | | | <0.44 | | | | |
| Sediment | West Mersea Beach Huts | 2[E] | | | 1.1 | | | <0.52 | | | | |
| Sediment | West Mersea Boatyard | 2[E] | | | 4.7 | | | <0.68 | | | | |
| Sediment | Pyefleet | 2[E] | | | 5.8 | | | <0.83 | | | | |
| Sediment | Rowhedge | 2[E] | | | 8.6 | | | <1.1 | | | | |
| Sediment | Alresford Creek | 2[E] | | | 4.2 | | | <1.2 | | | | |
| Sediment | Brightlingsea Bateman's Tower | 2[E] | | | <0.15 | | | <0.26 | | | | |
| Sediment | Brightlingsea saltwater pool | 2[E] | | | <0.26 | | | <0.30 | | | | |
| Sediment | St Osyth boat lake | 2[E] | | | 12 | | | <0.97 | | | | |
| Seawater | Bradwell Pipeline | 2[E] | <3.4 | | <0.19 | | | <0.28 | | | <4.3 | 20 |
| Seawater | Bradwell Marina | 2[E] | | | <0.25 | | | <0.27 | | | <4.2 | <11 |
| Seawater | Steeple | 2[E] | | | <0.19 | | | <0.28 | | | <4.1 | 11 |
| Seawater | Maylandsea Bay | 2[E] | | | <0.22 | | | <0.28 | | | <4.3 | 13 |
| Seawater | Blackwater | 2[E] | | | <0.26 | | | <0.26 | | | <4.0 | 12 |
| Seawater | Osea Causeway | 2[E] | | | <0.23 | | | <0.27 | | | <3.1 | 12 |
| Seawater | Maldon, Waterships Down | 2[E] | <3.2 | | <0.23 | | | <0.27 | | | <2.4 | <3.2 |
| Seawater | Heybridge | 2[E] | | | <0.22 | | | <0.27 | | | <3.1 | <9.2 |
| Seawater | Strood Channel | 2[E] | <3.3 | | <0.20 | | | <0.27 | | | <3.9 | <9.7 |
| Seawater | Tollesbury Boatyard | 2[E] | | | <0.23 | | | <0.28 | | | <3.9 | 16 |
| Seawater | Tollesbury saltwater pool | 2[E] | | | <0.19 | | | <0.29 | | | <4.0 | <10 |
| Seawater | Pyefleet | 2[E] | <3.3 | | <0.21 | | | <0.27 | | | <3.6 | 16 |
| Seawater | Rowhedge | 2[E] | | | <0.25 | | | <0.27 | | | <3.0 | 10 |
| Seawater | Alresford Creek | 2[E] | | | <0.20 | | | <0.28 | | | <3.0 | 11 |
| Seawater | Brightlingsea Bateman's Tower | 2[E] | | | <0.19 | | | <0.28 | | | <3.9 | 14 |
| Seawater | Brightlingsea saltwater pool | 2[E] | | | <0.22 | | | <0.28 | | | <4.1 | 13 |
| Seawater | St Osyth boat lake | 2[E] | | | <0.24 | | | <0.26 | | | <1.4 | 5.0 |

**Table 4.3(a) continued**

| Material | Location or selection[b] | No. of sampling observ-ations[c] | Mean radioactivity concentration (fresh)[a], Bq kg$^{-1}$ | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | $^{3}$H | $^{14}$C | $^{90}$Sr | $^{137}$Cs | Gross alpha | Gross beta |
| **Terrestrial samples** | | | | | | | | |
| Milk | | 2 | <2.6 | 25 | | <0.07 | | |
| Milk | max | | <2.7 | 26 | | <0.08 | | |
| Cabbage | | 1 | 8.4 | 21 | | <0.11 | | |
| Lucerne | | 1 | <3.9 | 12 | | <0.08 | | |
| Grass | Maldon, Promenade Park | 2[E] | <7.5 | <11 | | <1.8 | | |
| Grass | Strood Channel | 2[E] | <8.1 | <6.3 | | <0.92 | | |
| Grass | Tollesbury | 2[E] | <9.6 | <9.1 | | <1.3 | | |
| Grass | West Mersea, near Sewage Works | 2[E] | <9.6 | <7.9 | | <0.92 | | |
| Grass | St Osyth | 2[E] | <6.8 | <7.9 | | <0.92 | | |
| Freshwater | Coastal ditch, between power station and shore | 1[E] | <3.4 | | <0.030 | <0.25 | <0.62 | 5.1 |
| Freshwater | Coastal ditch, east face of sector building | 1[E] | <3.2 | | | <0.18 | <0.55 | 3.0 |
| Freshwater | Coastal ditch, east face of turbine hall | 1[E] | <3.2 | | 1.4 | <0.25 | <0.52 | 6.7 |
| Freshwater | Coastal ditch, drain pit overflow | 2[E] | <5.5 | | | <0.19 | <0.58 | 9.2 |

* *Not detected by the method used*

[a] *Except for milk and water where units are Bq l$^{-1}$, and for sediment where dry concentrations apply*

[b] *Data are arithmetic means unless stated as 'max' in this column. 'Max' data are selected to be maxima. If no 'max' value is given the mean value is the most appropriate for dose assessments*

[c] *The number of farms from which milk is sampled. The number of analyses is greater than this and depends on the bulking regime*

[E] *Measurements labelled "E" are made on behalf of the Environment Agency, all other measurements are made on behalf of the Food Standards Agency*

**Table 4.3(b) Monitoring of radiation dose rates near Bradwell, 2016**

| Location | Ground type | No. of sampling observations | µGy $h^{-1}$ |
|---|---|---|---|
| **Mean gamma dose rates at 1m over substrate** | | | |
| Bradwell Beach | Sand | 1 | 0.064 |
| Bradwell Beach | Mud and shingle | 1 | 0.059 |
| Beach opposite power station, N side of estuary | Mud and salt marsh | 2 | 0.061 |
| Bradwell Marina | Mud | 2 | 0.080 |
| Waterside | Mud | 1 | 0.056 |
| Waterside | Mud and pebbles | 1 | 0.053 |
| Steeple | Mud | 2 | 0.078 |
| Maylandsea Bay | Mud | 2 | 0.057 |
| Blackwater | Mud | 2 | 0.056 |
| Osea Causeway | Mud | 1 | 0.060 |
| Osea Causeway | Mud and rock | 1 | 0.057 |
| Maldon Harbour | Mud | 1 | 0.059 |
| Maldon Harbour | Mud and salt marsh | 1 | 0.053 |
| Maldon Promenade | Grass | 2 | 0.061 |
| Maldon Watership Down | Mud | 1 | 0.062 |
| Maldon Watership Down | Mud and saltmarsh | 1 | 0.065 |
| Heybridge | Mud | 1 | 0.055 |
| Heybridge | Mud and pebbles | 1 | 0.054 |
| Strood Channel | Mud | 1 | 0.062 |
| Strood Channel | Mud and salt marsh | 1 | 0.063 |
| Strood Channel | Grass | 2 | 0.067 |
| Tollesbury | Grass | 2 | 0.075 |
| Tollesbury boatyard | Mud and salt marsh | 2 | 0.069 |
| Tollesbury saltwater pool | Mud | 1 | 0.064 |
| Tollesbury saltwater pool | Sand | 1 | 0.048 |
| West Mersea Beach Huts | Mud and shingle | 1 | 0.059 |
| West Mersea Beach Huts | Mud and sand | 1 | 0.044 |
| SE of West Mersea boatyard | Mud and shells | 2 | 0.050 |
| West Mersea near Sewage Works | Grass | 2 | 0.064 |
| Pyefleet | Mud | 1 | 0.063 |
| Pyefleet | Mud and shingle | 1 | 0.063 |
| Rowhedge | Mud | 1 | 0.064 |
| Rowhedge | Mud and salt marsh | 1 | 0.062 |
| Alresford Creek | Mud | 1 | 0.055 |
| Alresford Creek | Mud and salt marsh | 1 | 0.057 |
| Brightlingsea Bateman's Tower | Sand | 1 | 0.050 |
| Brightlingsea Bateman's Tower | Sand and shingle | 1 | 0.048 |
| Brightlingsea saltwater pool | Sand | 1 | 0.049 |
| Brightlingsea saltwater pool | Sand and shingle | 1 | 0.045 |
| St Osyth | Grass | 2 | 0.065 |
| St Osyth boat lake | Mud | 2 | 0.071 |

## Table 4.4(a) Concentrations of radionuclides in food and the environment near Dungeness nuclear power stations, 2016

| Material | Location | No. of sampling observ-ations | Mean radioactivity concentration (fresh)[a], Bq kg$^{-1}$ | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Organic $^{3}$H | $^{3}$H | $^{14}$C | $^{60}$Co | $^{90}$Sr | $^{99}$Tc | $^{137}$Cs |
| **Marine samples** | | | | | | | | | |
| Cod | Pipeline | 1 | <25 | <25 | | <0.04 | | | 0.13 |
| Sole | Pipeline | 1 | <25 | <25 | | <0.06 | | | <0.13 |
| Crab | Pipeline | 1 | <25 | <25 | | <0.06 | | | <0.06 |
| Scallops | Pipeline | 1 | <25 | <25 | 30 | <0.04 | 0.016 | | <0.03 |
| Sea kale | Dungeness Beach | 1 | | | | <0.04 | | | 0.05 |
| Seaweed | Folkestone Harbout | 2[E] | | | | <0.37 | | <0.68 | <0.27 |
| Sediment | Rye Harbour | 2[E] | | | | <0.42 | <2.0 | | <0.51 |
| Sediment | Camber Sands | 2[E] | | | | <0.26 | <2.0 | | <0.22 |
| Sediment | Pilot Sands | 2[E] | | | | <0.30 | <2.0 | | <0.21 |
| Seawater | Dungeness South | 2[E] | | <3.3 | | <0.20 | | | <0.17 |

| Material | Location | No. of sampling observ-ations | Mean radioactivity concentration (fresh)[a], Bq kg$^{-1}$ | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | $^{238}$Pu | $^{239}$Pu + $^{240}$Pu | $^{241}$Am | $^{242}$Cm | $^{243}$Cm + $^{244}$Cm | Gross alpha | Gross beta |
| **Marine samples** | | | | | | | | | |
| Cod | Pipeline | 1 | | | <0.04 | | | | |
| Sole | Pipeline | 1 | | | <0.06 | | | | |
| Crab | Pipeline | 1 | | | <0.17 | | | | |
| Scallops | Pipeline | 1 | 0.00035 | 0.0021 | 0.00058 | * | 0.000013 | | |
| Sea kale | Dungeness Beach | 1 | | | <0.04 | | | | |
| Seaweed | Folkestone Harbout | 2[E] | | | <0.41 | | | | |
| Sediment | Rye Harbour | 2[E] | <0.36 | <0.29 | <0.68 | | | | 540 |
| Sediment | Camber Sands | 2[E] | | | <0.56 | | | | |
| Sediment | Pilot Sands | 2[E] | | | <0.33 | | | | |
| Seawater | Dungeness South | 2[E] | | | <0.28 | | | <3.8 | <8.8 |

| Material | Location or selection[b] | No. of sampling observ-ations[c] | Mean radioactivity concentration (fresh)[a], Bq kg$^{-1}$ | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | $^{3}$H | $^{14}$C | $^{35}$S | $^{60}$Co | $^{137}$Cs | Gross alpha | Gross beta |
| **Terrestrial Samples** | | | | | | | | | |
| Milk | | 3 | <3.7 | 21 | <0.40 | <0.05 | <0.04 | | |
| Milk | max | | <4.2 | 30 | <0.38 | <0.08 | <0.05 | | |
| Potatoes | | 1 | <2.7 | 22 | 0.70 | <0.09 | <0.08 | | |
| Wheat | | 1 | <3.5 | 89 | <0.20 | <0.04 | <0.04 | | |
| Grass | Lydd | 2[E] | <6.8 | <15 | | <2.1 | <1.6 | | |
| Grass | Denge Marsh | 2[E] | <17 | <28 | | <4.0 | <2.9 | | |
| Freshwater | Long Pits | 2[E] | <3.0 | | <0.39 | <0.30 | <0.22 | <0.026 | 0.11 |
| Freshwater | Pumping station Well number 1 | 1[E] | <3.3 | | <0.24 | <0.24 | <0.20 | <0.033 | 0.10 |
| Freshwater | Pumping station Well number 2 | 1[E] | <2.9 | | <0.52 | <0.32 | <0.23 | <0.022 | 0.17 |
| Freshwater | Reservoir | 1[E] | <3.0 | | <0.81 | <0.23 | | <0.029 | 0.22 |

* *Not detected by the method used*

[a] *Except for milk and water where units are Bq l$^{-1}$, and for wheat and sediment where dry concentrations apply*

[b] *Data are arithmetic means unless stated as 'max' in this column. 'Max' data are selected to be maxima. If no 'max' value is given the mean value is the most appropriate for dose assessments*

[c] *The number of farms from which milk is sampled. The number of analyses is greater than this and depends on the bulking regime*

[E] *Measurements labelled "E" are made on behalf of the Environment Agency, all other measurements are made on behalf of the Food Standards Agency*

**Table 4.4(b) Monitoring of radiation dose rates near Dungeness nuclear power stations, 2016**

| Location | Ground type | No. of sampling observations | µGy $h^{-1}$ |
|---|---|---|---|
| **Mean gamma dose rates at 1m over substrate** | | | |
| Littlestone-on-Sea | Pebbles and sand | 1 | 0.048 |
| Littlestone-on-Sea | Sand and shingle | 1 | 0.041 |
| Greatstone-on-Sea | Sand and mud | 2 | 0.048 |
| Pilot Sands | Sand and shingle | 2 | 0.045 |
| Dungeness West | Shingle | 2 | 0.042 |
| Jurys Gap | Sand and shingle | 1 | 0.056 |
| Jurys Gap | Sand and mud | 1 | 0.050 |
| Rye Bay | Sand and shingle | 1 | 0.060 |
| Rye Bay | Sand and mud | 1 | 0.054 |

## Table 4.5(a) Concentrations of radionuclides in food and the environment near Hartlepool nuclear power station, 2016

| Material | Location | No. of sampling observ-ations | Mean radioactivity concentration (fresh)[a], Bq kg$^{-1}$ | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Organic $^{3}$H | $^{3}$H | $^{14}$C | $^{60}$Co | $^{99}$Tc | $^{131}$I | $^{137}$Cs | $^{210}$Pb |
| **Marine samples** | | | | | | | | | | |
| Plaice | Pipeline | 1 | <25 | <25 | 37 | <0.08 | | * | 0.12 | |
| Crabs | Pipeline | 1 | <25 | <25 | 40 | <0.09 | | * | <0.08 | |
| Winkles | South Gare | 2 | <28 | <25 | 36 | <0.13 | | * | <0.12 | 0.50 |
| Seaweed | Pilot Station | 2[E] | | | | <0.52 | 3.3 | 10 | <0.34 | |
| Sediment | Old Town Basin | 2[E] | | | | <0.41 | | | 1.6 | |
| Sediment | Seaton Carew | 2[E] | | | | <0.26 | | | <0.21 | |
| Sediment | Paddy's Hole | 2[E] | | | | <0.32 | | | 1.2 | |
| Sediment | North Gare | 2[E] | | | | <0.27 | | | <0.21 | |
| Sediment | Greatham Creek | 2[E] | | | | <0.53 | | | 1.9 | |
| Sediment | Redcar Sands | 2[E] | | | | <0.28 | | | <0.21 | |
| Sea coal | Old Town Basin | 2[E] | | | | <0.44 | | | 0.97 | |
| Sea coal | Carr House Sands | 2[E] | | | | <0.43 | | | 1.3 | |
| Seawater[d] | North Gare | 2[E] | | <3.8 | | <0.29 | | | <0.21 | |

| Material | Location | No. of sampling observ-ations | Mean radioactivity concentration (fresh)[a], Bq kg$^{-1}$ | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | $^{210}$Po | $^{238}$Pu | $^{239}$Pu + $^{240}$Pu | $^{241}$Am | $^{242}$Cm | $^{243}$Cm + $^{244}$Cm | Gross alpha | Gross beta |
| **Marine samples** | | | | | | | | | | |
| Plaice | Pipeline | 1 | | | | <0.21 | | | | |
| Crabs | Pipeline | 1 | | | | <0.23 | | | | |
| Winkles | South Gare | 2 | 7.9 | 0.0013 | 0.0078 | 0.0054 | * | * | | |
| Seaweed | Pilot Station | 2[E] | | | | <0.38 | | | | |
| Sediment | Old Town Basin | 2[E] | | | | <0.56 | | | | |
| Sediment | Seaton Carew | 2[E] | | | | <0.32 | | | | |
| Sediment | Paddy's Hole | 2[E] | | | | <0.56 | | | | |
| Sediment | North Gare | 2[E] | | | | <0.34 | | | | |
| Sediment | Greatham Creek | 2[E] | | | | <0.77 | | | | |
| Sediment | Redcar Sands | 2[E] | | | | <0.33 | | | | |
| Sea coal | Old Town Basin | 2[E] | | | | <0.54 | | | | |
| Sea coal | Carr House Sands | 2[E] | | | | <0.49 | | | | |
| Seawater[d] | North Gare | 2[E] | | | | <0.27 | | | <3.6 | 20 |

| Material | Location or selection[b] | No. of sampling observ-ations[c] | Mean radioactivity concentration (fresh)[a], Bq kg$^{-1}$ | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | $^{3}$H | $^{14}$C | $^{35}$S | $^{60}$Co | $^{137}$Cs | Gross alpha | Gross beta |
| **Terrestrial samples** | | | | | | | | | |
| Milk | | 2 | <2.9 | 17 | <0.35 | <0.05 | <0.06 | | |
| Milk | max | | <3.0 | 20 | <0.50 | <0.06 | <0.08 | | |
| Potatoes | | 1 | <2.7 | 26 | <0.20 | <0.06 | <0.05 | | |
| Wheat | | 1 | <3.7 | 15 | 0.70 | <0.07 | <0.06 | | |
| Grass | 0.8km NW of site | 2[E] | <8.7 | 21 | <4.1 | <0.96 | <0.67 | | |
| Grass | 0.6km NE of site | 2[E] | <9.3 | 66 | <3.5 | <0.62 | <0.50 | | |
| Freshwater | Boreholes, Dalton Piercy | 2[E] | <3.6 | | <0.45 | <0.26 | <0.21 | <0.064 | <0.12 |

* *Not detected by the method used*

[a] *Except for milk and water where units are Bq l$^{-1}$, and for sediment and sea coal where dry concentrations apply*

[b] *Data are arithmetic means unless stated as 'max' in this column. 'Max' data are selected to be maxima. If no 'max' value is given the mean value is the most appropriate for dose assessments*

[c] *The number of farms from which milk is sampled. The number of analyses is greater than this and depends on the bulking regime*

[d] *The concentration of $^{35}$S was < 1.0 Bq kg$^{-1}$*

[E] *Measurements labelled "E" are made on behalf of the Environment Agency, all other measurements are made on behalf of the Food Standards Agency*

**Table 4.5(b) Monitoring of radiation dose rates near Hartlepool nuclear power station, 2016**

| Location | Ground type | No. of sampling observations | µGy $h^{-1}$ |
|---|---|---|---|
| **Mean gamma dose rates at 1m over substrate** | | | |
| Fish Sands | Sand and seacoal | 1 | 0.075 |
| Fish Sands | Sand and rock | 1 | 0.068 |
| Old Town Basin | Sand and seacoal | 1 | 0.077 |
| Old Town Basin | Sand and stones | 1 | 0.072 |
| Carr House | Sand | 2 | 0.068 |
| Seaton Carew | Sand | 2 | 0.065 |
| North Gare | Pebbles and sand | 1 | 0.072 |
| North Gare | Sand | 1 | 0.064 |
| Paddy's Hole | Grass and slag | 1 | 0.17 |
| Paddy's Hole | Grass and rock | 1 | 0.17 |
| Greatham Creek nature reserve | Mud and rock | 1 | 0.089 |
| Greatham Creek nature reserve | Mud | 1 | 0.083 |
| Redcar Sands | Sand | 2 | 0.067 |

## Table 4.6(a) Concentrations of radionuclides in food and the environment near Heysham nuclear power stations, 2016

| Material | Location | No. of sampling observ-ations | Mean radioactivity concentration (fresh)[a], Bq kg$^{-1}$ | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Organic $^{3}$H | $^{3}$H | $^{14}$C | $^{60}$Co | $^{90}$Sr | $^{99}$Tc | $^{137}$Cs | $^{155}$Eu |
| **Marine samples** | | | | | | | | | | |
| Flounder | Morecambe | 2 | <33 | <41 | 68 | <0.09 | <0.018 | 0.23 | 4.0 | <0.18 |
| Shrimps | Morecambe | 2 | 54 | 55 | 72 | <0.08 | <0.041 | 0.44 | 2.1 | <0.18 |
| Winkles[b] | Middleton Sands | 2 | 35 | 27 | 50 | <0.08 | 0.17 | 16 | 2.1 | <0.18 |
| Mussels[c] | Morecambe | 2 | 72 | 81 | 74 | <0.08 | 0.20 | 39 | 1.5 | <0.18 |
| Wildfowl | Morecambe | 1 | | | | <0.08 | | | 0.64 | <0.18 |
| Seaweed[e] | Half Moon Bay | 2[E] | | | | <0.61 | | 180 | 2.1 | |
| Sediment | Half Moon Bay | 2[E] | | | | <0.46 | | | 75 | |
| Sediment | Pott's Corner | 2[E] | | | | <0.41 | | | 13 | |
| Sediment | Morecambe central beach | 2[E] | | | | <0.31 | | | 20 | |
| Sediment | Red Nab Point | 2[E] | | | | <0.35 | | | 15 | |

| Material | Location | No. of sampling observ-ations | Mean radioactivity concentration (fresh)[a], Bq kg$^{-1}$ | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | $^{238}$Pu | $^{239}$Pu + $^{240}$Pu | $^{241}$Pu | $^{241}$Am | $^{242}$Cm | $^{243}$Cm + $^{244}$Cm | Gross beta |
| **Marine samples** | | | | | | | | | |
| Flounder | Morecambe | 2 | 0.00027 | 0.0016 | | 0.0035 | 0.000062 | 0.000028 | |
| Shrimps | Morecambe | 2 | 0.0025 | 0.017 | | 0.030 | * | * | |
| Winkles[b] | Middleton Sands | 2 | 0.19 | 1.2 | 5.8 | 2.3 | * | * | 160 |
| Mussels[c] | Morecambe | 2 | 0.22 | 1.3 | 6.7 | 2.5 | * | * | 140 |
| Wildfowl | Morecambe | 1 | | | | <0.22 | | | |
| Seaweed[e] | Half Moon Bay | 2[E] | | | | <0.81 | | | |
| Sediment | Half Moon Bay | 2[E] | 7.5 | 46 | | 91 | | | |
| Sediment | Pott's Corner | 2[E] | | | | 12 | | | |
| Sediment | Morecambe central beach | 2[E] | | | | 22 | | | |
| Sediment | Red Nab Point | 2[E] | | | | 14 | | | |

| Material | Location or selection[d] | No. of sampling observ-ations[e] | Mean radioactivity concentration (fresh)[a], Bq kg$^{-1}$ | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | $^{3}$H | $^{14}$C | $^{35}$S | $^{60}$Co | $^{137}$Cs | Gross alpha | Gross beta |
| **Terrestrial samples** | | | | | | | | | |
| Milk | | 2 | <4.7 | 22 | <0.25 | <0.04 | <0.08 | | |
| Milk | max | | <5.8 | 23 | <0.30 | <0.05 | 0.11 | | |
| Potatoes | | 1 | <2.6 | 13 | 0.40 | <0.06 | <0.05 | | |
| Grass | | 1 | <3.2 | 45 | 4.8 | <0.07 | 0.06 | | |
| Grass | Half Moon Bay, recreation ground | 2[E] | <12 | 12 | 3.7 | <0.49 | <0.36 | | |
| Grass | Overton | 2[E] | <12 | <10 | 3.0 | <0.73 | <0.53 | | |
| Freshwater | Damas Gill reservoir | 2[E] | <3.3 | <3.7 | <0.60 | <0.26 | <0.22 | <0.037 | 0.054 |
| Freshwater | Lower Halton Weir | 2[E] | <3.4 | <2.9 | <0.56 | <0.23 | <0.20 | <0.018 | 0.067 |

* *Not detected by the method used*

[a] *Except for milk and water where units are Bq l$^{-1}$, and for sediment where dry concentrations apply*

[b] *The concentration of $^{210}$Po was 11 Bq kg$^{-1}$*

[c] *The concentration of $^{210}$Po was 37 Bq kg$^{-1}$*

[d] *Data are arithmetic means unless stated as 'max' in this column. 'Max' data are selected to be maxima.*

[e] *The concentration of $^{129}$I was 2.3 Bq kg$^{-1}$*
*If no 'max' value is given the mean value is the most appropriate for dose assessments*

[e] *The number of farms from which milk is sampled. The number of analyses is greater than this and depends on the bulking regime*

[E] *Measurements labelled "E" are made on behalf of the Environment Agency, all other measurements are made on behalf of the Food Standards Agency*

**Table 4.6(b) Monitoring of radiation dose rates near Heysham nuclear power stations, 2016**

| Location | Ground type | No. of sampling observations | µGy $h^{-1}$ |
|---|---|---|---|
| **Mean gamma dose rates at 1m over substrate** | | | |
| Sand Gate Marsh | Salt marsh | 1 | 0.082 |
| Sand Gate Marsh | Grass | 1 | 0.080 |
| Arnside 2 | Salt marsh | 1 | 0.093 |
| Arnside 2 | Grass | 1 | 0.083 |
| Morecambe central beach | Sand | 1 | 0.071 |
| Morecambe central beach | Sand and shingle | 1 | 0.076 |
| Half Moon Bay | Sand | 1 | 0.081 |
| Half Moon Bay | Sand and stones | 1 | 0.081 |
| Red Nab Point | Sand and shingle | 1 | 0.081 |
| Red Nab Point | Pebbles | 1 | 0.083 |
| Middleton Sands | Sand | 2 | 0.078 |
| Sunderland Point | Mud and sand | 2 | 0.097 |
| Colloway Marsh | Salt marsh | 2 | 0.11 |
| Lancaster | Grass and sand | 1 | 0.084 |
| Lancaster | Grass | 1 | 0.083 |
| Aldcliffe Marsh | Salt marsh | 2 | 0.094 |
| Conder Green | Mud | 1 | 0.092 |
| Conder Green | Mud and salt marsh | 1 | 0.092 |

## Table 4.7(a) Concentrations of radionuclides in food and the environment near Hinkley Point nuclear power stations, 2016

| Material | Location | No. of sampling observ-ations | Mean radioactivity concentration (fresh)[a], Bq kg$^{-1}$ | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Organic $^{3}$H | $^{3}$H | $^{14}$C | $^{60}$Co | $^{90}$Sr | $^{99}$Tc | $^{137}$Cs |
| **Marine samples** | | | | | | | | | |
| Cod | Stolford | 1 | <25 | <25 | 25 | <0.06 | | | 0.26 |
| Shrimps | Stolford | 1 | <25 | <25 | 31 | <0.08 | | | <0.08 |
| Limpets | Stolford | 1 | <25 | 14 | 28 | <0.04 | | | 0.14 |
| Pacific Oyster | Stolford | 1 | <25 | <25 | 17 | <0.08 | | | <0.06 |
| Seaweed | Pipeline | 2[E] | | | | <0.58 | | 2.1 | <0.44 |
| Sediment | Pipeline | 2[E] | | | | <0.41 | <2.2 | | 2.5 |
| Sediment | Stolford | 2[E] | | | | <0.55 | <2.0 | | 11 |
| Sediment | Steart Flats | 2[E] | | | | <0.52 | <6.3 | | 11 |
| Sediment | River Parrett | 2[E] | | | | <0.99 | <3.5 | | 17 |
| Sediment | River Parrett Central 1 | 2[E] | | | | <0.46 | <2.3 | | 7.1 |
| Sediment | River Parrett Central 2 | 2[E] | | | | <0.54 | <2.0 | | 8.4 |
| Sediment | Burrowbridge | 2[E] | | | | <0.48 | <5.7 | | 6.6 |
| Sediment | Pawlett | 2[E] | | | | <0.52 | <2.0 | | 12 |
| Sediment | East Bank | 2[E] | | | | <0.54 | <2.0 | | 17 |
| Sediment | Weston-Super-Mare | 2[E] | | | | <0.35 | <2.0 | | 0.88 |
| Sediment | Burnham-On-Sea | 2[E] | | | | <0.36 | <2.0 | | 1.1 |
| Sediment | Kilve | 2[E] | | | | <0.38 | <2.0 | | 1.1 |
| Sediment | Helwell Bay | 2[E] | | | | <0.36 | <2.0 | | 1.6 |
| Sediment | Blue Anchor Bay | 2[E] | | | | <0.36 | <2.0 | | 1.6 |
| Seawater | Pipeline | 1[E] | 4.2 | | | <0.21 | <0.034 | | <0.18 |

| Material | Location | No. of sampling observ-ations | Mean radioactivity concentration (fresh)[a], Bq kg$^{-1}$ | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | $^{238}$Pu | $^{239}$Pu + $^{240}$Pu | $^{241}$Am | $^{242}$Cm | $^{243}$Cm + $^{244}$Cm | Gross alpha | Gross beta |
| **Marine samples** | | | | | | | | | |
| Cod | Stolford | 1 | | | <0.17 | | | | |
| Shrimps | Stolford | 1 | 0.00019 | 0.0010 | 0.0011 | * | 0.0000092 | | |
| Limpets | Stolford | 1 | | | <0.04 | | | | |
| Pacific Oyster | Stolford | 1 | | | <0.06 | | | | |
| Seaweed | Pipeline | 2[E] | | | <0.59 | | | | |
| Sediment | Pipeline | 2[E] | | | <0.50 | | | | |
| Sediment | Stolford | 2[E] | | | <0.66 | | | | |
| Sediment | Steart Flats | 2[E] | | | <0.77 | | | | |
| Sediment | River Parrett | 2[E] | | | <1.2 | | | | |
| Sediment | River Parrett Central 1 | 2[E] | | | <0.70 | | | | |
| Sediment | River Parrett Central 2 | 2[E] | | | <0.65 | | | | |
| Sediment | Burrowbridge | 2[E] | | | <0.71 | | | | |
| Sediment | Pawlett | 2[E] | | | <0.73 | | | | |
| Sediment | East Bank | 2[E] | | | <0.71 | | | | |
| Sediment | Weston-Super-Mare | 2[E] | | | <0.38 | | | | |
| Sediment | Burnham-On-Sea | 2[E] | | | <0.37 | | | | |
| Sediment | Kilve | 2[E] | | | <0.49 | | | | |
| Sediment | Helwell Bay | 2[E] | | | <0.61 | | | | |
| Sediment | Blue Anchor Bay | 2[E] | | | <0.51 | | | | |
| Seawater | Pipeline | 1[E] | | | <0.29 | | | <4.3 | 8.7 |

## Table 4.7(a) continued

| Material | Location or selection[b] | No. of sampling observ-ations[c] | Mean radioactivity concentration (fresh)[a], Bq kg$^{-1}$ | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | $^{3}$H | $^{14}$C | $^{35}$S | $^{60}$Co | $^{137}$Cs | Gross alpha | Gross beta |
| **Terrestrial samples** | | | | | | | | | |
| Milk | | 3 | <3.5 | 25 | <0.31 | <0.06 | <0.06 | | |
| Milk | max | | <4.8 | 31 | <0.40 | <0.09 | <0.07 | | |
| Blackberries | | 1 | <2.4 | 33 | 0.60 | <0.05 | <0.05 | | |
| Honey | | 1 | <4.0 | 82 | <0.20 | <0.04 | <0.06 | | |
| Wheat | | 1 | <4.3 | 90 | 1.4 | <0.03 | <0.07 | | |
| Grass | Gunter's Grove | 2[E] | <5.7 | 27 | | <1.2 | <0.85 | | |
| Grass | Wall Common | 2[E] | <12 | <22 | | <0.99 | <0.74 | | |
| Freshwater | Durleigh Reservoir | 2[E] | <3.2 | | <0.46 | <0.34 | <0.25 | <0.031 | 0.20 |
| Freshwater | Ashford Reservoir | 2[E] | <3.2 | | <0.45 | <0.21 | <0.19 | <0.064 | 0.061 |

* *Not detected by the method used*

[a] *Except for milk and water where units are Bq l$^{-1}$ and for sediment and soil where dry concentrations apply*

[b] *Data are arithmetic means unless stated as 'max' in this column. 'Max' data are selected to be maxima. If no 'max' value is given the mean value is the most appropriate for dose assessments*

[c] *The number of farms from which milk is sampled. The number of analyses is greater than this and depends on the bulking regime*

[E] *Measurements labelled "E" are made on behalf of the Environment Agency, all other measurements are made on behalf of the Food Standards Agency*

## Table 4.7(b) Monitoring of radiation dose rates near Hinkley Point nuclear power stations, 2016

| Location | Ground type | No. of sampling observations | µGy h$^{-1}$ |
|---|---|---|---|
| **Mean gamma dose rates at 1m over substrate** | | | |
| Weston-Super-Mare | Sand | 1 | 0.074 |
| Weston-Super-Mare | Mud and sand | 1 | 0.057 |
| Burnham-on-Sea | Sand | 1 | 0.075 |
| Burnham-on-Sea | Mud and sand | 1 | 0.058 |
| River Parrett | Mud | 2 | 0.081 |
| River Parrett 1 | Mud | 1 | 0.077 |
| River Parrett 1 | Mud and salt marsh | 1 | 0.075 |
| River Parrett 2 | Mud | 1 | 0.085 |
| River Parrett 2 | Mud and salt marsh | 1 | 0.074 |
| River Parrett Burrowbridge | Mud and salt marsh | 2 | 0.071 |
| River Parrett Pawlett | Mud | 1 | 0.078 |
| River Parrett Pawlett | Mud and salt marsh | 1 | 0.075 |
| River Parrett East bank | Mud | 1 | 0.069 |
| River Parrett East bank | Mud and salt marsh | 1 | 0.073 |
| Steart Flats | Mud | 2 | 0.075 |
| Stolford | Mud | 2 | 0.090 |
| Hinkley Point | Mud and sand | 1 | 0.092 |
| Hinkley Point | Mud and rock | 1 | 0.086 |
| Kilve | Mud and sand | 1 | 0.096 |
| Kilve | Mud and shingle | 1 | 0.083 |
| Helwell Bay | Rock and mud | 1 | 0.11 |
| Helwell Bay | Mud and shingle | 1 | 0.10 |
| Blue Anchor Bay | Mud and sand | 2 | 0.076 |

## Table 4.8(a) Concentrations of radionuclides in food and the environment near Sizewell nuclear power stations, 2016

| Material | Location | No. of sampling observations | Mean radioactivity concentration (fresh)[a], Bq kg$^{-1}$ | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Organic $^{3}$H | $^{3}$H | $^{14}$C | $^{137}$Cs | $^{238}$Pu | $^{239}$Pu + $^{240}$Pu |
| **Marine samples** | | | | | | | | |
| Cod | Sizewell | 1 | <25 | <25 | | 0.31 | | |
| Sole | Sizewell | 1 | <25 | <25 | | 0.09 | | |
| Crabs | Sizewell | 1 | <25 | <25 | | <0.03 | | |
| Mussels | River Alde | 1 | <25 | <25 | 30 | 0.11 | 0.0012 | 0.0075 |
| Sediment | Aldeburgh | 2[E] | | | | <0.16 | | |
| Sediment | Southwold harbour | 2[E] | | | | 5.8 | | |
| Sediment | Minsmere river outfall | 2[E] | | | | 6.7 | | |
| Seawater | Sizewell beach | 2[E] | | <3.3 | | <0.22 | | |

| Material | Location | No. of sampling observations | Mean radioactivity concentration (fresh)[a], Bq kg$^{-1}$ | | | | |
|---|---|---|---|---|---|---|---|
| | | | $^{241}$Am | $^{242}$Cm | $^{243}$Cm + $^{244}$Cm | Gross alpha | Gross beta |
| **Marine samples** | | | | | | | |
| Cod | Sizewell | 1 | <0.04 | | | | |
| Sole | Sizewell | 1 | <0.09 | | | | |
| Crabs | Sizewell | 1 | <0.03 | | | | |
| Mussels | River Alde | 1 | 0.0064 | * | 0.00013 | | |
| Sediment | Aldeburgh | 2[E] | <0.30 | | | | |
| Sediment | Southwold harbour | 2[E] | <0.72 | | | | 940 |
| Sediment | Minsmere river outfall | 2[E] | <0.49 | | | | |
| Seawater | Sizewell beach | 2[E] | <0.27 | | | <3.9 | 12 |

| Material | Location or selection[b] | No. of sampling observations[c] | Mean radioactivity concentration (fresh)[a], Bq kg$^{-1}$ | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | $^{3}$H | $^{14}$C | $^{35}$S | $^{137}$Cs | Gross alpha | Gross beta |
| **Terrestrial samples** | | | | | | | | |
| Milk | | 3 | <4.9 | 22 | <0.33 | <0.07 | | |
| Milk | max | | <6.2 | 25 | | <0.09 | | |
| Potatoes | | 1 | <2.6 | 26 | <0.20 | <0.09 | | |
| Wheat | | 1 | <3.7 | 83 | 1.2 | <0.08 | | |
| Grass | Sizewell belts | 2[E] | <18 | <8.1 | | <0.87 | | |
| Grass | Sizewell common | 2[E] | <7.1 | <11 | | <0.63 | | |
| Freshwater | Minsmere nature reserve | 2[E] | <3.4 | | <0.41 | <0.24 | <0.031 | 0.14 |
| Freshwater | The Meare | 2[E] | <3.3 | | <0.39 | <0.19 | <0.035 | 0.26 |
| Freshwater | Leisure Park | 2[E] | <6.6 | | <0.39 | <0.20 | <0.051 | 0.37 |
| Freshwater | Farm reservoir | 2[E] | <3.3 | | <0.41 | <0.21 | <0.030 | 0.12 |

* *Not detected by the method used*

[a] *Except for milk and water where units are Bq l$^{-1}$, and for sediment where dry concentrations apply*

[b] *Data are arithmetic means unless stated as 'max' in this column. 'Max' data are selected to be maxima. If no 'max' value is given the mean value is the most appropriate for dose assessments*

[c] *The number of farms from which milk is sampled. The number of analyses is greater than this and depends on the bulking regime*

[E] *Measurements labelled "E" are made on behalf of the Environment Agency, all other measurements are made on behalf of the Food Standards Agency*

## Table 4.8(b) Monitoring of radiation dose rates near Sizewell, 2016

| Location | Ground type | No. of sampling observations | µGy $h^{-1}$ |
|---|---|---|---|
| **Mean gamma dose rates at 1m over substrate** | | | |
| Sizewell Beach | Sand and shingle | 2 | 0.046 |
| Dunwich | Sand and shingle | 2 | 0.044 |
| Aldeburgh | Sand and shingle | 2 | 0.056 |
| Southwold Harbour | Mud and salt marsh | 2 | 0.062 |

## Table 4.9(a) Concentrations of radionuclides in food and the environment near Chapelcross nuclear power station, 2016

| Material | Location | No. of sampling observations | Mean radioactivity concentration (fresh)[a], Bq $kg^{-1}$ | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $^{3}H$ | $^{14}C$ | $^{60}Co$ | $^{90}Sr$ | $^{95}Nb$ | $^{95}Zr$ | $^{99}Tc$ | $^{106}Ru$ | $^{110m}Ag$ |
| **Marine samples** | | | | | | | | | | | |
| Flounder | Inner Solway | 2 | | 21 | <0.10 | <0.10 | <0.36 | <0.32 | <0.39 | <0.86 | <0.12 |
| Salmon | Inner Solway | 1 | <5.0 | | <0.10 | | <0.40 | <0.35 | | <0.85 | <0.12 |
| Sea trout | Inner Solway | 1 | <5.0 | | <0.10 | | <0.23 | <0.24 | | <0.73 | <0.11 |
| Shrimps | Inner Solway | 2 | <5.0 | | <0.10 | <0.10 | <0.37 | <0.31 | <0.21 | <0.74 | <0.15 |
| Cockles | North Solway | 1 | | | <0.10 | | <0.25 | <0.21 | | <0.53 | <0.10 |
| Mussels | North Solway | 2 | <5.0 | 54 | <0.10 | | <0.24 | <0.20 | 11 | <0.51 | <0.12 |
| *Fucus vesiculosus* | Pipeline | 4 | | | <0.10 | | <0.59 | <0.35 | 270 | <0.82 | <0.16 |
| *Fucus vesiculosus* | Browhouses | 2 | | | <0.10 | | <0.89 | <0.49 | 51 | <0.76 | <0.16 |
| *Fucus vesiculosus* | Dornoch Brow | 2 | | | <0.13 | | <0.91 | <0.60 | 50 | <0.85 | <0.17 |
| Sediment | Priestside Bank | 1 | | | <0.10 | | <0.72 | <0.37 | | <0.63 | <0.12 |
| Sediment | Pipeline | 4 | <5.0 | | 0.46 | | <1.3 | <0.45 | | <0.96 | <0.19 |
| Sediment | Dornoch Brow | 1 | | | 0.26 | | <0.40 | <0.33 | | <0.52 | <0.10 |
| Sediment | Powfoot | 1 | | | <0.10 | | <0.10 | <0.10 | | <0.30 | <0.10 |
| Sediment | Redkirk | 1 | | | <0.10 | | <0.10 | <0.10 | | <0.32 | <0.10 |
| Sediment | Stormont | 1 | | | <0.10 | | <0.10 | <0.10 | | <0.34 | <0.10 |
| Seawater | Pipeline | 2 | 2.0 | | <0.10 | | <0.36 | <0.22 | | <0.43 | <0.10 |

| Material | Location | No. of sampling observations | Mean radioactivity concentration (fresh)[a], Bq $kg^{-1}$ | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $^{125}Sb$ | $^{137}Cs$ | $^{154}Eu$ | $^{155}Eu$ | $^{238}Pu$ | $^{239}Pu$ + $^{240}Pu$ | $^{241}Am$ | Gross alpha | Gross beta |
| **Marine samples** | | | | | | | | | | | |
| Flounder | Inner Solway | 2 | <0.25 | <0.10 | <0.12 | <0.20 | 0.0074 | 0.0074 | 0.013 | | |
| Salmon | Inner Solway | 1 | <0.24 | 0.21 | <0.12 | <0.20 | | | <0.12 | | |
| Sea trout | Inner Solway | 1 | <0.22 | <0.10 | <0.12 | <0.19 | | | <0.11 | | |
| Shrimps | Inner Solway | 2 | <0.22 | 3.1 | <0.11 | <0.19 | 0.0019 | 0.015 | 0.031 | | |
| Cockles | North Solway | 1 | <0.15 | 2.0 | <0.10 | <0.13 | 0.41 | 3.0 | 5.2 | | |
| Mussels | North Solway | 2 | <0.15 | 0.98 | <0.10 | <0.15 | 0.34 | 2.0 | 4.4 | | |
| *Fucus vesiculosus* | Pipeline | 4 | <0.23 | 2.7 | <0.13 | <0.29 | 0.35 | 2.5 | 1.5 | 9.1 | 430 |
| *Fucus vesiculosus* | Browhouses | 2 | <0.21 | 4.4 | <0.12 | <0.36 | 0.47 | 3.0 | 6.3 | 11 | 250 |
| *Fucus vesiculosus* | Dornoch Brow | 2 | <0.24 | 3.2 | <0.13 | <0.34 | 0.50 | 3.0 | 6.6 | 11 | 240 |
| Sediment | Priestside Bank | 1 | <0.20 | 18 | <0.19 | 0.73 | 0.0026 | 0.014 | 33 | | |
| Sediment | Pipeline | 4 | <0.36 | 110 | <0.26 | 1.5 | 14 | 91 | 0.086 | | |
| Sediment | Dornoch Brow | 1 | <0.18 | 75 | 0.23 | 1.3 | 6.5 | 36 | 75 | | |
| Sediment | Powfoot | 1 | 0.11 | 21 | <0.10 | 1.0 | 2.6 | 14 | 22 | | |
| Sediment | Redkirk | 1 | <0.12 | 30 | <0.11 | 0.36 | 3.1 | 18 | 30 | | |
| Sediment | Stormont | 1 | <0.10 | 34 | <0.10 | 0.61 | 4.0 | 21 | 38 | | |
| Seawater | Pipeline | 2 | <0.13 | <0.10 | <0.10 | <0.12 | | | <0.10 | | |

## Table 4.9(a) continued

| Material | Location or selection[b] | No. of sampling observations[c] | Mean radioactivity concentration (fresh)[a], Bq kg$^{-1}$ | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | $^{3}$H | $^{14}$C | $^{35}$S | $^{60}$Co | $^{90}$Sr | $^{95}$Nb | $^{106}$Ru |
| **Terrestrial samples** | | | | | | | | | |
| Milk | | 10 | <5.5 | 17 | <0.50 | <0.05 | <0.10 | <0.18 | <0.31 |
| Milk | max | | <8.2 | 23 | <0.51 | | | <0.24 | <0.35 |
| Apples | | 1 | <5.0 | <15 | <0.50 | <0.05 | <0.10 | <0.24 | <0.37 |
| Beef | | 1 | <5.0 | 60 | <0.52 | <0.07 | <0.10 | <0.45 | <0.68 |
| Beetroot | | 1 | <5.0 | 22 | <0.50 | <0.05 | 0.16 | <0.14 | <0.38 |
| Broccoli | | 1 | <5.0 | <15 | <0.50 | <0.05 | <0.10 | <0.11 | <0.40 |
| Cabbage | | 1 | <5.0 | <15 | <0.50 | <0.05 | <0.10 | <0.12 | <0.40 |
| Cauliflower | | 1 | <5.0 | <15 | <0.50 | <0.05 | <0.10 | <0.13 | <0.20 |
| Duck | | 2 | <5.0 | 30 | <0.50 | <0.05 | <0.10 | <0.12 | <0.36 |
| Duck | max | | | 33 | | | | <0.15 | <0.37 |
| Eggs | | 1 | <5.0 | 39 | <0.50 | <0.05 | <0.10 | <0.23 | <0.35 |
| Goose | | 1 | <5.0 | 26 | <0.50 | <0.05 | <0.10 | <0.08 | <0.29 |
| Onion | | 1 | <5.0 | <15 | <0.50 | <0.05 | <0.10 | <0.09 | <0.36 |
| Potatoes | | 1 | <5.0 | | <0.50 | <0.05 | <0.10 | <0.09 | <0.23 |
| Rosehips | | 1 | <5.0 | 33 | <0.50 | <0.05 | 0.32 | <0.26 | <0.38 |
| Turnips | | 1 | <5.0 | <15 | <0.50 | <0.05 | <0.10 | <0.14 | <0.44 |
| Grass | | 4 | <6.2 | <16 | <0.83 | <0.05 | <0.20 | <0.19 | <0.29 |
| Grass | max | | 9.9 | 20 | 1.8 | | 0.35 | <0.30 | <0.43 |
| Soil | | 4 | <5.0 | <15 | <1.8 | <0.06 | 1.1 | <0.19 | <0.43 |
| Soil | max | | | | <2.7 | <0.10 | 1.6 | 0.22 | <0.48 |
| Freshwater | Purdomstone | 1 | <1.0 | | | <0.01 | | <0.01 | <0.03 |
| Freshwater | Winterhope | 1 | <1.0 | | | <0.01 | | <0.01 | <0.03 |
| Freshwater | Black Esk | 1 | <1.0 | | | <0.01 | | <0.01 | <0.03 |
| Freshwater | Gullielands Burn | 1 | 34 | | | <0.01 | | <0.01 | <0.02 |

| Material | Location or selection[b] | No. of sampling observations[c] | Mean radioactivity concentration (fresh)[a], Bq kg$^{-1}$ | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | $^{134}$Cs | $^{137}$Cs | $^{155}$Eu | $^{241}$Am | Gross alpha | Gross beta |
| **Terrestrial samples** | | | | | | | | |
| Milk | | 10 | <0.05 | <0.05 | | <0.05 | | |
| Milk | max | | | | | <0.06 | | |
| Apples | | 1 | <0.05 | <0.05 | | <0.05 | | |
| Beef | | 1 | <0.08 | <0.07 | | <0.11 | | |
| Beetroot | | 1 | <0.05 | <0.05 | | <0.06 | | |
| Broccoli | | 1 | <0.05 | <0.05 | | <0.06 | | |
| Cabbage | | 1 | <0.05 | 0.24 | | <0.06 | | |
| Cauliflower | | 1 | <0.05 | <0.05 | | <0.05 | | |
| Duck | | 2 | <0.05 | 1.9 | | <0.09 | | |
| Duck | max | | | 2.3 | | <0.10 | | |
| Eggs | | 1 | <0.05 | <0.05 | | <0.05 | | |
| Goose | | 1 | <0.05 | 0.10 | | <0.13 | | |
| Onion | | 1 | <0.05 | <0.05 | | <0.05 | | |
| Potatoes | | 1 | <0.05 | <0.05 | | <0.05 | | |
| Rosehips | | 1 | <0.05 | <0.05 | | <0.09 | | |
| Turnips | | 1 | <0.05 | <0.05 | | <0.06 | | |
| Grass | | 4 | <0.05 | <0.05 | | <0.09 | 1.5 | 220 |
| Grass | max | | | | | <0.11 | 1.7 | 330 |
| Soil | | 4 | <0.07 | 11 | 1.6 | <0.36 | 200 | 1500 |
| Soil | max | | <0.10 | 16 | 1.8 | 0.76 | 240 | 1600 |
| Freshwater | Purdomstone | 1 | <0.01 | <0.01 | | <0.004 | 0.013 | 0.28 |
| Freshwater | Winterhope | 1 | <0.01 | <0.01 | | <0.004 | <0.010 | 0.039 |
| Freshwater | Black Esk | 1 | <0.01 | <0.01 | | <0.003 | <0.010 | 0.065 |
| Freshwater | Gullielands Burn | 1 | <0.01 | <0.01 | | <0.010 | 0.020 | 0.15 |

[a] *Except for milk and water where units are Bq l$^{-1}$, and for sediment and soil where dry concentrations apply*
[b] *Data are arithmetic means unless stated as 'max' in this column. 'Max' data are selected to be maxima. If no 'max' value is given the mean value is the most appropriate for dose assessments*
[c] *The number of farms from which milk is sampled. The number of analyses is greater than this and depends on the bulking regime*

## Table 4.9(b) Monitoring of radiation dose rates near Chapelcross, 2016

| Location | Material or ground type | No. of sampling observations | μGy $h^{-1}$ |
|---|---|---|---|
| **Mean gamma dose rates at 1m over substrate** | | | |
| Glencaple Harbour | Sediment | 1 | 0.078 |
| Priestside Bank | Salt marsh | 1 | 0.074 |
| Powfoot Merse | Sand | 1 | 0.074 |
| Gullielands | Grass | 1 | 0.073 |
| Seafield | Sand | 1 | 0.080 |
| Woodhead | Grass | 1 | 0.078 |
| East Bretton | Grass | 1 | 0.077 |
| Pipeline | Sand | 2 | 0.077 |
| Pipeline | Salt marsh | 2 | 0.081 |
| Dumbretton | Grass | 1 | 0.071 |
| Battlehill | Sand | 1 | 0.085 |
| Battlehill | Sediment and rocks | 1 | 0.079 |
| Dornoch Brow | Salt marsh | 1 | 0.079 |
| Dornoch Brow | Sand | 1 | 0.071 |
| Browhouses | Sand | 1 | 0.076 |
| Redkirk | Sand | 2 | 0.082 |
| Stormont | Sand | 2 | 0.070 |
| **Mean beta dose rates** | | | μSv $h^{-1}$ |
| Pipeline | Stake nets | 2 | <1.0 |

## Table 4.9(c) Radioactivity in air near Chapelcross, 2016

| Location | No. of sampling observations | Mean radioactivity concentration, mBq $m^{-3}$ | | |
|---|---|---|---|---|
| | | $^{137}Cs$ | Gross alpha | Gross beta |
| Eastriggs | 12 | <0.010 | <0.0079 | <0.20 |
| Kirtlebridge | 9 | <0.010 | <0.014 | <0.20 |
| Brydekirk | 10 | <0.012 | <0.028 | <0.20 |

**Table 4.10(a) Concentrations of radionuclides in food and the environment near Hunterston nuclear power station, 2016**

| Material | Location | No. of sampling observ-ations | Mean radioactivity concentration (fresh)[a], Bq kg$^{-1}$ | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | $^{3}$H | $^{35}$S | $^{54}$Mn | $^{60}$Co | $^{65}$Zn | $^{95}$Nb | $^{99}$Tc | $^{110m}$Ag |
| **Marine samples** | | | | | | | | | | |
| Cod | Millport | 2 | | | <0.10 | <0.10 | <0.23 | <0.43 | | <0.13 |
| Hake | Millport | 2 | | | <0.10 | <0.10 | <0.24 | <0.45 | | <0.13 |
| Crabs | Millport | 2 | | | <0.11 | <0.10 | <0.26 | <0.53 | <0.36 | <0.13 |
| *Nephrops* | Millport | 2 | | | <0.20 | <0.15 | <0.53 | <1.8 | | <0.26 |
| Lobsters | Largs | 1 | | | <0.10 | <0.10 | <0.24 | <2.1 | 10 | <0.12 |
| Squat lobsters | Largs | 2 | | | <0.10 | <0.10 | <0.16 | <0.36 | 4.7 | <0.10 |
| Mussels | Pipeline | 1 | | | <0.11 | <0.10 | <0.26 | <0.31 | | <0.12 |
| Winkles | Pipeline | 2 | | | <0.11 | <0.10 | <0.25 | <0.62 | | 0.45 |
| Scallops | Largs | 2 | | | <0.10 | <0.10 | <0.15 | <0.24 | | <0.10 |
| Oysters | Hunterston | 1 | | | <0.10 | <0.10 | <0.17 | <0.17 | | <0.10 |
| *Fucus vesiculosus* | N of pipeline | 2 | | | 0.35 | 0.20 | <0.25 | <0.39 | | <0.11 |
| *Fucus vesiculosus* | S of pipeline | 2 | | | 0.29 | <0.10 | <0.29 | <0.65 | | <0.14 |
| Sediment | Largs | 1 | | | <0.10 | <0.10 | <0.21 | <0.26 | | <0.11 |
| Sediment | Millport | 1 | | | <0.10 | <0.10 | <0.16 | <0.33 | | <0.10 |
| Sediment | Gull's Walk | 1 | | | <0.10 | 0.13 | <0.19 | <0.24 | | <0.10 |
| Sediment | Ardneil Bay | 1 | | | <0.10 | <0.10 | <0.12 | <0.16 | | <0.10 |
| Sediment | Fairlie | 1 | | | <0.10 | <0.10 | <0.15 | <0.15 | | <0.10 |
| Sediment | Pipeline | 1 | | | <0.10 | <0.10 | <0.12 | <0.14 | | <0.10 |
| Sediment | Ardrossan North Bay | 1 | | | <0.10 | <0.10 | <0.10 | <0.13 | | <0.10 |
| Sediment | Ardrossan South Bay | 1 | | | <0.10 | <0.10 | <0.18 | <0.21 | | <0.10 |
| Seawater | Pipeline | 2 | 12 | 0.50 | <0.10 | <0.10 | <0.12 | <0.13 | | <0.10 |

| Material | Location | No. of sampling observ-ations | Mean radioactivity concentration (fresh)[a], Bq kg$^{-1}$ | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | $^{125}$Sb | $^{137}$Cs | $^{154}$Eu | $^{155}$Eu | $^{238}$Pu | $^{239}$Pu + $^{240}$Pu | $^{241}$Am |
| **Marine samples** | | | | | | | | | |
| Cod | Millport | 2 | <0.21 | 0.96 | <0.11 | <0.18 | | | <0.11 |
| Hake | Millport | 2 | <0.22 | 0.70 | <0.11 | <0.19 | | | <0.11 |
| Crabs | Millport | 2 | <0.25 | <0.10 | <0.13 | <0.22 | 0.010 | 0.026 | 0.12 |
| *Nephrops* | Millport | 2 | <0.40 | 0.28 | <0.19 | <0.33 | | | <0.16 |
| Lobsters | Largs | 1 | <0.19 | 0.17 | <0.12 | <0.20 | | | <0.10 |
| Squat lobsters | Largs | 2 | <0.16 | <0.22 | <0.10 | <0.12 | 0.0082 | 0.053 | 0.065 |
| Mussels | Pipeline | 1 | <0.25 | <0.10 | <0.14 | <0.24 | | | <0.14 |
| Winkles | Pipeline | 2 | <0.27 | 0.47 | <0.13 | <0.19 | 0.081 | 0.64 | 1.3 |
| Scallops | Largs | 2 | <0.15 | 0.14 | <0.10 | <0.13 | 0.033 | 0.055 | 0.26 |
| Oysters | Hunterston | 1 | <0.21 | <0.10 | <0.11 | <0.18 | | | <0.10 |
| *Fucus vesiculosus* | N of pipeline | 2 | <0.22 | 0.43 | <0.12 | <0.20 | | | <0.13 |
| *Fucus vesiculosus* | S of pipeline | 2 | <0.25 | 0.17 | <0.15 | <0.25 | | | <0.15 |
| Sediment | Largs | 1 | <0.18 | 6.9 | <0.17 | 0.99 | | | <0.30 |
| Sediment | Millport | 1 | <0.13 | 3.2 | <0.11 | <0.22 | | | 0.25 |
| Sediment | Gull's Walk | 1 | <0.18 | 16 | <0.13 | 0.45 | | | 1.50 |
| Sediment | Ardneil Bay | 1 | <0.10 | 2.0 | <0.10 | <0.15 | | | <0.14 |
| Sediment | Fairlie | 1 | <0.13 | 4.6 | <0.10 | <0.18 | | | 0.31 |
| Sediment | Pipeline | 1 | <0.10 | 2.4 | <0.10 | <0.18 | | | 0.44 |
| Sediment | Ardrossan North Bay | 1 | <0.10 | 3.2 | <0.10 | <0.16 | | | <0.15 |
| Sediment | Ardrossan South Bay | 1 | <0.14 | 2.5 | <0.11 | 0.20 | | | 0.97 |
| Seawater | Pipeline | 2 | <0.14 | <0.10 | <0.10 | <0.12 | | | <0.10 |

**Table 4.10(a) continued**

| Material | Selection[b] | No. of sampling observ-ations[c] | Mean radioactivity concentration (fresh)[a], Bq kg$^{-1}$ | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $^{3}$H | $^{14}$C | $^{35}$S | $^{60}$Co | $^{90}$Sr | $^{95}$Nb | $^{110m}$Ag | $^{137}$Cs | $^{155}$Eu | $^{241}$Am | Gross alpha | Gross beta |
| **Terrestrial Samples** | | | | | | | | | | | | | | |
| Milk | | 3 | <5.0 | <18 | <0.50 | <0.05 | <0.10 | <0.14 | <0.05 | <0.05 | | <0.05 | | |
| Milk | max | | | <19 | | | | <0.17 | | | | <0.08 | | |
| Apples | | 1 | <5.0 | 28 | <0.50 | <0.05 | <0.10 | <0.26 | <0.07 | <0.05 | | <0.06 | | |
| Beef | | 1 | <5.0 | 32 | <0.50 | <0.05 | <0.10 | <0.24 | <0.06 | 0.33 | | <0.05 | | |
| Beetroot | | 1 | <5.0 | <15 | <0.50 | <0.05 | <0.10 | <0.18 | <0.05 | <0.05 | | <0.05 | | |
| Cabbage | | 1 | <5.0 | <15 | <0.50 | <0.05 | <0.10 | <0.19 | <0.05 | <0.05 | | <0.05 | | |
| Carrots | | 1 | <5.0 | <15 | <0.50 | <0.05 | <0.10 | <0.19 | <0.05 | <0.05 | | <0.06 | | |
| Eggs | | 1 | <5.0 | 31 | <0.50 | <0.05 | 0.10 | <0.21 | <0.05 | <0.05 | | <0.05 | | |
| Honey | | 1 | <6.1 | 84 | <0.75 | <0.05 | 0.57 | <0.06 | <0.05 | 0.07 | | <0.07 | | |
| Lamb | | 1 | <5.0 | 44 | 0.81 | <0.05 | <0.10 | <0.24 | <0.06 | 0.16 | | <0.05 | | |
| Leeks | | 1 | <5.0 | <15 | <0.50 | <0.05 | <0.10 | <0.10 | <0.05 | <0.05 | | <0.05 | | |
| Pheasant | | 1 | <5.0 | 40 | <0.67 | <0.05 | | | | 0.08 | | | | |
| Potatoes | | 1 | <5.0 | <15 | <0.50 | <0.05 | <0.10 | <0.19 | <0.05 | 0.13 | | <0.05 | | |
| Rosehips | | 1 | <5.0 | 46 | <0.50 | <0.05 | 0.26 | <0.25 | <0.07 | 0.07 | | <0.12 | | |
| Turnips | | 1 | <5.0 | <15 | <0.50 | <0.05 | 0.16 | <0.20 | <0.06 | 0.05 | | <0.06 | | |
| Wild blackberries | | 1 | <5.0 | 23 | 1.0 | <0.05 | 0.61 | <0.35 | <0.05 | 0.12 | | <0.07 | | |
| Grass | | 3 | <5.0 | <21 | 1.5 | <0.05 | 0.31 | <0.16 | <0.06 | 0.11 | | <0.06 | 2.4 | 380 |
| Grass | max | | | 30 | 2.8 | | 0.48 | <0.26 | | 0.16 | | | 2.8 | 400 |
| Soil[d] | | 3 | <5.0 | <15 | <1.2 | <0.05 | 1.1 | <0.27 | <0.09 | 14 | 0.65 | <0.21 | 140 | 990 |
| Soil | max | | | | <1.4 | | 1.6 | <0.33 | | 23 | 0.96 | <0.27 | 180 | 1300 |
| Freshwater | Knockenden Reservoir | 1 | 1.1 | | | <0.01 | | <0.01 | <0.01 | <0.01 | | <0.004 | <0.010 | 0.024 |
| Freshwater | Loch Ascog | 1 | <1.0 | | | <0.01 | | <0.01 | <0.01 | <0.01 | | <0.004 | <0.010 | 0.11 |
| Freshwater | Munnoch Reservoir | 1 | <1.0 | | | <0.01 | | <0.03 | <0.01 | <0.01 | | <0.01 | 0.018 | 0.076 |
| Freshwater | Camphill | 1 | <1.0 | | | <0.01 | | <0.03 | <0.01 | <0.01 | | <0.01 | 0.017 | 0.047 |
| Freshwater | Outerwards | 1 | <1.0 | | | <0.01 | | <0.04 | <0.01 | <0.01 | | <0.01 | 0.023 | 0.050 |

[a] *Except for milk, seawater and freshwater where units are Bq l$^{-1}$ and for sediment and soil where dry concentrations apply*

[b] *Data are arithmetic means unless stated as 'max' in this column. 'Max' data are selected to be maxima. If no 'max' value is given the mean value is the most appropriate for dose assessments*

[c] *The number of farms from which milk is sampled. The number of analyses is greater than this and depends on the bulking regime*

[d] *The concentration of $^{131}$I was <21 Bq kg$^{-1}$*

## Table 4.10(b) Monitoring of radiation dose rates near Hunterston nuclear power station, 2016

| Location | Ground type | No. of sampling observations | μGy $h^{-1}$ |
|---|---|---|---|
| **Mean gamma dose rates at 1m over substrate** | | | |
| Meigle Bay | Sand | 2 | 0.064 |
| Largs Bay | Stones | 2 | 0.070 |
| Kilchatten Bay | Sand | 2 | 0.055 |
| Millport | Sand | 2 | 0.066 |
| Gull's Walk | Sand | 2 | 0.067 |
| Hunterston | Sand | 2 | 0.065 |
| 0.5 km north of pipeline | Sand | 2 | 0.062 |
| 0.5 km south of pipeline | Rocks and sediment | 2 | 0.073 |
| Portencross | Grass | 1 | 0.059 |
| Ardneil Bay | Sand | 2 | 0.056 |
| Ardrossan North Bay | Sand | 2 | 0.055 |
| Ardrossan South Bay | Sand | 2 | 0.056 |
| Milstonford | Grass | 1 | 0.062 |
| Biglies | Grass | 1 | 0.062 |
| **Beta dose rates** | | | μSv $h^{-1}$ |
| Millport | Sand | 1 | <1.0 |
| 0.5 km north of pipeline | Sand | 1 | <1.0 |
| 0.5 km south of pipeline | Sand | 1 | <1.0 |

## Table 4.10(c) Radioactivity in air near Hunterston, 2016

| Location | No. of sampling observations | Mean radioactivity concentration, mBq $m^{-3}$ | | |
|---|---|---|---|---|
| | | $^{137}Cs$ | Gross alpha | Gross beta |
| Fairlie | 12 | <0.010 | <0.016 | <0.20 |
| West Kilbride | 9 | <0.010 | <0.022 | <0.20 |
| Low Ballees | 12 | <0.014 | <0.024 | <0.20 |

## Table 4.11(a) Concentrations of radionuclides in food and the environment near Torness nuclear power station, 2016

| Material | Location | No. of sampling observations | Mean radioactivity concentration (fresh)[a], Bq kg$^{-1}$ | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | $^{54}$Mn | $^{60}$Co | $^{65}$Zn | $^{99}$Tc | $^{110m}$Ag | $^{137}$Cs |
| **Marine samples** | | | | | | | | |
| Cod | White Sands | 2 | <0.10 | <0.10 | <0.27 | | <0.13 | 0.22 |
| Mackerel | Pipeline | 2 | <0.11 | <0.10 | <0.22 | | <0.12 | 0.16 |
| Crabs[d] | Torness | 1 | <0.10 | <0.10 | <0.13 | <0.13 | <0.10 | <0.10 |
| Lobsters | Torness | 1 | <0.10 | <0.10 | <0.19 | 3.4 | <0.10 | <0.10 |
| *Nephrops* | Dunbar | 2 | <0.10 | <0.10 | <0.23 | | <0.11 | <0.11 |
| Winkles | Pipeline | 2 | <0.10 | <0.10 | <0.21 | | 0.88 | <0.10 |
| *Fucus vesiculosus* | Pipeline | 2 | <0.14 | 0.33 | <0.24 | | <0.12 | <0.10 |
| *Fucus vesiculosus* | Thornton Loch | 2 | <0.10 | 0.14 | <0.20 | 11 | <0.10 | <0.10 |
| *Fucus vesiculosus* | White Sands | 2 | <0.10 | <0.10 | <0.28 | | <0.11 | <0.12 |
| *Fucus vesiculosus* | Pease Bay | 2 | <0.10 | <0.10 | <0.22 | | <0.11 | <0.10 |
| *Fucus vesiculosus* | Coldingham Bay | 2 | <0.10 | <0.10 | <0.27 | | <0.12 | <0.11 |
| Sediment | Dunbar | 1 | <0.10 | <0.10 | <0.11 | | <0.10 | 1.7 |
| Sediment | Barns Ness | 1 | <0.10 | <0.10 | <0.13 | | <0.10 | 0.52 |
| Sediment | Thornton Loch | 1 | <0.10 | <0.10 | <0.14 | | <0.10 | 0.80 |
| Sediment | Heckies Hole | 1 | <0.10 | <0.10 | <0.19 | | <0.10 | 1.1 |
| Sediment | Belhaven Bay | 1 | <0.10 | <0.10 | <0.18 | | <0.10 | 0.37 |
| Sediment | Coldingham Bay | 1 | <0.10 | <0.10 | <0.16 | | <0.10 | 0.71 |
| Sediment | Pease Bay | 1 | <0.10 | <0.10 | <0.28 | | <0.10 | 1.2 |
| Seawater[e] | Pipeline | 2 | <0.10 | <0.10 | <0.17 | | <0.10 | <0.10 |

| Material | Location | No. of sampling observations | Mean radioactivity concentration (fresh)[a], Bq kg$^{-1}$ | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | $^{155}$Eu | $^{238}$Pu | $^{239}$Pu + $^{240}$Pu | $^{241}$Am | Gross alpha | Gross beta |
| **Marine samples** | | | | | | | | |
| Cod | White Sands | 2 | <0.20 | | | <0.12 | | |
| Mackerel | Pipeline | 2 | <0.20 | | | <0.15 | | |
| Crabs[d] | Torness | 1 | <0.10 | | | <0.10 | | |
| Lobsters | Torness | 1 | <0.15 | | | <0.10 | | |
| *Nephrops* | Dunbar | 2 | <0.18 | 0.00046 | 0.0048 | 0.0080 | | |
| Winkles | Pipeline | 2 | <0.16 | | | <0.10 | 4.5 | 110 |
| *Fucus vesiculosus* | Pipeline | 2 | <0.19 | | | <0.17 | | |
| *Fucus vesiculosus* | Thornton Loch | 2 | <0.14 | | | <0.10 | | |
| *Fucus vesiculosus* | White Sands | 2 | <0.23 | | | <0.19 | | |
| *Fucus vesiculosus* | Pease Bay | 2 | <0.19 | | | <0.11 | | |
| *Fucus vesiculosus* | Coldingham Bay | 2 | <0.28 | | | <0.25 | | |
| Sediment | Dunbar | 1 | <0.21 | | | <0.20 | | |
| Sediment | Barns Ness | 1 | <0.18 | | | <0.17 | | |
| Sediment | Thornton Loch | 1 | <0.22 | | | <0.21 | | |
| Sediment | Heckies Hole | 1 | 0.62 | | | <0.27 | | |
| Sediment | Belhaven Bay | 1 | <1.1 | | | <0.27 | | |
| Sediment | Coldingham Bay | 1 | 0.33 | | | <0.17 | | |
| Sediment | Pease Bay | 1 | 0.49 | | | <0.18 | | |
| Seawater[e] | Pipeline | 2 | <0.16 | | | <0.11 | | |

## Table 4.11(a) continued

| Material | Location or Selection[b] | No. of sampling observations[c] | Mean radioactivity concentration (fresh)[a], Bq kg$^{-1}$ | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $^{3}$H | $^{14}$C | $^{35}$S | $^{90}$Sr | $^{110m}$Ag | $^{137}$Cs | $^{155}$Eu | $^{241}$Am | Gross alpha | Gross beta |
| **Terrestrial Samples** | | | | | | | | | | | | |
| Milk | | 2 | <5.0 | <18 | <0.50 | <0.10 | <0.05 | <0.05 | | <0.05 | | |
| Milk | max | | | <20 | | | | | | | | |
| Brussel sprouts | | 1 | <5.0 | 26 | <0.50 | 0.11 | <0.05 | <0.05 | | <0.06 | | |
| Carrots | | 1 | <5.0 | <15 | <0.50 | 0.16 | <0.06 | <0.05 | | <0.06 | | |
| Eggs | | 1 | <5.0 | 39 | <0.56 | <0.10 | <0.06 | <0.05 | | <0.05 | | |
| Leeks | | 1 | <5.0 | <15 | <0.50 | 0.14 | <0.07 | <0.06 | | <0.07 | | |
| Parsnips | | 1 | <5.0 | 21 | <0.50 | <0.10 | <0.06 | <0.05 | | <0.07 | | |
| Partridge | | 1 | <5.0 | 37 | <0.61 | <0.10 | <0.07 | <0.05 | | <0.06 | | |
| Pheasant | | 1 | <5.0 | 34 | <0.69 | 0.16 | <0.07 | <0.05 | | <0.07 | | |
| Pork | | 1 | <5.0 | <15 | <0.59 | <0.10 | <0.05 | 0.12 | | <0.06 | | |
| Potatoes | | 1 | <5.0 | 29 | <0.50 | <0.10 | <0.06 | <0.05 | | <0.06 | | |
| Rosehips | | 1 | <5.0 | 30 | 0.57 | 0.39 | <0.06 | <0.05 | | <0.13 | | |
| Turnip | | 1 | <5.0 | 17 | <0.50 | 0.16 | <0.06 | <0.05 | | <0.06 | | |
| Venison | | 1 | <5.0 | 43 | <0.78 | | <0.09 | <0.07 | | <0.10 | | |
| Wild blackberries | | 1 | <5.0 | 23 | <0.50 | 0.34 | <0.06 | <0.05 | | <0.14 | | |
| Wild mushrooms | | 1 | <5.0 | <15 | <0.50 | <0.10 | <0.05 | <0.05 | | <0.05 | | |
| Grass | | 3 | <5.0 | 31 | <0.71 | 0.16 | <0.06 | <0.05 | | <0.14 | 1.8 | 330 |
| Grass | max | | | 37 | 1.1 | 0.20 | <0.07 | | | <0.28 | 2.5 | 370 |
| Soil | | 3 | <5.1 | <15 | <3.0 | 0.74 | <0.10 | 7.7 | 1.5 | <0.20 | 200 | 1100 |
| Soil | max | | <5.2 | | 4.5 | 1.1 | | 11 | | <0.28 | 280 | 1400 |
| Freshwater | Hopes Reservoir | 1 | 1.1 | | | | <0.01 | <0.01 | | <0.01 | <0.010 | 0.017 |
| Freshwater | Thorter's Reservoir | 1 | <1.0 | | | | <0.01 | <0.01 | | <0.003 | 0.015 | 0.062 |
| Freshwater | Whiteadder | 1 | <1.0 | | | | <0.01 | <0.01 | | | <0.010 | 0.053 |
| Freshwater | Thornton Loch Burn | 1 | <1.0 | | | | <0.01 | <0.01 | | <0.003 | 0.015 | 0.095 |

[a] *Except for milk and seawater where units are Bq l$^{-1}$ and for sediment and soil where dry concentrations apply*
[b] *Data are arithmetic means unless stated as 'max' in this column. 'Max' data are selected to be maxima. If no 'max' value is given the mean value is the most appropriate for dose assessments*
[c] *The number of farms from which milk is sampled. The number of analyses is greater than this and depends on the bulking regime*
[d] *The concentration of $^{14}$C was 50 Bq kg$^{-1}$*
[e] *The concentrations of $^{3}$H and $^{35}$S were 9.5 and <0.50 Bq l$^{-1}$ respectively*

## Table 4.11(b) Monitoring of radiation dose rates near Torness nuclear power station, 2016

| Location | Ground type | No. of sampling observations | µGy h$^{-1}$ |
|---|---|---|---|
| **Mean gamma dose rates at 1m over substrate** | | | |
| Heckies Hole | Sand | 2 | 0.073 |
| Dunbar Inner Harbour | Sediment | 2 | 0.087 |
| Belhaven Bay | Sediment | 2 | 0.056 |
| Barns Ness | Sediment | 2 | 0.071 |
| Skateraw | Sand | 2 | 0.056 |
| Thornton Loch | Grass | 1 | 0.061 |
| Thornton Loch beach | Sand | 2 | 0.067 |
| Ferneylea | Grass | 1 | 0.074 |
| Pease Bay | Sediment | 2 | 0.076 |
| St Abbs Head | Shingle | 1 | 0.096 |
| St Abbs Head | Rocks | 1 | 0.097 |
| Coldingham Bay | Sediment | 2 | 0.059 |
| West Meikle Pinkerton | Grass | 1 | 0.070 |
| **Mean beta dose rates on fishing gear** | | | µSv h$^{-1}$ |
| Torness | Lobster Pots | 2 | <1.0 |

## Table 4.11(c) Radioactivity in air near Torness, 2016

| Location | No. of sampling observations | Mean radioactivity concentration, mBq m$^{-3}$ | | | |
|---|---|---|---|---|---|
| | | $^{60}$Co | $^{137}$Cs | Gross alpha | Gross beta |
| Innerwick | 11 | 0.012 | <0.010 | <0.012 | <0.20 |
| Cockburnspath | 12 | | <0.010 | <0.0095 | <0.20 |
| West Barns | 12 | <0.010 | <0.014 | <0.014 | <0.20 |

## Table 4.12(a) Concentrations of radionuclides in food and the environment near Trawsfynydd nuclear power station, 2016

| Material | Location | No. of sampling observ-ations | Mean radioactivity concentration (fresh)[a], Bq kg$^{-1}$ | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | $^{3}$H | $^{14}$C | $^{60}$Co | $^{90}$Sr | $^{134}$Cs | $^{137}$Cs | $^{154}$Eu |
| **Freshwater samples** | | | | | | | | | |
| Rainbow trout | Trawsfynydd Lake | 2 | | 44 | <0.10 | 0.57 | <0.10 | 0.79 | <0.34 |
| Sediment | Lake shore near café | 2[E] | | | <0.83 | <2.0 | <0.72 | 120 | |
| Sediment | 1.5km SE of power station | 1[E] | | | <1.3 | <2.0 | <1.3 | 12 | |
| Sediment | SE of footbridge | 1[E] | | | <1.4 | 3.9 | <1.3 | 10 | |
| Sediment | Cae Adda | 2[E] | | | <0.65 | <2.5 | <0.56 | 60 | |
| Freshwater | Pipeline | 1[E] | <3.0 | | <0.32 | | <0.32 | <0.25 | |
| Freshwater | Gwylan Stream | 2[E] | <3.5 | | <0.21 | | <0.22 | <0.18 | |
| Freshwater | Afon Prysor | 2[E] | <3.2 | | <0.22 | | <0.24 | <0.19 | |
| Freshwater | 1.5km SE of power station | 2[E] | <3.1 | | <0.20 | | <0.19 | <0.14 | |
| Freshwater | Afon Tafarn-helyg | 2[E] | <3.1 | | <0.23 | | <0.24 | <0.19 | |

| Material | Location | No. of sampling observ-ations | Mean radioactivity concentration (fresh)[a], Bq kg$^{-1}$ | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | $^{238}$Pu | $^{239}$Pu + $^{240}$Pu | $^{241}$Am | $^{242}$Cm | $^{243}$Cm + $^{244}$Cm | Gross alpha | Gross beta |
| **Freshwater samples** | | | | | | | | | |
| Rainbow trout | Trawsfynydd Lake | 2 | 0.000022 | 0.000099 | 0.00039 | * | * | | |
| Sediment | Lake shore near café | 2[E] | <0.36 | <0.51 | <1.6 | | | | |
| Sediment | 1.5km SE of power station | 1[E] | <0.57 | <0.29 | <0.40 | | | | |
| Sediment | SE of footbridge | 1[E] | <0.57 | <0.34 | <1.3 | | | | |
| Sediment | Cae Adda | 2[E] | <0.44 | <0.32 | <0.47 | | | | |
| Freshwater | Pipeline | 1[E] | | | | | | <0.019 | <0.027 |
| Freshwater | Gwylan Stream | 2[E] | | | | | | <0.020 | 0.11 |
| Freshwater | Afon Prysor | 2[E] | | | | | | <0.020 | <0.063 |
| Freshwater | 1.5km SE of power station | 2[E] | | | | | | <0.021 | <0.028 |
| Freshwater | Afon Tafarn-helyg | 2[E] | | | | | | <0.022 | 0.042 |

| Material | Selection[c] | No. of sampling observ-ations[d] | Mean radioactivity concentration (fresh)[a], Bq kg$^{-1}$ | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | $^{3}$H | $^{14}$C | $^{90}$Sr | $^{137}$Cs | Total Cs | $^{238}$Pu | $^{239}$Pu + $^{240}$Pu | $^{241}$Am |
| **Terrestrial Samples** | | | | | | | | | | |
| Milk | | 2 | <3.2 | 23 | <0.022 | <0.05 | <0.055 | | | <0.11 |
| Milk | max | | <3.4 | 25 | | <0.06 | <0.058 | | | <0.16 |
| Potatoes | | 1 | <3.1 | 18 | | <0.04 | | <0.000053 | 0.00040 | 0.00034 |
| Grass | | 1 | <2.9 | 12 | | 0.18 | | 0.0010 | 0.0056 | 0.011 |

* *Not detected by the method used*

[a] *Except for milk and water where units are Bq l$^{-1}$, and for sediment where dry concentrations apply*

[b] *Data are arithmetic means unless stated as 'max' in this column. 'Max' data are selected to be maxima. If no 'max' value is given the mean value is the most appropriate for dose assessments*

[c] *The number of farms from which milk is sampled. The number of analyses is greater than this and depends on the bulking regime*

[E] *Measurements labelled "E" are made on behalf of the Environment Agency, all other measurements are made on behalf of the Food Standards Agency*

**Table 4.12(b) Monitoring of radiation dose rates near Trawsfynydd nuclear power station, 2016**

| Location | Ground type | No. of sampling observations | μGy $h^{-1}$ |
|---|---|---|---|
| **Mean gamma dose rates at 1m over substrate** | | | |
| Lake shore (SE of footbridge) | Grass | 2 | 0.10 |
| Lake shore (1.5km SE) | Grass and stones | 1 | 0.093 |
| Lake shore (1.5km SE) | Grass | 1 | 0.093 |
| Cae Adda | Grass and pebbles | 1 | 0.079 |
| Cae Adda | Pebbles and stones | 1 | 0.090 |
| Lake shore | Pebbles | 1 | 0.093 |
| Lake shore | Pebbles and stones | 1 | 0.085 |

## Table 4.13(a) Concentrations of radionuclides in food and the environment near Wylfa nuclear power station, 2016

| Material | Location | No. of sampling observations | Mean radioactivity concentration (fresh)[a], Bq kg$^{-1}$ | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Organic $^{3}$H | $^{3}$H | $^{14}$C | $^{99}$Tc | $^{137}$Cs | $^{238}$Pu | $^{239}$Pu + $^{240}$Pu |
| **Marine samples** | | | | | | | | | |
| Plaice | Pipeline | 1 | <25 | <25 | 40 | | 0.60 | | |
| Crabs | Pipeline | 1 | <25 | <25 | 39 | | <0.08 | | |
| Lobsters | Pipeline | 1 | 28 | 33 | 61 | 18 | 0.37 | 0.0033 | 0.021 |
| Winkles | Cemaes Bay | 1 | <25 | <25 | 42 | 9.4 | 0.28 | 0.025 | 0.16 |
| Seaweed | Cemaes Bay | 2[E] | | | | 15 | <0.44 | | |
| Sediment | Cemaes Bay | 2[E] | | | | | 2.9 | | |
| Sediment | Cemlyn Bay West | 2[E] | | | | | 2.2 | | |
| Seawater | Cemaes Bay | 2[E] | | <3.2 | | | <0.20 | | |

| Material | Location | No. of sampling observations | Mean radioactivity concentration (fresh)[a], Bq kg$^{-1}$ | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | $^{241}$Pu | $^{241}$Am | $^{242}$Cm | $^{243}$Cm + $^{244}$Cm | Gross alpha | Gross beta |
| **Marine samples** | | | | | | | | |
| Plaice | Pipeline | 1 | | <0.13 | | | | |
| Crabs | Pipeline | 1 | | <0.09 | | | | |
| Lobsters | Pipeline | 1 | 0.30 | 0.12 | * | * | | 110 |
| Winkles | Cemaes Bay | 1 | 0.53 | 0.24 | * | * | | 72 |
| Seaweed | Cemaes Bay | 2[E] | | <0.44 | | | | |
| Sediment | Cemaes Bay | 2[E] | | 1.3 | | | | |
| Sediment | Cemlyn Bay West | 2[E] | | <0.78 | | | | |
| Seawater | Cemaes Bay | 2[E] | | <0.28 | | | <3.7 | 13 |

| Material | Location or selection[b] | No. of sampling observations[c] | Mean radioactivity concentration (fresh)[a], Bq kg$^{-1}$ | | | |
|---|---|---|---|---|---|---|
| | | | $^{3}$H | $^{14}$C | $^{35}$S | $^{137}$Cs |
| **Terrestrial samples** | | | | | | |
| Milk | | 2 | <3.8 | 24 | <0.36 | <0.06 |
| Milk | max | | <5.2 | | <0.38 | |
| Potatoes | | 1 | <2.2 | 15 | 0.50 | <0.07 |
| Grass | | 1 | <3.2 | 14 | 2.0 | <0.03 |
| Grass | Wylfa Head Nature Reserve | 1[E] | <28 | <5.6 | | <1.1 |
| Grass | Foel Fawr | 2[E] | <13 | <8.2 | | <0.45 |

* *Not detected by the method used*

[a] *Except for milk and water where units are Bq l$^{-1}$, and sediment where dry concentrations apply*

[b] *Data are arithmetic means unless stated as 'max' in this column. 'Max' data are selected to be maxima. If no 'max' value is given the mean value is the most appropriate for dose assessments*

[c] *The number of farms from which milk is sampled. The number of analyses is greater than this and depends on the bulking regime*

[E] *Measurements labelled "E" are made on behalf of the Environment Agency, all other measurements are made on behalf of the Food Standards Agency*

## Table 4.13(b) Monitoring of radiation dose rates near Wylfa nuclear power station, 2016

| Location | Ground type | No. of sampling observations | µGy h$^{-1}$ |
|---|---|---|---|
| **Mean gamma dose rates at 1m over substrate** | | | |
| Cemaes Bay | Sand | 2 | 0.075 |
| Cemlyn Bay West | Shingle | 2 | 0.072 |
| Porth Yr Ogaf | Sand | 1 | 0.087 |

# 5. Defence establishments

This section considers the results of monitoring, under the responsibility of the Environment Agency, FSA, FSS and SEPA, undertaken routinely near nine defence-related establishments in the UK. In addition, the MoD makes arrangements for monitoring at other defence sites where contamination may occur. The operator at the Atomic Weapons Establishment (AWE) in Berkshire carries out environmental monitoring to determine the effects from low level gaseous discharges at its sites. Monitoring at nuclear submarine berths is also conducted by the MoD (DSTL Radiological Protection Services, 2016).

In 2016, gaseous and liquid discharges were below regulated limits for each of the defence establishments (see Appendix 2, Tables A2.1 and A2.2). Solid waste transfers in 2016 from nuclear establishments in Scotland (Coulport, Faslane, Rosyth and Vulcan) are also given in Appendix 2 (Table A2.4).

## Key points

- *Total doses* for the representative person were less than 2 per cent of the dose limit for all sites assessed, except at Barrow where the dose is mainly the result of historical discharges from Sellafield

### Aldermaston, Berkshire

- Gaseous discharges of 'volatile beta' decreased in 2016

### Barrow, Cumbria

- *Total dose* for the representative person increased in 2016

### Faslane and Coulport, Argyll and Bute

- *Total dose* for the representative person increased in 2016

### Rosyth, Fife

- *Total dose* for the representative person increased in 2016

## 5.1 Aldermaston, Berkshire


AWE plc at Aldermaston provides and maintains the fundamental components of the UK's nuclear deterrent (Trident). The site and facilities at Aldermaston remain in Government ownership under a Government Owned Contractor Operator (GOCO) arrangement. The day-to-day operations and the maintenance of Britain's nuclear stockpile are managed, on behalf of the MoD, by AWE plc. The site is regulated by the Environment Agency to discharge low concentrations of radioactive waste to the environment.

The most recent habits survey to determine the consumption and occupancy rates by members of the public in the vicinity of the site was undertaken in 2011 (Ly *et al.*, 2012).

### Doses to the public

In 2016, the *total dose* from all pathways and sources of radiation was less than 0.005 mSv (Table 5.1), or less than 0.5 per cent of the dose limit. The representative person was an infant (1 year-old) consuming local cows' milk at high-rates.

Source specific assessments for high-rate consumers of locally grown foods, for sewage workers and for anglers, give exposures that were also less than 0.005 mSv in 2016 (Table 5.1). Estimates of activity concentrations in fish have been based on shellfish samples from the aquatic monitoring programme for the dose determination. A low consumption rate of 1 kg per year for fish has been included in the dose assessment for anglers.

### Gaseous discharges and terrestrial monitoring

Gaseous radioactive waste is discharged via stacks on the site. In 2016, discharges of 'volatile beta' decreased, in comparison to releases in 2015. Samples of milk, terrestrial foodstuffs, grass and soil were taken from locations close to the site (Figure 3.4) and environmental results for 2016 are given in Table 5.2(a). Activity concentrations in milk and foodstuffs were generally below the limits of detection, as in 2015. The tritium concentrations in milk, foodstuffs, grass and soil are reported as less than values in 2016. Tritium is considered in the dose assessment and is of very low significance. In soil samples, where comparisons can be drawn at the same location, concentrations of caesium-137

were similar to values in 2015. Levels of uranium isotopes also remained similar to those in 2015. Natural background or weapon test fallout would have made a significant contribution to the levels detected.

## Liquid waste discharges and aquatic monitoring

Discharges of radioactive liquid effluent are made under permit to the sewage works at Silchester (Figure 3.4), and to the Aldermaston stream. Discharges of alpha and other beta radionuclides to Silchester in 2016 were similar to those reported in 2015; discharges of tritium to Aldermaston Stream were very low and similar to those in previous years. There are two factors behind the longer-term decline in discharges of tritium from Aldermaston (Figure 5.1): the closure and decommissioning of the original tritium facility (the replacement facility uses sophisticated abatement technology that results in the discharge of significantly less tritium into the environment), and the historical contamination of groundwater. The historical contamination has been reduced in recent years by radioactive decay and dilution by natural processes. Environmental monitoring of the River Thames (Pangbourne and Mapledurham) has continued to assess the effect of historical discharges.

Activity concentrations for freshwater, fish, crayfish, sediment samples (including gully pot sediments from road drains), liquid effluent and sewage sludge from Silchester treatment works, and measurements of dose rates, are given in Tables 5.2(a) and (b). In 2016, the Environment Agency carried out enhanced environmental monitoring of sediments and freshwater samples, following the review of their programme. The concentrations of artificial radioactivity detected in the Thames catchment were very low and generally similar to those in 2015. Iodine-131 was not detected in fish and crayfish in 2016; in recent years iodine-131 has been detected in sediments and sludges (most likely due to waste discharges from the therapeutic use in medicine). Tritium concentrations in all collected samples are reported as less than values. Activity concentrations of artificial radionuclides in River Kennet shellfish were measured at very low levels and similar to those reported in 2015. Analyses of caesium-137 and uranium activity concentrations in River Kennet sediments were broadly consistent with those in recent years. Gross alpha and beta activities in freshwater samples were below the investigation levels for drinking water in the European Directive 2013/51. Gamma dose rates were below or close to natural background.

## 5.2 Barrow, Cumbria


At Barrow, BAE Systems Marine Limited builds, tests and commissions new nuclear powered submarines. Permitted gaseous and liquid discharges were reported as nil and less than 1 per cent of the discharge limit, respectively, in 2016. The FSA's terrestrial monitoring is limited to vegetable and grass sampling and the Environment Agency monitors dose rates and analyses sediment samples from local intertidal areas. The latter is directed primarily at the far-field effects of Sellafield discharges. A habits survey was undertaken in 2012 (Garrod *et al.*, 2013b).

The *total dose* from all pathways and sources of radiation was 0.082 mSv (Table 5.1), or approximately 8 per cent of the dose limit, and up from 0.051 mSv in 2015. The representative person was an adult living on a local houseboat. Virtually all of this dose was due to the effects of Sellafield discharges. The apparent increase in *total dose* is mostly because gamma dose rates were measured on different ground types (at Roa Island and Askam Pier), from one year to the next.

Source specific assessments for a high-rate consumer of locally grown food and a person living on a local houseboat give exposures that were less than the *total dose* (Table 5.1). No assessment of seafood consumption was undertaken in 2016 because of the absence of relevant monitoring data. However, the dose from seafood consumption is less important than that from external exposure on a houseboat (EA, FSA, NIEA, NRW and SEPA, 2014).

Dose rates in intertidal areas near Barrow were slightly enhanced above those expected due to natural background (Table 5.3(b) and Table 2.9). This enhancement was due to the far-field effects of historical discharges from Sellafield as evidenced by the results of sediment analysis from the local area (Table 5.3(a)). No effects of discharges from Barrow were apparent in the concentrations of radioactivity in vegetables and grass. All but one of such results are reported as less than values (Table 5.3(a)).

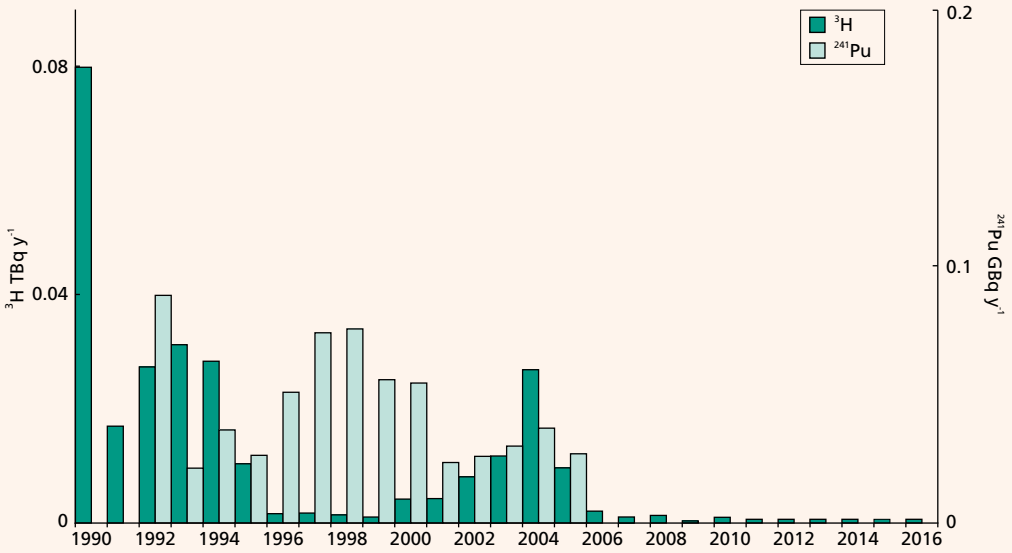



**Figure 5.1.** Trends in liquid discharges of tritium and plutonium-241 from Aldermaston, Berkshire 1990-2016 (including discharges to River Thames at Pangbourne, Silchester sewer and Aldermaston Stream)

## 5.3 Derby, Derbyshire


Rolls-Royce Marine Power Operations Limited (RRMPOL), a subsidiary of Rolls-Royce plc, carries out design, development, testing and manufacture of nuclear-powered submarine fuel at its two adjacent sites in Derby. Small discharges of liquid effluent are made via the Megaloughton Lane Sewage Treatment Works to the River Derwent and very low concentrations of alpha activity are present in releases to atmosphere. Other wastes are disposed of by transfer to other sites, including the LLWR (near Drigg). A habits survey was undertaken at Derby in 2009 (Elliott *et al.*, 2010).

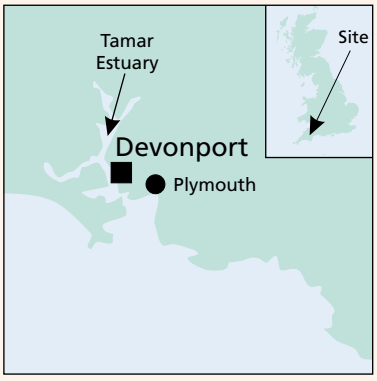
### Doses to the public

In 2016, the *total dose* from all pathways and sources of radiation was less than 0.005 mSv (Table 5.1), which is less than 0.5 per cent of the dose limit. Source specific assessments for consumption of vegetables, fish and drinking river water at high-rates, and for a local resident exposed to external and inhalation pathways from gaseous discharges, give exposures that were also less than 0.005 mSv in 2016 (Table 5.1).

Results of the routine monitoring programme at Derby are given in Table 5.3(a). Analysis of uranium activity in samples taken around the site in 2016 found levels broadly consistent with previous years. More detailed analysis in previous years has shown the activity as being consistent with natural sources. Gross alpha and beta activities in water from the River Derwent were less than the investigation levels for drinking water in the European Directive 2013/51, and the dose from using the river as a source of drinking water was much less than 0.005 mSv per year (Table 5.1). Caesium-137 detected in sediments from local water courses is most likely to have been from fallout from overseas sources.

Table 5.3(a) also includes analysis results from a water sample taken from Fritchley Brook, downstream of Hilts Quarry. RRMPOL formerly used the quarry for the controlled burial of solid low level radioactive waste. Concentrations of uranium isotopes detected in the sample in 2016 were broadly similar to those levels reported elsewhere in Derbyshire in previous RIFE reports (e.g. Environment Agency, FSA, FSS, NIEA, NRW and SEPA, 2016).

## 5.4 Devonport, Devon




The Devonport Royal Dockyard consists of two parts and is operated by Her Majesty's Naval Base (owned and operated by the MoD) and Devonport Royal Dockyard Limited (owned by Babcock International Group plc). Devonport Royal Dockyard refits, refuels, repairs and

maintains the Royal Navy's nuclear powered submarine fleet and has a permit granted by the Environment Agency to discharge liquid radioactive waste to the Hamoaze, which is part of the Tamar Estuary, and to the local sewer, and gaseous waste to the atmosphere.

In May 2016, Devonport Royal Dockyard Limited, were granted a variation to their permit to increase the gaseous discharge limit for carbon-14. This variation was to accommodate a potential increase in gaseous carbon-14 discharges resulting from the decontamination of the primary circuit of HMS Vanguard's reactor. The most recent habits survey to determine the consumption and occupancy rates by members of the public was undertaken in 2011 (Clyne *et al.*, 2012). The routine monitoring programme in 2016 consisted of measurements of gamma dose rate and analysis of grass, vegetables, fish, shellfish and other indicator materials (Tables 5.3(a) and (b)).

## Doses to the public

In 2016, the *total dose* from all pathways and sources of radiation was less than 0.005 mSv (Table 5.1), which was less than 0.5 per cent of the dose limit. The representative person was an adult seafood consumer. Trends in *total doses* in the area of the south coast (and the Severn Estuary) are shown in Figure 6.1.

Source specific assessments for a high-rate consumer of locally grown food (including doses from external and inhalation from gaseous discharges) and of fish and shellfish, and for an occupant of a houseboat, give exposures that were also less than 0.005 mSv (Table 5.1) which was less than 0.5 per cent of the dose limit for members of the public of 1 mSv.

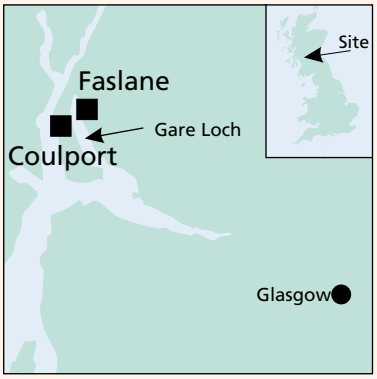
## Gaseous discharges and terrestrial monitoring

Gaseous discharges were generally similar to those in 2015. Samples of grass and vegetables were analysed for a number of radionuclides, and concentrations are reported as less than values in both.

## Liquid waste discharges and marine monitoring

Discharges to the Hamoaze in 2016 were similar to those reported in 2015. Figure 5.2 shows the discharge trends of tritium and cobalt-60 since 1990. The main contributor to the variations in tritium discharges over time has been the re-fitting of Vanguard class submarines. These submarines have a high tritium inventory as they do not routinely discharge primary circuit coolant until they undergo refuelling at Devonport. The underlying reason for the overall decrease in cobalt-60 discharges over this period was the improvement in submarine reactor design so that less cobalt-60 was produced during operation, and therefore less was released during submarine maintenance operations. In marine samples, most concentrations of tritium and cobalt-60 are reported as less than values. Tritium was positively detected at low concentrations in one sediment sample (at Lopwell). Trace amounts of caesium-137, likely to originate from Chernobyl and global weapon test fallout, were measured in sediment samples. Carbon-14 concentrations in fish species are similar to those in recent years and are likely to be due to natural sources. The seaweed samples contained very low concentrations of iodine-131 in 2016. These were most likely to have originated from the therapeutic use of this radionuclide in a local hospital. Gamma dose rates in the vicinity of Devonport were similar to 2015. They reflect the local effects of enhanced background radiation from natural sources.

## 5.5 Faslane and Coulport, Argyll and Bute




The HMNB Clyde establishment consists of the naval base at Faslane and the armaments depot at Coulport. Babcock Marine, a subsidiary of Babcock International Group plc, operates HMNB Clyde, Faslane in partnership with the MoD. However, the MoD remains in control of the undertaking, through the Naval Base Commander, Clyde (NBC Clyde) in relation to radioactive waste disposal. MoD through NBC Clyde also remains in control of the undertaking at Coulport although many of the activities undertaken at Coulport have been outsourced to an industrial alliance comprising of AWE plc, Babcock and Lockheed Martin UK (known as ABL).

Discharges of liquid radioactive waste, into Gare Loch from Faslane and the discharge of gaseous radioactive waste in the form of tritium to the atmosphere from Coulport, are made under letters of agreement between SEPA and the MoD. SEPA reviewed these letters in 2012 and concluded that radioactive waste disposal was broadly in line with authorisations, in place for civil sites, under RSA 93. SEPA began a process to update the agreements, but in 2016 this process was superseded by the requirement for new agreements to cover operations at a new radioactive waste treatment facility on the Base. The new facility will replace the existing facilities and is expected to be in service by late 2018. An application for new agreements is expected to be made during 2017. This timing coincided with the planning to update the existing agreements and so it was decided to

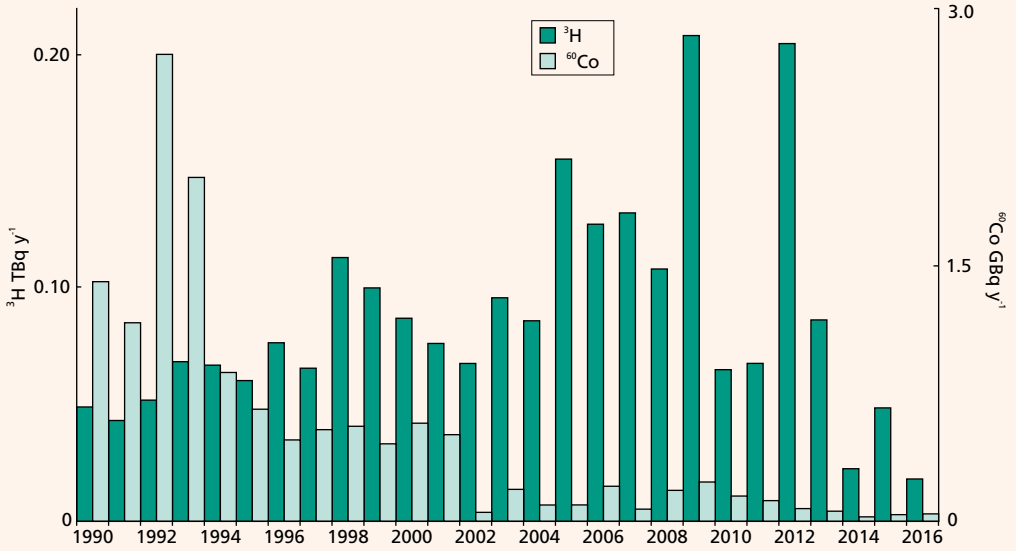



**Figure 5.2.** Trends in liquid discharges of tritium and cobalt-60 from Devonport, Devon 1990-2016

supersede the update with the process to determine new agreements for the new facilities.

The liquid discharges are given in Appendix 2 (Table A2.2). The disposal of solid radioactive waste from each site is also made under letters of agreement between SEPA and the MoD. Solid waste transfers from Faslane and Coulport in 2016 are also given in Appendix 2 (Table A2.4).

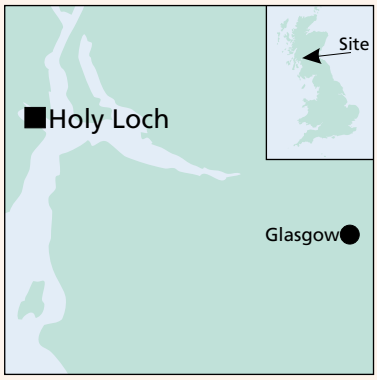
During the summer of 2016, a habits survey was conducted to determine the consumption and occupancy rates by members of the public (SEPA, *in press/b*). Large increases in the consumption rates of fish and crustacean, and intertidal occupancy rates have been observed, in comparison with those of the previous survey in 2011. The habits survey in 2016 used a similar methodology to the survey in 2011. The increase in consumption and occupancy rates in certain areas (in 2016) was verified using a follow up survey later in the year with a sub-set of willing individuals. The follow up survey confirmed that the initial data were valid. In addition, the follow up survey identified a reduction in fish consumption for the high-rate individuals, due to a change in anticipated fishing time during that year. This provided SEPA with two sets of validated data for a dose assessment. The revised figures for consumption rates, together with occupancy rates are provided in Appendix 1 (Table X2.2).

The *total dose* from all pathways and sources of radiation was 0.009 mSv in 2016 (Table 5.1), which is less than 1 per cent of the dose limit, and up from less than 0.005 mSv in 2015. The assessment of *total dose* is conservative by estimating activities in fish using reported environmental data in 2016. The representative person was an adult fish consumer. The increase in *total dose*, and change in representative person, was mostly due to the increase of the fish consumption rate and occupancy time over sand from the revised habits data in 2016. Source specific assessments for a high-rate consumer of fish and shellfish and a consumer of locally grown food (based on limited data), give exposures of 0.012 mSv and less than 0.005 mSv, respectively. The reason for the increase in dose (from < 0.005 mSv in 2015) to the consumer of fish and shellfish is the same as that contributing to the maximum *total dose*.

The increase in dose is largely a result of the higher consumption and occupancy values recorded as a result of the new habits survey. Whilst the increase in dose is measurable, it is notable that this is not due to environmental monitoring results, which have stayed in line with previous years' data. At SEPA's request, Cefas used previous 2011 habits data to calculate the dose with 2016 monitoring data, which confirmed that the dose would have been less than 0.005 mSv to a similar group.

The routine marine monitoring programme consisted of the analysis of shellfish, seawater, seaweed and sediment samples, and gamma dose rate measurements. Terrestrial monitoring included beef, honey, water, grass and soil sampling. The results are given in Tables 5.3(a) and (b) and were generally similar to those in 2015. Caesium-137 was positively detected at a low concentration in one local food sample (honey). Radionuclide concentrations were generally below the limits of detection, with caesium-137 concentrations in sediment consistent with the distant effects of discharges from Sellafield, and with weapon testing and Chernobyl fallout. Tritium, gross alpha and gross beta concentrations in freshwater were much lower than the investigation levels in the European Directive 2013/51. Carbon-14 concentrations in shellfish were similar to natural background levels. Gamma dose rates measured in the surrounding area were difficult to distinguish from natural background.

## 5.6 Holy Loch, Argyll and Bute




A small programme of monitoring at Holy Loch continued during 2016 in order to determine the effects of past discharges from the US submarine support facilities which closed in 1992. Radionuclide concentrations were low (Table 5.3(a)). Gamma dose rate measurements from intertidal areas (Table 5.3(b)) were similar to those observed in 2015. The external radiation dose to a person spending time on the loch shore was 0.013 mSv in 2016, which was approximately 1 per cent of the dose limit for members of the public of 1 mSv (Table 5.1).

## 5.7 Rosyth, Fife


The Rosyth naval dockyard is located on the north bank of the River Forth in Fife, 3 km west of the Forth Road Bridge and some 50 km from the mouth of the Firth of Forth. It is sited on reclaimed land, with reclamation completed in 1916. From 1916, the site was known as HM Dockyard Rosyth and activities conducted there included refitting and maintaining warships.

In 1997, Rosyth Royal Dockyard Limited (RRDL), a wholly owned subsidiary of Babcock International Group Marine Division was set up to be responsible for the decommissioning of the dockyard site and the management of radioactive waste that had arisen from the re-fitting of nuclear submarines which ended in 2003. Site decommissioning started in 2006 and has mainly been completed, except for some small areas of the site where facilities continue to be required to manage radioactive wastes.

The MoD sold the site to Babcock International Group Marine Division who now manage and operate the site. However, radioactive waste that was generated by the site, to support the nuclear submarine fleet, is owned by the MoD. Therefore, MoD has entered into a contract with RRDL to manage all radioactive waste on the dockyard site. As the radioactive waste owner, the MoD undertakes an assurance function to ensure RRDL fully complies with the terms and conditions of its contract.

In 2008, SEPA granted RRDL an authorisation, under RSA 93, to dispose of radioactive waste arising on the Rosyth dockyard site. This allowed RRDL to dispose of LLW that had arisen from the decommissioning of the Rosyth premises and from former submarine re-fitting operations.

The focus of the work is now on the dismantling of the seven redundant nuclear submarines currently stored afloat on the dockyard site. Therefore, following separate applications made by RRDL and the MoD, SEPA granted a Letter of Approval (effective from 1st December 2016) to the MoD to allow the transfer of LLW from the seven nuclear submarines berthed at the Rosyth dockyard site to RRDL. Furthermore, on 1st December 2016, SEPA also issued a new authorisation to RRDL (revoking the authorisation in 2008), under RSA 93, to make the final disposals of LLW from the Rosyth dockyard premises. The new authorisation contains annual authorised site limits for the disposals of gaseous and liquid waste. This allows RRDL to receive and dispose of solid LLW that has arisen from former submarine re-fitting operations and from on-going decommissioning of the Rosyth dockyard premises. The annual authorised limits for the disposals of gaseous and liquid waste from the site have been mostly reduced (or kept at the same level), compared to the previous authorisation. Discharge limits effective during 2016 (January to November; December) for gaseous and liquid releases are given in Appendix 2 (Table A2.1 and Table A2.2, respectively). Solid waste transfers in 2016 from Rosyth are also given in Appendix 2 (Table A2.4).

Granting of the Letter of Approval and new authorisation to RRDL permits the start of the MoD submarine dismantling programme at Rosyth. Work to dismantle and remove radioactive and conventional wastes from each submarine and subsequently clean up the Rosyth site is expected to take up to 15 years to complete.

New conditions on the accumulation of radioactive waste were included authorising RRDL to accumulate radioactive waste on those parts of the Rosyth site that are not subject to the conditions contained in the Nuclear Site Licence granted by the Office for Nuclear Regulation under the Nuclear Installations Act (United Kingdom - Parliament, 1965). Specific conditions relating to non-radiological discharge quality standards for liquid waste discharges were also included in the new authorisation, under RSA 93, to incorporate the requirements of the Water Environment (Controlled Activities) (Scotland) Regulations 2011, or CAR, noting that RSA 93 is a "relevant licence" for the purposes of CAR.

SEPA, and other stakeholders, continue to engage with the MoD Nuclear Legacy Works Team based at Rosyth to identify the optimised arrangements to manage radiologically contaminated ion-exchange resins stored securely in the Active Waste Accumulation Facility on

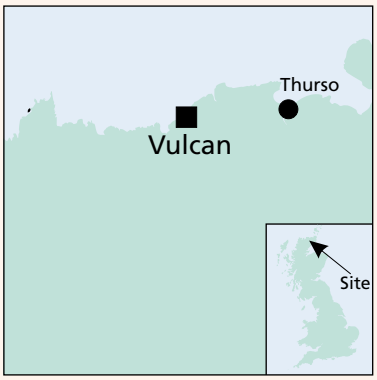
the Rosyth site. This will include trials to assess suitable treatment technologies to manage resin wastes. SEPA is working closely with the ONR and the Environment Agency on resin management as the issue is common to the Rosyth and Devonport naval sites.

The *total dose* from all pathways and sources was 0.017 mSv in 2016 (Table 5.1), which was less than 2 per cent of the dose limit, and up from 0.006 mSv in 2015. In 2016, the representative person was an adult who spends a large amount of time over marine sediments. The increase in *total dose* from 2015 was mostly due to higher gamma dose rates over sand in 2016. The source specific assessment for marine pathways (fishermen and beach users) was estimated to be 0.020 mSv in 2016. The reason for the increase in the source specific assessment is the same as that contributing to the maximum *total dose*.

In 2016, authorised gaseous discharges from Rosyth were reported as nil. Liquid wastes are discharged via a dedicated pipeline to the Firth of Forth. In all cases the activities in the liquid discharged were below authorised limits.

SEPA's routine monitoring programme included analysis of fish, shellfish, environmental indicator materials and measurements of gamma dose rates in intertidal areas. Results are shown in Tables 5.3(a) and (b). The radioactivity levels detected were at similar low levels to 2015 and in most part due to the combined effects of Sellafield, weapon testing and Chernobyl. Gamma dose rates were generally higher (where comparisons can be made), in comparison to those in recent years. Gamma dose rates were difficult to distinguish from natural background. The most recent habits survey was undertaken in 2015 and the results were incorporated in the dose assessment given above (Tyler *et al.*, 2016).

## 5.8 Vulcan NRTE, Highland




The Vulcan Naval Reactor Test Establishment is operated by Defence Equipment and Support, part of the MoD, and its purpose was to prototype submarine nuclear reactors. It is located adjacent to the Dounreay site and the impact of its discharges is considered along with those from Dounreay (in Section 3). The site ceased critical reactor operations in 2015 and will not be required for further prototyping. Since the reactor shutdown for the last time, work has focused on post-operational clean out. This will include de-fuelling of the reactor, clearance of fuel from the site and preparations for future decommissioning and disposal of both the reactors from the site and their component parts expected sometime after 2022. During 2016, the Letter of Approval was reviewed and varied. The variation placed improved conditions from SEPA's standard templated into the Agreement as well as strengthening the description of the Authorised Limits to make them all encompassing.

Gaseous discharges from Vulcan NRTE are given in Appendix 2 (Table A2.1) and solid waste transfers in 2016 are given in Table A2.4.

## Table 5.1 Individual doses – defence sites, 2016

| Site | Representative person[a,b] | Exposure mSv, per year | | | | | |
|---|---|---|---|---|---|---|---|
| | | Total | Fish and shellfish | Other local food | External radiation from intertidal areas or river banks[h] | Intakes of sediment or water | Gaseous plume related pathways |
| Aldermaston and Burghfield | | | | | | | |
| ***Total dose* – all sources** | **Infant milk consumers** | **<0.005** | **–** | **<0.005** | **–** | **–** | **–** |
| Source specific doses | Anglers | <0.005 | <0.005 | – | <0.005 | – | – |
| | Infant inhabitants and consumers of locally grown food | <0.005 | – | <0.005 | – | – | <0.005 |
| | Workers at Silchester STW | <0.005 | – | – | <0.005 | <0.005 | – |
| Barrow | | | | | | | |
| ***Total dose* – all sources** | **Adult occupants on houseboats[g]** | **0.082** | **–** | **–** | **0.082** | **–** | **–** |
| Source specific doses | Houseboat occupants | 0.081 | – | – | 0.081 | – | – |
| | Consumers of locally grown food | <0.005 | – | <0.005 | – | – | – |
| Derby | | | | | | | |
| ***Total dose* – all sources** | **Adult consumers of locally sourced water** | **<0.005** | **<0.005** | **–** | **<0.005** | **<0.005** | **–** |
| Source specific doses | Anglers consuming fish and drinking water[f] | <0.005 | <0.005 | – | <0.005 | <0.005 | – |
| | Children Inhabitants and consumers of locally grown food | <0.005 | – | <0.005 | – | – | <0.005 |
| Devonport | | | | | | | |
| ***Total dose* – all sources** | **Adult fish consumers** | **<0.005** | **<0.005** | **–** | **<0.005** | **–** | **–** |
| Source specific doses | Seafood consumers | <0.005 | <0.005 | – | <0.005 | – | – |
| | Houseboat occupants | <0.005 | – | – | <0.005 | – | – |
| | Prenatal children of inhabitants and consumers of locally grown food | <0.005 | – | <0.005 | – | – | <0.005 |
| Faslane | | | | | | | |
| ***Total dose* – all sources** | **Adult fish consumers** | **0.009** | **0.005** | **–** | **<0.005** | **–** | **–** |
| Source specific doses | Seafood consumers | 0.012 | 0.006 | – | 0.006 | – | – |
| | Consumers of locally grown food | <0.005 | – | <0.005 | – | – | – |
| Holy Loch | | | | | | | |
| Source specific doses | Anglers | 0.013 | – | – | 0.013 | – | – |
| Rosyth | | | | | | | |
| ***Total dose* – all sources** | **Adult occupants over sediment** | **0.017** | **<0.005** | **–** | **0.017** | **–** | **–** |
| Source specific doses | Fishermen and beach users | 0.020 | <0.005 | – | 0.017 | – | – |

[a] *The* total dose *is the dose which accounts for all sources including gaseous and liquid discharges and direct radiation.*
*The* total dose *for the representative person with the highest dose is presented.*
*Other dose values are presented for specific sources, either liquid discharges or gaseous discharges, and their associated pathways.*
*They serve as a check on the validity of the* total dose *assessment.*
*The representative person is an adult unless otherwise specified*

[b] *None of the people represented in this table were considered to receive direct radiation from the sites listed*

[c] *Includes a component due to natural sources of radionuclides*

[d] *External radiation from raw sewage and sludge*

[e] *Intakes of resuspended raw sewage and sludge*

[f] *Water is from rivers and streams and not tap water*

[g] *Exposures at Barrow are largely due to discharges from the Sellafield site*

[h] *Doses (*total dose *and source specific doses) only include estimates of anthropogenic inputs (by substracting background and cosmic sources from measured gamma dose rates)*

## Table 5.2(a) Concentrations of radionuclides in food and the environment near Aldermaston, 2016

| Material | Location | No. of sampling observations | Mean radioactivity concentration (fresh)[a], Bq kg$^{-1}$ | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Organic $^{3}$H | $^{3}$H | $^{131}$I | $^{137}$Cs | $^{234}$U | $^{235}$U | $^{238}$U |
| **Freshwater samples** | | | | | | | | | |
| Flounder | Woolwich Reach | 1 | | <25 | * | 0.05 | | | |
| Signal crayfish | Ufton Bridge - Theale | 1 | <25 | <25 | * | 0.05 | 0.027 | 0.00049 | 0.018 |
| Sediment | Pangbourne | 2[E] | | | | <0.53 | 17 | <1.2 | 21 |
| Sediment | Mapledurham | 2[E] | | | | 15 | 12 | <0.95 | 12 |
| Sediment | Aldermaston | 4[E] | | | | 4.7 | 24 | <1.4 | 23 |
| Sediment | Spring Lane | 4[E] | | | | <1.3 | 9.7 | <0.87 | 9.7 |
| Sediment | Stream draining south | 4[E] | | | | <1.3 | 25 | <1.8 | 27 |
| Sediment | Near Chamber 39 of PPL | 4[E] | | | | 4.5 | 18 | <1.3 | 17 |
| Sediment | Oval pond near Chamber 14 | 3[E] | | | | 2.3 | 18 | <1.6 | 17 |
| Sediment | River Kennet | 4[E] | | | | 3.5 | 15 | <0.99 | 14 |
| Sediment | Hosehill Lake | 2[E] | | | | 2.1 | 27 | <1.8 | 25 |
| Gullypot sediment | Falcon Gate | 1[E] | | <29 | | <2.2 | 18 | <1.4 | 16 |
| Gullypot sediment | Main Gate | 1[E] | | <16 | | <1.3 | 17 | <1.1 | 18 |
| Gullypot sediment | Tadley Entrance | 1[E] | | <57 | | 5.7 | 15 | <1.5 | 15 |
| Gullypot sediment | Burghfield Gate | 1[E] | | <18 | | 2.2 | 17 | <1.7 | 15 |
| Freshwater | Pangbourne | 2[E] | | <8.6 | | <0.20 | 0.0073 | <0.0011 | 0.0055 |
| Freshwater | Mapledurham | 2[E] | | <8.1 | | <0.18 | 0.0089 | <0.0021 | 0.0069 |
| Freshwater | Aldermaston | 4[E] | | <4.3 | | <0.22 | 0.0073 | <0.0015 | 0.0058 |
| Freshwater | Spring Lane | 4[E] | | <3.7 | | <0.23 | <0.0020 | <0.0010 | <0.0021 |
| Freshwater | Stream draining south | 4[E] | | <3.7 | | <0.19 | <0.0035 | <0.00086 | <0.0035 |
| Freshwater | Near Chamber 39 of PPL | 4[E] | | <3.5 | | <0.20 | 0.0076 | <0.0015 | <0.0054 |
| Freshwater | Oval pond near Chamber 14 | 4[E] | | <3.7 | | <0.19 | <0.0016 | <0.0011 | <0.0013 |
| Freshwater | River Kennet | 4[E] | | <3.5 | | <0.20 | 0.0064 | <0.00078 | 0.0058 |
| Freshwater | Hosehill Lake | 4[E] | | <3.5 | | <0.23 | <0.0060 | <0.0014 | <0.0045 |
| Crude liquid effluent | Silchester treatment works | 2[E] | | <3.6 | | <0.24 | <0.010 | <0.0021 | 0.0092 |
| Final Liquid effluent | Silchester treatment works | 2[E] | | <3.4 | | <0.19 | <0.012 | <0.0029 | <0.012 |
| Sewage sludge | Silchester treatment works | 2[E] | | <8.8 | | <0.16 | 0.64 | <0.046 | 0.64 |

| Material | Location | No. of sampling observations | Mean radioactivity concentration (fresh)[a], Bq kg$^{-1}$ | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | $^{238}$Pu | $^{239}$Pu + $^{240}$Pu | $^{241}$Am | $^{242}$Cm | $^{243}$Cm + $^{244}$Cm | Gross alpha | Gross beta |
| **Freshwater samples** | | | | | | | | | |
| Flounder | Woolwich Reach | 1 | | | <0.04 | | | | |
| Signal crayfish | Ufton Bridge - Theale | 1 | 0.000031 | 0.000090 | 0.00017 | * | * | | |
| Sediment | Pangbourne | 2[E] | <0.57 | <0.43 | <0.78 | | | 450 | 520 |
| Sediment | Mapledurham | 2[E] | <0.42 | <0.65 | <0.92 | | | 160 | 390 |
| Sediment | Aldermaston | 4[E] | <0.47 | 4.1 | <1.2 | | | 420 | 610 |
| Sediment | Spring Lane | 4[E] | <0.50 | <0.36 | <0.85 | | | <130 | 350 |
| Sediment | Stream draining south | 4[E] | <0.54 | <0.42 | <0.85 | | | 370 | 790 |
| Sediment | Near Chamber 39 of PPL | 4[E] | <0.48 | <0.54 | <0.63 | | | 190 | 420 |
| Sediment | Oval pond near Chamber 14 | 3[E] | <0.47 | <0.34 | <0.69 | | | 210 | 560 |
| Sediment | River Kennet | 4[E] | <0.56 | <0.39 | <0.70 | | | 220 | 420 |
| Sediment | Hosehill Lake | 2[E] | <0.42 | <0.29 | <0.65 | | | 230 | 630 |
| Gullypot sediment | Falcon Gate | 1[E] | <1.3 | <0.53 | <2.0 | | | 150 | 490 |
| Gullypot sediment | Main Gate | 1[E] | <1.3 | <0.85 | <1.4 | | | 230 | 560 |
| Gullypot sediment | Tadley Entrance | 1[E] | <0.40 | <0.23 | <1.5 | | | 500 | 530 |
| Gullypot sediment | Burghfield Gate | 1[E] | <0.46 | <0.25 | <1.6 | | | 360 | 540 |
| Freshwater | Pangbourne | 2[E] | <0.0029 | <0.0024 | 0.0059 | | | <0.065 | 0.30 |
| Freshwater | Mapledurham | 2[E] | <0.0031 | <0.0024 | 0.0059 | | | <0.055 | 0.33 |
| Freshwater | Aldermaston | 4[E] | <0.0029 | <0.0021 | <0.0054 | | | <0.033 | 0.30 |
| Freshwater | Spring Lane | 4[E] | <0.0025 | <0.0019 | <0.0062 | | | <0.032 | 0.17 |
| Freshwater | Stream draining south | 4[E] | <0.0025 | <0.0021 | <0.0045 | | | <0.032 | 0.16 |
| Freshwater | Near Chamber 39 of PPL | 4[E] | <0.0025 | <0.0017 | <0.0052 | | | <0.046 | 0.11 |
| Freshwater | Oval pond near Chamber 14 | 4[E] | <0.0021 | <0.0013 | <0.0062 | | | <0.035 | <0.068 |
| Freshwater | River Kennet | 4[E] | <0.0021 | <0.0017 | <0.0056 | | | <0.061 | 0.11 |
| Freshwater | Hosehill Lake | 4[E] | <0.0024 | <0.0014 | <0.0057 | | | <0.027 | 0.29 |
| Crude liquid effluent | Silchester treatment works | 2[E] | <0.0046 | <0.0023 | <0.26 | | | <0.064 | 0.92 |
| Final Liquid effluent | Silchester treatment works | 2[E] | <0.0046 | <0.0025 | <0.28 | | | <0.053 | <0.29 |
| Sewage sludge | Silchester treatment works | 2[E] | <0.025 | <0.036 | <0.20 | | | 7.0 | 8.1 |

## Table 5.2(a) continued

| Material | Location or selection[b] | No. of sampling observations[c] | Mean radioactivity concentration (fresh)[a], Bq kg$^{-1}$ | | | | |
|---|---|---|---|---|---|---|---|
| | | | $^{3}$H | $^{137}$Cs | $^{234}$U | $^{235}$U | $^{238}$U |
| **Terrestrial samples** | | | | | | | |
| Milk | | 2 | <4.1 | <0.07 | <0.00045 | <0.00034 | <0.00028 |
| Milk | max | | <5.4 | | <0.00051 | <0.00038 | <0.00030 |
| Potatoes | | 1 | <2.2 | <0.07 | 0.012 | <0.00024 | 0.011 |
| Wheat | | 1 | <8.9 | <0.04 | 0.0027 | <0.00023 | 0.0020 |
| Grass | Black Pightle | 1[E] | <7.5 | <1.4 | <0.71 | <0.25 | <0.61 |
| Grass | 0.25km east of Main gate | 1[E] | | <4.2 | 0.55 | <0.070 | 0.60 |
| Grass | Opposite Gate 36 | 1[E] | | <7.8 | <0.23 | <0.13 | <0.28 |
| Grass | Young's Industrial Estate | 1[E] | | <7.1 | <0.40 | <0.16 | 0.37 |
| Grass | Kestrel Meads | 1[E] | | <6.3 | <0.28 | <0.089 | <0.26 |
| Grass | Tadley | 1[E] | <6.5 | <1.8 | <0.70 | <0.62 | <0.80 |
| Soil | Black Pightle | 1[E] | <5.7 | 12 | 15 | <1.3 | 16 |
| Soil | 0.25km east of Main gate | 1[E] | | 7.7 | 18 | <1.7 | 17 |
| Soil | Opposite Gate 36 | 1[E] | | 14 | 15 | <0.96 | 14 |
| Soil | Young's Industrial Estate | 1[E] | | 3.5 | 21 | <1.1 | 21 |
| Soil | Kestrel Meads | 1[E] | | 2.9 | 16 | <1.2 | 15 |
| Soil | Tadley | 1[E] | <5.1 | 3.0 | 20 | <0.88 | 21 |

| Material | Location or selection[b] | No. of sampling observations[c] | Mean radioactivity concentration (fresh)[a], Bq kg$^{-1}$ | | | | |
|---|---|---|---|---|---|---|---|
| | | | $^{238}$Pu | $^{239}$Pu + $^{240}$Pu | $^{241}$Am | Gross alpha | Gross beta |
| **Terrestrial samples** | | | | | | | |
| Milk | | 2 | <0.000021 | <0.000019 | <0.000027 | | |
| Milk | max | | <0.000022 | | <0.000029 | | |
| Potatoes | | 1 | <0.00013 | 0.00013 | 0.00010 | | |
| Wheat | | 1 | <0.000055 | 0.000032 | 0.00010 | | |
| Grass | Black Pightle | 1[E] | <0.27 | <0.13 | | 6.9 | 270 |
| Grass | 0.25km east of Main gate | 1[E] | <0.13 | <0.080 | | 6.1 | 210 |
| Grass | Opposite Gate 36 | 1[E] | <0.15 | <0.068 | | 6.8 | 290 |
| Grass | Young's Industrial Estate | 1[E] | <0.16 | <0.067 | | 8.0 | 300 |
| Grass | Kestrel Meads | 1[E] | <0.13 | <0.075 | | <3.8 | 240 |
| Grass | Tadley | 1[E] | <0.20 | <0.12 | | 6.9 | 150 |
| Soil | Black Pightle | 1[E] | <0.47 | <0.32 | | 190 | 530 |
| Soil | 0.25km east of Main gate | 1[E] | <0.58 | 0.49 | | 180 | 230 |
| Soil | Opposite Gate 36 | 1[E] | <0.84 | <0.90 | | 190 | 400 |
| Soil | Young's Industrial Estate | 1[E] | <0.54 | <0.42 | | 180 | 330 |
| Soil | Kestrel Meads | 1[E] | <0.44 | <0.32 | | 190 | 430 |
| Soil | Tadley | 1[E] | <0.41 | <0.25 | | 240 | 430 |

* *Not detected by the method used*

[a] *Except for milk, sewage effluent and water where units are Bq l$^{-1}$, and for sediment and soil where dry concentrations apply (except for those marked with a # which are fresh concentrations)*

[b] *Data are arithmetic means unless stated as 'max'. 'Max' data are selected to be maxima. If no 'max' value is given the mean value is the most appropriate for dose assessments*

[c] *The number of farms from which milk is sampled. The number of analyses is greater than this and depends on the bulking regime*

[E] *Measurements labelled "E" are made on behalf of the Environment Agency, all other measurements are made on behalf of the Food Standards Agency*

## Table 5.2(b) Monitoring of radiation dose rates near Aldermaston, 2016

| Location | Ground type | No. of sampling observations | μGy h$^{-1}$ |
|---|---|---|---|
| **Mean gamma dose rates at 1m over substrate** | | | |
| Pangbourne, riverbank | Grass and mud | 2 | 0.059 |
| Mapledurham, riverbank | Grass and mud | 1 | 0.062 |
| Mapledurham, riverbank | Grass and pebbles | 1 | 0.054 |

## Table 5.3(a) Concentrations of radionuclides in food and the environment near defence establishments, 2016

| Material | Location or selection[a] | No. of sampling observ-ations | Mean radioactivity concentration (fresh)[b], Bq kg$^{-1}$ | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Organic $^{3}$H | $^{3}$H | $^{14}$C | $^{60}$Co | $^{125}$Sb | $^{131}$I | $^{134}$Cs | $^{137}$Cs |
| **Barrow** | | | | | | | | | | |
| Potatoes | Barrow | 1[F] | | <2.2 | | <0.07 | | <0.10 | <0.09 | 0.10 |
| Grass | Barrow | 1[F] | | <2.7 | | <0.04 | | <0.14 | <0.10 | <0.10 |
| Sediment | Walney Channel – N of discharge point | 2 | | | | <0.52 | <1.8 | | <0.45 | 60 |
| **Derby** | | | | | | | | | | |
| Potatoes | Derby | 1[F] | | | | <0.06 | | <0.13 | <0.05 | <0.05 |
| Wheat | Derby | 1[F] | | | | <0.06 | | <0.38 | <0.06 | <0.06 |
| Sediment | River Derwent, upstream | 1 | | | | <0.57 | | | | 3.2 |
| Sediment | Fritchley Brook | 1 | | | | <0.43 | | | | 0.66 |
| Sediment | River Derwent, downstream | 4 | | | | <1.4 | | | | 3.6 |
| Water | River Derwent, upstream | 1 | | | | <0.30 | | | | |
| Water[c] | Fritchley Brook | 1 | | <3.2 | | <0.30 | | | | <0.24 |
| Water | River Derwent, downstream | 4 | | | | <0.25 | | | | |
| **Devonport** | | | | | | | | | | |
| Ballan wrasse | Plymouth Sound | 1[F] | <25 | <25 | 30 | <0.06 | | <0.86 | <0.06 | 0.13 |
| Crabs | Plymouth Sound | 1[F] | | | 19 | <0.09 | | <0.45 | <0.07 | <0.08 |
| Shrimp | River Lynher | 1[F] | | | 41 | <0.07 | | * | <0.07 | <0.06 |
| Mussels | River Lynher | 1[F] | <25 | <25 | 25 | <0.12 | | <2.3 | <0.11 | <0.11 |
| Seaweed[d] | Kinterbury | 2 | | | | <0.64 | | 2.2 | | |
| Sediment[e] | Kinterbury | 2 | | <5.3 | | <1.1 | | | | 4.2 |
| Sediment | Torpoint South | 2 | | <6.7 | | <0.65 | | | | 0.98 |
| Sediment | Lopwell | 2 | | 47 | | <1.9 | | | | 5.9 |
| Seawater | Torpoint South | 1 | | <3.3 | 19 | <0.21 | | | | |
| Seawater | Millbrook Lake | 1 | | <3.0 | <9.1 | <0.23 | | | | |
| Sludge | Camel's Head Sewage Treatment Works | 1 | | | | <2.8 | | | | |
| Potatoes | | 1[F] | | <2.0 | | <0.06 | | <0.04 | <0.03 | <0.02 |
| Grass | | 1[F] | | <2.8 | | <0.05 | | <0.21 | <0.06 | <0.06 |
| **Faslane** | | | | | | | | | | |
| Mussels[f] | Rhu | 1 | | | | <0.10 | | | <0.11 | 0.35 |
| Winkles | Rhu | 1 | | | | <0.10 | | | <0.10 | 0.47 |
| *Fucus vesiculosus* | Rhu | 1 | | | | <0.10 | | | <0.10 | 0.39 |
| *Fucus vesiculosus* | Garelochhead | 1 | | | | <0.10 | | | <0.10 | 0.30 |
| *Fucus vesiculosus* | Carnban | 1 | | | | <0.10 | | | <0.10 | 0.33 |
| Sediment | Rhu | 1 | | | | <0.10 | | | <0.10 | 6.6 |
| Sediment | Garelochhead | 1 | | | | <0.10 | | | <0.10 | 2.8 |
| Sediment | Carnban | 1 | | | | <0.10 | | | <0.10 | 2.5 |
| Seawater | Carnban | 2 | | 2.0 | | <0.10 | | | <0.10 | <0.10 |
| Beef muscle | Faslane | 1 | | | | <0.05 | | | <0.05 | <0.05 |
| Honey | Faslane | 1 | | | | <0.07 | | | <0.07 | 5.9 |
| Grass | Auchengaich Reservoir | 1 | | <5.0 | | <0.05 | | | <0.05 | <0.05 |
| Grass | Lochan Ghlas Laoigh | 1 | | <5.0 | | <0.05 | | | <0.05 | 0.22 |
| Soil | Auchengaich | 1 | | <5.0 | | <0.05 | | | <0.07 | 14 |
| Soil | Lochan Ghlas Laoigh | 1 | | <5.0 | | <0.14 | | | <0.19 | 2.6 |
| Freshwater | Helensburgh Reservoir | 1 | | <1.0 | | <0.01 | | | <0.01 | <0.01 |
| Freshwater | Loch Finlas | 1 | | <1.0 | | <0.01 | | | <0.01 | <0.01 |
| Freshwater | Auchengaich Reservoir | 1 | | <1.0 | | <0.01 | | | <0.01 | <0.01 |
| Freshwater | Lochan Ghlas Laoigh | 1 | | <1.0 | | <0.01 | | | <0.01 | <0.01 |
| Freshwater | Loch Eck | 1 | | <1.0 | | <0.01 | | | <0.01 | <0.01 |
| Freshwater | Loch Lomond | 1 | | <1.0 | | <0.01 | | | <0.01 | <0.01 |

## Table 5.3(a) continued

| Material | Location or selection[a] | No. of sampling observ-ations | Mean radioactivity concentration (fresh)[b], Bq kg$^{-1}$ | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Organic $^{3}$H | $^{3}$H | $^{14}$C | $^{60}$Co | $^{125}$Sb | $^{131}$I | $^{134}$Cs | $^{137}$Cs |
| **Holy Loch** | | | | | | | | | | |
| Sediment | Mid-Loch | 1 | | | | <0.10 | | | <0.10 | 3.1 |
| **Rosyth** | | | | | | | | | | |
| Mackerel | Rosyth | 1 | | | | <0.10 | | | <0.10 | 0.16 |
| Winkles | St David's Bay | 1 | | | | <0.10 | | | <0.10 | 0.23 |
| Fucus vesiculosus | East of dockyard | 1 | | | | <0.10 | | | <0.10 | <0.10 |
| Sediment | East of dockyard | 1 | | | | <0.10 | | | <0.10 | 1.8 |
| Sediment | Port Edgar | 1 | | | | <0.10 | | | <0.13 | 9.3 |
| Sediment | West of dockyard | 1 | | | | <0.10 | | | <0.10 | 1.2 |
| Sediment | East Ness Pier | 1 | | | | <0.10 | | | <0.10 | 4.9 |
| Sediment | Blackness Castle | 1 | | | | <0.10 | | | <0.10 | 1.5 |
| Sediment | Charlestown Pier | 1 | | | | <0.10 | | | <0.10 | 1.1 |
| Seawater | East of dockyard | 2 | | <1.0 | | <0.10 | | | <0.10 | <0.10 |
| Freshwater | Castlehill Reservoir | 1 | | <1.0 | | <0.01 | | | <0.01 | <0.01 |
| Freshwater | Holl Reservoir | 1 | | <1.0 | | <0.01 | | | <0.01 | <0.01 |
| Freshwater | Gartmorn Dam | 1 | | <1.0 | | <0.01 | | | <0.01 | <0.01 |
| Freshwater | Morton No. 2 Reservoir | 1 | | 1.0 | | <0.01 | | | <0.01 | <0.01 |

| Material | Location or selection[a] | No. of sampling observ-ations | Mean radioactivity concentration (fresh)[b], Bq kg$^{-1}$ | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | $^{154}$Eu | $^{155}$Eu | $^{234}$U | $^{235}$U | $^{238}$U | $^{241}$Am | Gross alpha | Gross beta |
| **Barrow** | | | | | | | | | | |
| Potatoes | Barrow | 1[F] | <0.17 | <0.16 | | | | <0.09 | | |
| Grass | Barrow | 1[F] | <0.28 | <0.21 | | | | <0.13 | | |
| Sediment | Walney Channel – N of discharge point | 2 | <1.3 | <0.75 | | | | 130 | 410 | 680 |
| **Derby** | | | | | | | | | | |
| Potatoes | Derby | 1[F] | <0.19 | <0.15 | 0.012 | 0.00070 | 0.011 | <0.15 | | |
| Wheat | Derby | 1[F] | <0.15 | <0.22 | 0.0022 | 0.00037 | 0.0022 | <0.62 | | |
| Sediment | River Derwent, upstream | 1 | | | 33 | <1.5 | 27 | | 370 | 520 |
| Sediment | Fritchley Brook | 1 | | | 18 | <1.2 | 20 | | 230 | 550 |
| Sediment | River Derwent, downstream | 4 | | | 33 | <1.7 | 32 | | 410 | 590 |
| Water | River Derwent, upstream | 1 | | | | | | | <0.029 | 0.29 |
| Water[c] | Fritchley Brook | 1 | | | 0.010 | <0.0023 | 0.0094 | | <0.031 | 0.25 |
| Water | River Derwent, downstream | 4 | | | | | | | <0.096 | 0.20 |
| **Devonport** | | | | | | | | | | |
| Ballan wrasse | Plymouth Sound | 1[F] | <0.20 | <0.10 | | | | <0.06 | | |
| Crabs | Plymouth Sound | 1[F] | <0.23 | <0.12 | | | | <0.06 | | |
| Shrimp | River Lynher | 1[F] | <0.21 | <0.14 | | | | <0.18 | | |
| Mussels | River Lynher | 1[F] | <0.32 | <0.18 | | | | <0.09 | | |
| Sediment[e] | Kinterbury | 2 | | | | | | <0.53 | | |
| Potatoes | | 1[F] | <0.23 | <0.16 | | | | <0.12 | | |
| Grass | | 1[F] | <0.17 | <0.14 | | | | <0.09 | | |

**Table 5.3(a) continued**

| Material | Location or selection[a] | No. of sampling observ-ations | Mean radioactivity concentration (fresh)[b], Bq kg$^{-1}$ | | | | |
|---|---|---|---|---|---|---|---|
| | | | $^{154}$Eu | $^{155}$Eu | $^{241}$Am | Gross alpha | Gross beta |
| **Faslane** | | | | | | | |
| Mussels[f] | Rhu | 1 | <0.15 | <0.25 | 0.080 | | |
| Winkles | Rhu | 1 | <0.10 | <0.16 | 0.10 | | |
| *Fucus vesiculosus* | Rhu | 1 | <0.10 | <0.13 | <0.10 | | |
| *Fucus vesiculosus* | Garelochhead | 1 | <0.10 | <0.15 | <0.10 | | |
| *Fucus vesiculosus* | Carnban | 1 | <0.10 | <0.16 | <0.10 | | |
| Sediment | Rhu | 1 | <0.10 | 0.50 | 0.69 | | |
| Sediment | Garelochhead | 1 | <0.14 | 0.30 | <0.24 | | |
| Sediment | Carnban | 1 | <0.14 | 0.40 | <0.22 | | |
| Seawater | Carnban | 2 | <0.10 | <0.13 | <0.10 | | |
| Beef muscle | Faslane | 1 | | | <0.05 | | |
| Honey | Faslane | 1 | | | <0.10 | | |
| Grass | Auchengaich Reservoir | 1 | | | <0.06 | | |
| Grass | Lochan Ghlas Laoigh | 1 | | | <0.07 | | |
| Soil | Auchengaich | 1 | | 2.2 | <0.25 | | |
| Soil | Lochan Ghlas Laoigh | 1 | | 2.5 | <0.26 | | |
| Freshwater | Helensburgh Reservoir | 1 | | | <0.01 | <0.010 | 0.025 |
| Freshwater | Loch Finlas | 1 | | | <0.01 | <0.010 | 0.023 |
| Freshwater | Auchengaich Reservoir | 1 | | | <0.01 | <0.010 | 0.035 |
| Freshwater | Lochan Ghlas Laoigh | 1 | | | <0.01 | <0.010 | 0.026 |
| Freshwater | Loch Eck | 1 | | | <0.01 | <0.010 | 0.025 |
| Freshwater | Loch Lomond | 1 | | | <0.01 | <0.010 | 0.036 |
| **Holy Loch** | | | | | | | |
| Sediment | Mid-Loch | 1 | <0.19 | 0.64 | <0.37 | | |
| **Rosyth** | | | | | | | |
| Mackerel | Rosyth | 1 | <0.12 | <0.20 | <0.11 | | |
| Winkles | St David's Bay | 1 | <0.10 | <0.11 | <0.10 | | |
| *Fucus vesiculosus* | East of dockyard | 1 | <0.11 | <0.19 | <0.11 | | |
| Sediment | East of dockyard | 1 | <0.14 | <0.25 | <0.24 | | |
| Sediment | Port Edgar | 1 | <0.19 | 1.4 | 1.7 | | |
| Sediment | West of dockyard | 1 | <0.11 | 0.28 | <0.20 | | |
| Sediment | East Ness Pier | 1 | <0.17 | 0.27 | <0.32 | | |
| Sediment | Blackness Castle | 1 | <0.11 | 0.19 | 0.41 | | |
| Sediment | Charlestown Pier | 1 | <0.10 | 0.18 | <0.12 | | |
| Seawater | East of dockyard | 2 | <0.10 | <0.10 | <0.10 | | |
| Freshwater | Castlehill Reservoir | 1 | | | <0.01 | <0.010 | 0.024 |
| Freshwater | Holl Reservoir | 1 | | | <0.01 | <0.010 | 0.018 |
| Freshwater | Gartmorn Dam | 1 | | | <0.01 | <0.010 | 0.10 |
| Freshwater | Morton No. 2 Reservoir | 1 | | | <0.01 | 0.0046 | 0.040 |

* *Not detected by the method used*

[a] *Data are arithmetic means unless stated as 'max' in this column. 'Max' data are selected to be maxima. If no 'max' value is given the mean value is the most appropriate for dose assessments*

[b] *Except for sediment and sewage pellets where dry concentrations apply, and for water where units are Bq l$^{-1}$*

[c] *The concentrations of $^{228}$Th, $^{230}$Th and $^{232}$Th were <0.0074, <0.0023 and <0.0015 Bq l$^{-1}$ respectively*

[d] *The concentration of $^{99}$Tc was <2.0 Bq kg$^{-1}$*

[e] *The concentrations of $^{238}$Pu and $^{239+240}$Pu were <1.7 and <0.60 Bq kg$^{-1}$*

[f] *The concentrations of $^{238}$Pu and $^{239+240}$Pu were 0.035 and 0.17 Bq kg$^{-1}$*

[F] *Measurements labelled "F" are made on behalf of the Food Standards Agency, all other measurements are made on behalf of the environment agencies*

## Table 5.3(b) Monitoring of radiation dose rates near defence establishments, 2016

| Establishment | Location | Ground type | No. of sampling observations | μGy $h^{-1}$ |
|---|---|---|---|---|
| **Mean gamma dose rates at 1m over substrate** | | | | |
| Barrow | Walney Channel, N of discharge point | Sand | 1 | 0.089 |
| Barrow | Walney Channel, N of discharge point | Mud and sand | 2 | 0.086 |
| Barrow | Walney Channel, N of discharge point | Mud | 1 | 0.083 |
| Devonport | Torpoint South | Mud and pebbles | 1 | 0.097 |
| Devonport | Torpoint South | Mud and rock | 1 | 0.091 |
| Devonport | Kinterbury Access Gate | Mud | 2 | 0.090 |
| Devonport | Lopwell | Mud | 1 | 0.083 |
| Devonport | Lopwell | Mud and stones | 1 | 0.078 |
| Faslane | Garelochhead | Sand | 1 | 0.057 |
| Faslane | Garelochhead | Rocks | 1 | 0.064 |
| Faslane | Gulley Bridge Pier | Stones | 2 | 0.066 |
| Faslane | Rhu | Sand | 2 | 0.059 |
| Faslane | Helensburgh | Sand | 2 | 0.061 |
| Faslane | Carnban | Sediment | 1 | 0.072 |
| Faslane | Rahane | Stones | 1 | 0.069 |
| Faslane | Rahane | Rocks | 1 | 0.072 |
| Faslane | Rosneath Bay | Sediment | 2 | 0.058 |
| Faslane | Auchengaich | Grass | 1 | 0.077 |
| Faslane | Lochan Ghlas | Grass | 1 | 0.076 |
| Holy Loch | Kilmun Pier | Rock and sediment | 1 | 0.070 |
| Holy Loch | Mid-Loch | Sediment | 1 | 0.072 |
| Holy Loch | North Sandbank | Rock and sediment | 1 | 0.072 |
| Rosyth | Blackness Castle | Sand | 1 | 0.062 |
| Rosyth | Charlestown Pier | Sand | 1 | 0.060 |
| Rosyth | East Ness Pier | Sand | 1 | 0.062 |
| Rosyth | East of Dockyard | Rubble and sand | 1 | 0.061 |
| Rosyth | Port Edgar | Sand | 1 | 0.069 |
| Rosyth | West of Dockyard | Sand | 1 | 0.055 |

# 6. Radiochemical production

This section considers the results of monitoring by the Environment Agency and FSA at two sites associated with the radiopharmaceutical industry. The sites, at Amersham and Cardiff, are operated by GE Healthcare Limited. This is a health science company functioning in world-wide commercial healthcare and life science markets.

Permits have been issued by the Environment Agency and Natural Resources Wales (NRW) to the Amersham and Cardiff sites, respectively, allowing the discharge of radioactive wastes (Appendix 2). Independent monitoring of the environment around the Amersham and Cardiff sites is conducted by the Environment Agency and the FSA. The Environment Agency has an agreement with NRW to carry out monitoring on its behalf in Wales.

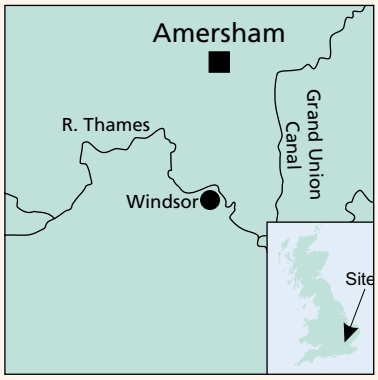
## Key points

- *Total doses* for the representative person were 15 per cent (or less) of the dose limit

**GE Healthcare Limited, Grove Centre, Amersham, Buckinghamshire**

- The highest dose was due to direct radiation from the site

## 6.1 Grove Centre, Amersham, Buckinghamshire




GE Healthcare Limited's principal establishment is located in Amersham, Buckinghamshire. It consists of a range of plants for manufacturing diagnostic imaging products for use in medicine and research. The monitoring programme consists of analysis of fish, crops, water, sediments and environmental materials, and measurements of gamma dose rates. The monitoring locations are shown in Figure 3.4.

In August 2016, a habits survey was conducted to determine the consumption and occupancy rates by members of the public (Clyne *et al.*, 2017). A decrease in the occupancy rate over riverbank has been observed in comparison with that of the previous survey in 2009. Revised figures for consumption rates, together with occupancy rates, are provided in Appendix 1 (Table X2.2).

### Doses to the public

The *total dose* from all pathways and sources of radiation was 0.15 mSv in 2016 (Table 6.1) or 15 per cent of the dose limit, and similar to that in 2015 (0.14 mSv). As in 2015, the dominant contribution to *total dose* was from direct radiation and the representative person was adults living in the vicinity of the site in 2016. Exposure from direct radiation varies around the boundary of the Grove Centre and therefore the *total dose* is determined as a cautious upper value. The trend in *total dose* over the period 2004 – 2016 is given in Figure 1.2. *Total doses* remained broadly similar with time (up until 2013) and were dominated by direct radiation. The lower value in 2014 (and subsequently thereafter) was due to changes in working practices (for distribution activities, products spend less time in the dispatch yard) and the construction of a shield wall on the western side of a building that contains legacy radioactive wastes.

Source specific assessments for a high-rate consumer of locally grown foods, for an angler and for a worker at Maple Lodge STW, which serves the sewers to which permitted discharges are made, give exposures that were less than the *total dose* in 2016 (Table 6.1). The dose for a high-rate consumer of locally grown foods (which included a contribution from the gaseous plume related pathways) was 0.009 mSv, or less than 1 per cent of the dose limit to members of the public of 1 mSv, and similar to that in 2015 (0.010 mSv). As in previous years, atmospheric discharges of radon-222 remain the dominant contributor in 2016. It should be noted that the current assessment methodology uses a conservative dose factor based on this nuclide being in equilibrium with its daughter products. The dose to a local angler in 2016 was less than 0.005 mSv. The small decrease in dose (from 0.006 mSv in 2015) was attributed to the lower gamma dose rates over grass, on the bank and downstream of the outfall (Grand Union Canal) in 2016.

The 2016 habits survey at Amersham did not directly identify any consumers of fish, shellfish or freshwater plants. As in previous surveys, however, there were reports of occasional coarse fish and signal crayfish consumption (but no actual consumption rates). To allow for this, a consumption rate of 1 kg per year for fish and crayfish has been included in the dose assessment for an angler.

The Grove Centre discharges liquid waste to Maple Lodge STW, and the proximity to raw sewage and sludge experienced by sewage treatment workers is a likely exposure pathway (National Dose Assessment Working Group, 2004). The dose received by one of these workers in 2016 was modelled using the methods described in Appendix 1 (Annex 1). The dose from a combination of external exposure to contaminated raw sewage and sludge and the inadvertent ingestion and inhalation of re-suspended radionuclides was less than 0.005 mSv.

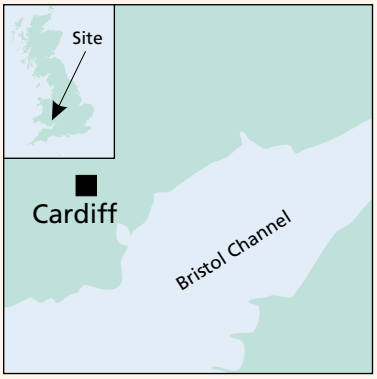
## Gaseous discharges and terrestrial monitoring

The Amersham facility is permitted to discharge gaseous radioactive wastes via stacks on the site. The results for the terrestrial monitoring are given in Table 6.2(a). Sulphur-35 was positively detected at a low concentration (just above the LoD) in one crop sample (wheat) in 2016. As in previous years, caesium-137 activities were detected in soil near the site, and this is likely to be due to global fallout from testing of weapons or from the Chernobyl accident.

## Liquid waste discharges and aquatic monitoring

Radioactive liquid wastes are discharged to sewers serving the Maple Lodge STW; treated effluent subsequently enters the Grand Union Canal and the River Colne. The results of the aquatic monitoring programme are given in Table 6.2(a). Activity concentrations in freshwater, and effluent and sludge from Maple Lodge STW, are mostly reported as less than values in 2016. The sludge samples contained very low concentrations of iodine-131 (reported just above the less than value, as in recent years), which were most likely to have originated from the therapeutic use of this radionuclide in a local hospital. The caesium-137 detected in sediments from the River Colne and upstream of the STW outfall is likely to be derived from weapons test fallout or the Chernobyl accident. Tritium, gross alpha and gross beta concentrations in water were below the investigation levels for drinking water in the European Directive 2013/51. Gamma dose rates over grass were mostly indistinguishable from natural background in 2016 (Table 6.2(b)), although dose rates were slightly higher at locations next to the site (relative to natural background). Gamma dose rates on the banks of the Grand Union Canal and downstream of the outfall decreased in comparison to those in 2015.

## 6.2 Maynard Centre, Cardiff




GE Healthcare Limited operates a second establishment, on the Forest Farm industrial estate near Whitchurch, Cardiff. GE Healthcare Limited ceased manufacturing a range of radio-labelled products containing tritium in 2009 and products containing carbon-14 in 2010.

In 2015, GE Healthcare Limited partially surrendered the environmental permit for the Maynard Centre site and around 90 per cent of the footprint of the site was de-licensed, following decommissioning and clean-up of the wider Maynard Centre. The remainder of the site (10 per cent) was re-licensed as a stand-alone nuclear licensed site. The area of the site covered by the new nuclear site licence and EPR permit is known as the Cardiff Nuclear Licensed Site (CNLS) and continues to be operated by GE Healthcare Limited. In addition to this change, liquid discharges were removed from the permit, since the site no longer discharges radioactive liquid waste. The current activities at CNLS relate to the storage and repackaging of legacy ILW for off-site disposal and is located entirely within the confines of the previously licenced site (and its security boundary). Gaseous discharges from the Maynard Centre are now the result of out-gassing of tritium and carbon-14 from stored wastes with only small amounts originating from decommissioning.

GE Healthcare Limited's custom radio-labelling division was acquired by Quotient Bioresearch in 2010. In February 2016, Pharmaron UK Limited (known as Pharmaron), which also operates from premises in Cardiff (referred to as The Old Glassworks) acquired Quotient Bioresearch. This non-nuclear facility also discharges carbon-14 and tritium to atmosphere and in liquid wastes. These are at much reduced levels in comparison to when the Maynard Centre was manufacturing radio-labelled products. The effluents discharged from the site are also treated to ensure that organic matter present is destroyed prior to discharge. The facility has an environmental permit issued and regulated by NRW.

The Environment Agency and FSA conduct a routine monitoring programme on behalf of NRW and the Welsh Government. This includes sampling of locally produced food, fish and shellfish, and external dose rate measurements over muddy, intertidal areas. Environmental materials including seawater, intertidal sediment, freshwater, seaweed, and grass provide additional

information. The most recent habits survey was undertaken in 2003 (McTaggart *et al*., 2004a).

Previous monitoring data from Cardiff has been reviewed in order to compare the apparent enhancement of tritium concentrations on uptake by marine biota with bioaccumulation at other UK sites (Hunt *et al*., 2010). The observed enhancement factor at Cardiff remains at least an order of magnitude greater than at the other sites studied, although the organically bound fractions were uniformly high. Various earlier monitoring and research efforts have targeted OBT in foodstuffs (FSA, 2001b; Swift, 2001; Williams *et al*., 2001; Leonard *et al*., 2001 and McCubbin *et al*., 2001).

## Doses to the public

The *total dose* from all pathways and sources was less than 0.005 mSv (Table 6.1) in 2016, or less than 0.5 per cent of the dose limit, and unchanged from 2015. This dose estimates take into account the increased dose coefficients for OBT derived for historical discharges from the Maynard Centre and includes consideration of prenatal children. The representative person was an infant (1 year-old) consuming milk at high-rates in 2016 (a change from prenatal children of occupants over sediment in 2015). Trends in *total doses* over time (2004 – 2016) in the Severn Estuary (and areas of the south coast) are shown in Figure 6.1. At Cardiff, the most significant reductions in the *total dose*, prior to 2007, were largely due to lower concentrations of tritium and carbon-14 in seafood. Since 2007, the *total doses* have generally continued to decrease over time and were low (and very recently, less than 0.005 mSv). The increase in *total dose* in 2013 was attributed to higher carbon-14 concentrations in milk.

Source specific assessments for a high-rate consumer of locally grown foods, a high-rate consumer of seafood and a recreational user of the River Taff give doses that were also less than 0.005 mSv in 2016 (Table 6.1). The dose to a high-rate consumer of seafood was 0.006 mSv in 2015, the small decrease was because gamma dose rates were measured on different ground types (east of pipeline) from one year to the next.

The dose coefficients for OBT differ from those for tritiated water (see Appendix 1, Annex 3.4) and the estimates of dose to members of the public account for this. For ingestion of seafood caught near Cardiff, an area taken to be equivalent to the Bristol Channel, a dose coefficient based on a site-specific study of the consumption of fish caught in Cardiff Bay is used. An experimental study suggests that this raised dose coefficient is conservative (Hunt *et al*., 2009), but it is retained for 2016 dose assessments on the advice of PHE. For ingestion of other food, the ICRP dose coefficient for OBT is applied.

The monitoring locations for seafood, water, environmental materials and dose rates near the Cardiff site are shown in Figure 6.2.

## Gaseous discharges and terrestrial monitoring

The Maynard Centre discharges radioactivity to the atmosphere via stacks on the site. As a result of the cessation of commercial operations, discharges of tritium and carbon-14 continued to be low in 2016.

The focus of the terrestrial sampling was for the content of tritium, carbon-14 and sulphur-35 in milk, crops, freshwater and grass. In recent years, the Environment Agency have also analysed additional samples of sewage products from the Cardiff East WWTW. This additional monitoring ceased in 2013 and monitoring returned to normal frequencies in 2014. The constraints of the Sludge (Use in Agriculture) Regulations (United Kingdom – Parliament, 1989) (commonly referred to as the Safe Sludge Matrix) require that crops cannot be harvested within 10 months of the application of sludge pellets. An FSA research project investigated the transfer of tritium from treated soil to crops, under the Safe Sludge Matrix conditions, and concluded that the transfer of tritium to each of the crops considered was small (Ham *et al*., 2007).

Tritium concentrations in terrestrial food samples are reported as less than values in 2016 (Table 6.3(a)). These values were similar in comparison to those in previous years and are consistent with progressive discharge reductions in recent years. Carbon-14 was detected in locally produced foods at concentrations close to background values. Low concentrations of sulphur-35, which is not discharged by the site, were detected in food (milk and potatoes) and grass samples (and were generally similar to those in recent years). Phosphorus-32 and iodine-125 concentrations are reported as less than values in all terrestrial samples. Samples of raw effluent, treated effluent and sludge pellets (analysed in previous years) from Cardiff East WWTW are no longer sampled. The most recent results (in 2013) show that all activity concentrations in effluent are reported as less than values (Environment Agency, FSA, NIEA, NRW and SEPA, 2014).

As in previous years (but unlike in 2015), there was evidence of tritium being detected in sediment (reported as just above the less than value) from the Glamorganshire Canal in 2016; however, this is not used as a source of water for the public water supply. Tritium concentrations in freshwater, downstream (and upstream) from the outfall into the River Taff (potentially containing site run-off water) are reported as less than values in 2016. Furthermore in 2016, freshwater was also collected from the outfall and reported as a less than value (sample not collected in 2015 and 2014, as run-off water originating from the site is not continuous). The trend of discharges, with tritium concentrations in sediment from the marine

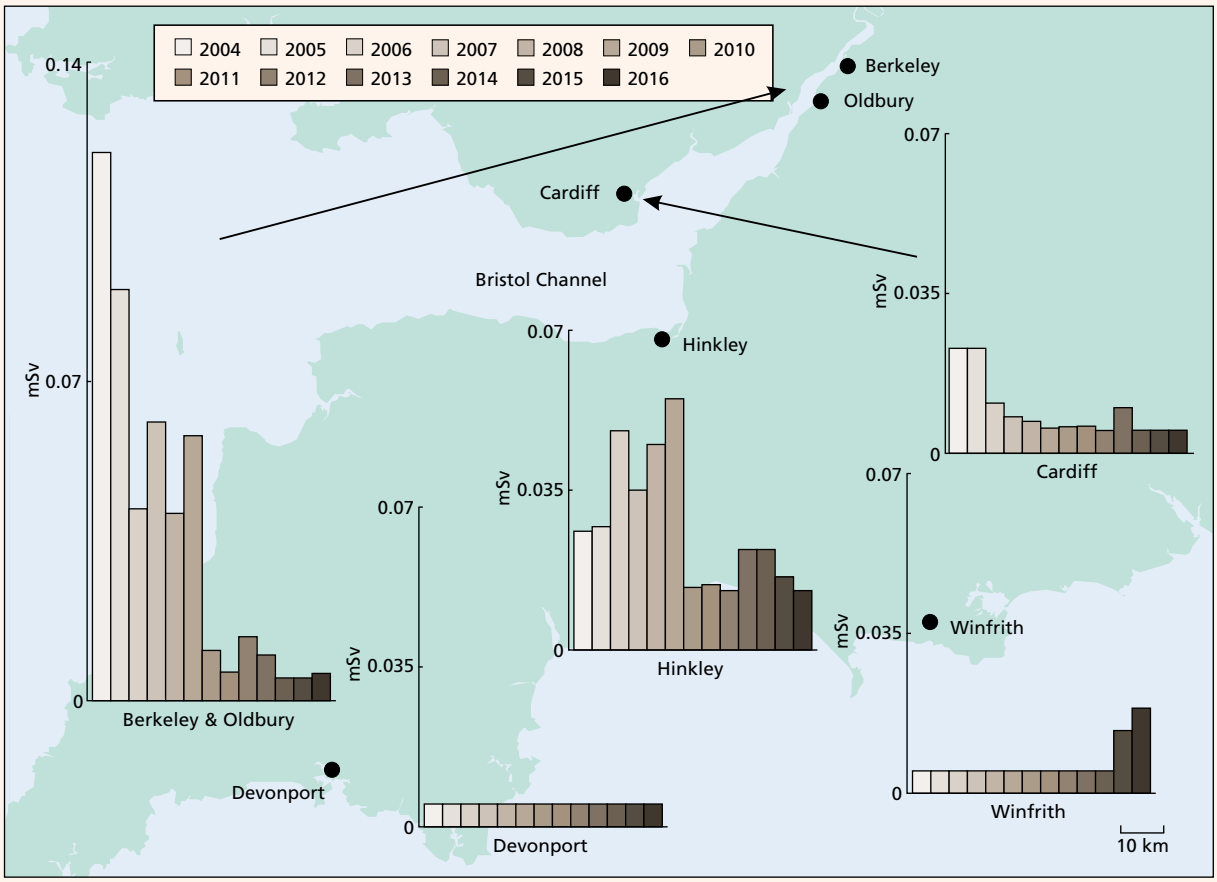



**Figure 6.1.** *Total dose* for major sites in the Severn Estuary and south coast, 2004-2016
(Note small doses, less than or equal to 0.005 mSv, are recorded as being 0.005 mSv)

and freshwater environments, over time (2004 – 2016) are shown in Figure 6.3. The overall decline in activity concentrations generally replicates that of the tritium discharges, although the decrease in marine levels (east/west of the pipeline) is less pronounced than that in the canal sediments over the whole time period. The apparent increase in tritium concentrations, in the canal and west of pipeline samples in 2015 is because concentrations are reported as less than values.

## Liquid waste discharges and aquatic monitoring

Permission to discharge radioactive liquid waste to the Ystradyfodwg and Pontypridd (YP) public sewer ceased in 2015, because of the partial surrender of the permit. The permit does not consent to discharges of radioactive waste to the sewer. The bulk of the radioactivity previously discharged to the YP sewer was tritium and carbon-14. Recent trends over time (2004 – 2016) are given in Figures 6.4 and 6.5 and longer trends are reported in earlier RIFE reports (e.g. Environment Agency, FSA, FSS, NIEA, NRW and SEPA, 2015).

Marine sampling included locally caught seafood and indicator materials (e.g. seaweed). These were supported by external dose rate measurements over intertidal areas.

The results of routine monitoring in 2016 are given in Tables 6.3(a) and (b). Tritium and carbon-14 concentrations were enhanced by small amounts in fish samples (as in 2015). It is still likely (from the positively detected values of both tritium forms) that a high proportion of the tritium in seafood samples continues to be associated with organic matter, a situation that has been observed since the late 1990s (McCubbin *et al.*, 2001; Leonard *et al.*, 2001; Williams *et al.*, 2001). The tritium is strongly bound to organic matter and has the potential to transfer through the marine food chain from small organisms to accumulate in fish. The tritium (OBT) concentration in flounder in 2016 was similar to that in 2015 (the latter value being the lowest in recent years). The continued overall decline in tritium concentrations in fish from the Cardiff area is likely to be a direct response to the decreasing inputs, and subsequent cessation of discharges, from the Maynard Centre, as well as a shift in the composition of this discharge away from organically bound compounds. However, the annual uncertainty and variation in certain species in recent years suggests that complex indirect uptake mechanisms continue to affect tritium concentrations in the region.

Figure 6.4 indicates that the overall tritium concentrations in fish and mollusc samples have decreased significantly over a period of time. The mean concentrations of carbon-14 in fish and molluscs in 2016 were generally

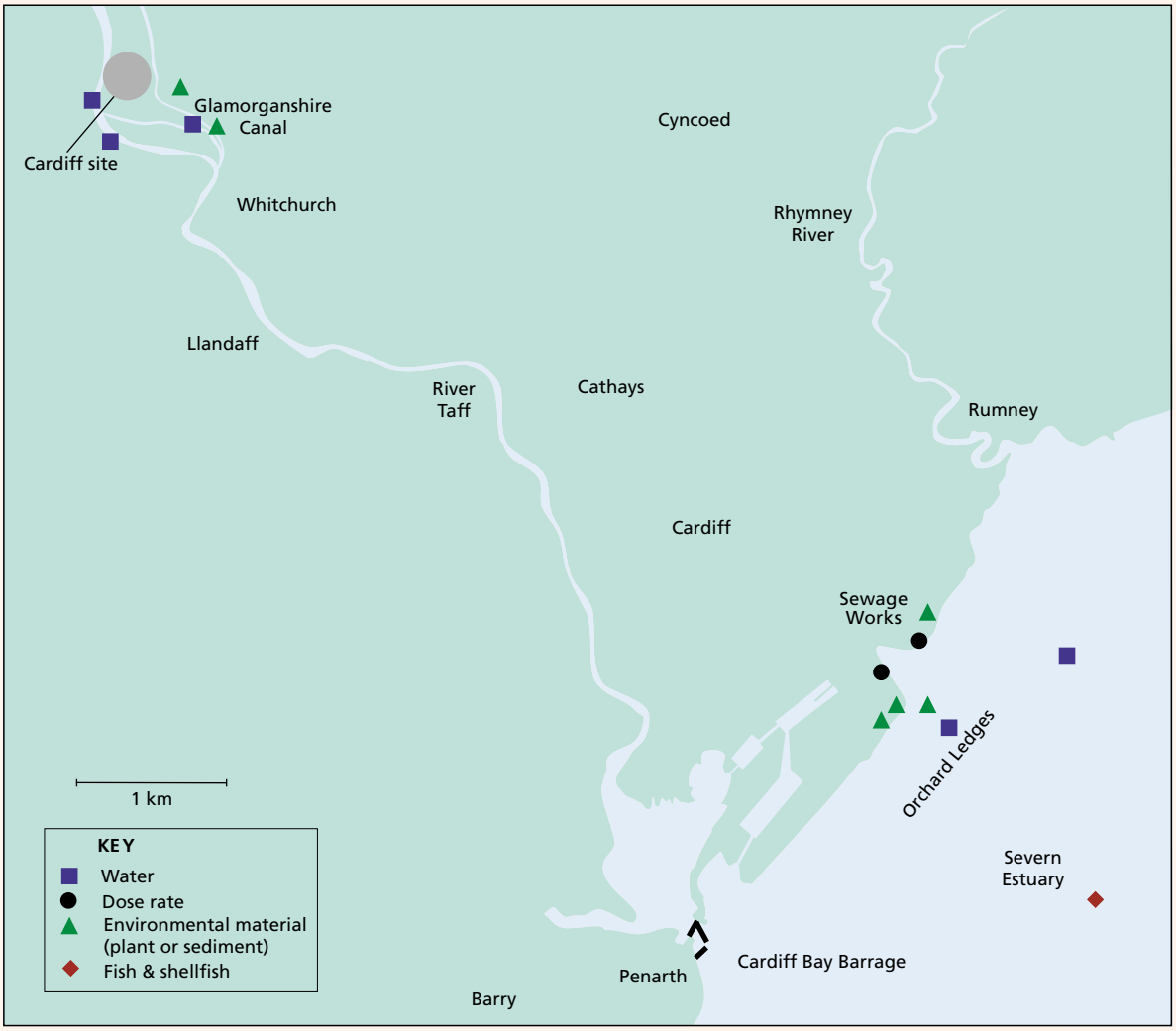



**Figure 6.2.** Monitoring locations at Cardiff, 2016 (not including farms)

similar to those in 2015. The trend of carbon-14 concentrations and the relationship to discharges is shown in Figure 6.5 (overall, concentrations in both species declining). Tritium concentrations in marine sediment samples (where comparisons can be made) were measured at similar levels to those in recent years. Concentrations of caesium-137 in marine samples remain low and can largely be explained by other sources such as Chernobyl, weapon test fallout and discharges from other establishments such as the Hinkley Point, Berkeley and Oldbury nuclear licensed sites. Where comparisons can be made (from similar ground types and locations), gamma dose rates over sediment (Table 6.3(b)) in 2016 were generally similar to those in 2015. These rates are not (in the main) attributable to discharges from the Maynard Centre or Pharmaron.

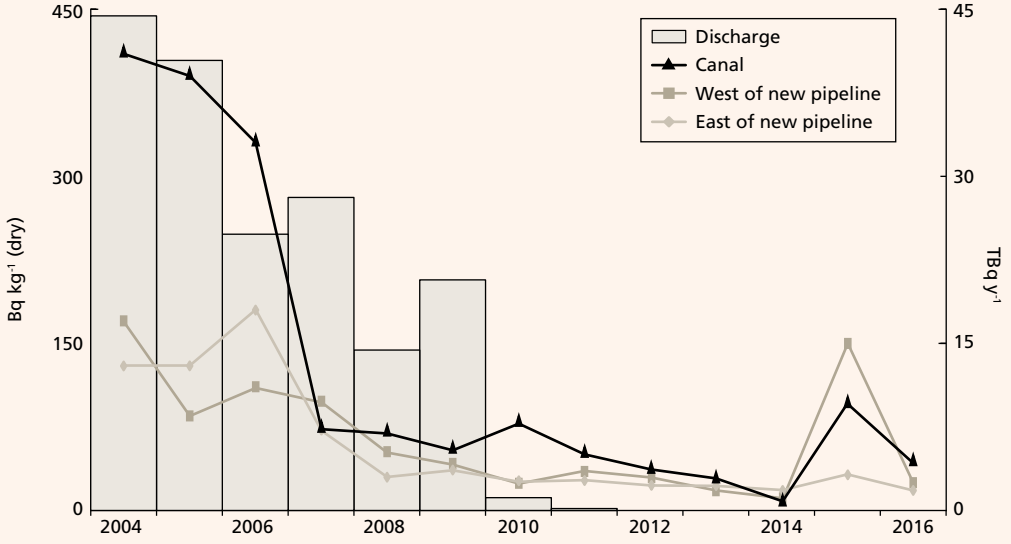



**Figure 6.3.** Tritium liquid discharge from Cardiff and mean concentrations in sediment near Cardiff, 2004-2016

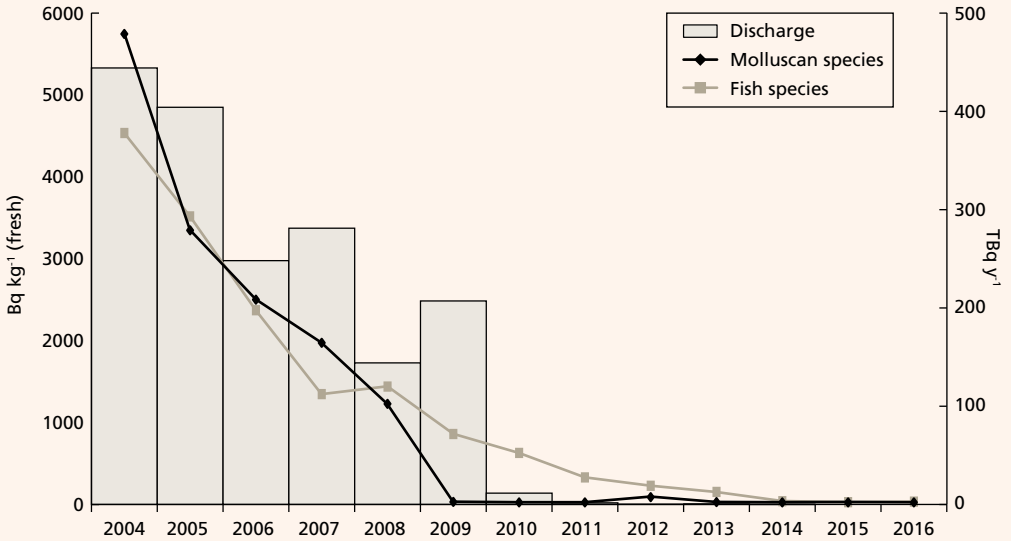



**Figure 6.4.** Tritium liquid discharge from Cardiff and mean concentrations in fish and molluscs near Cardiff, 2004-2016 (species include all those reported in RIFE for the given year)

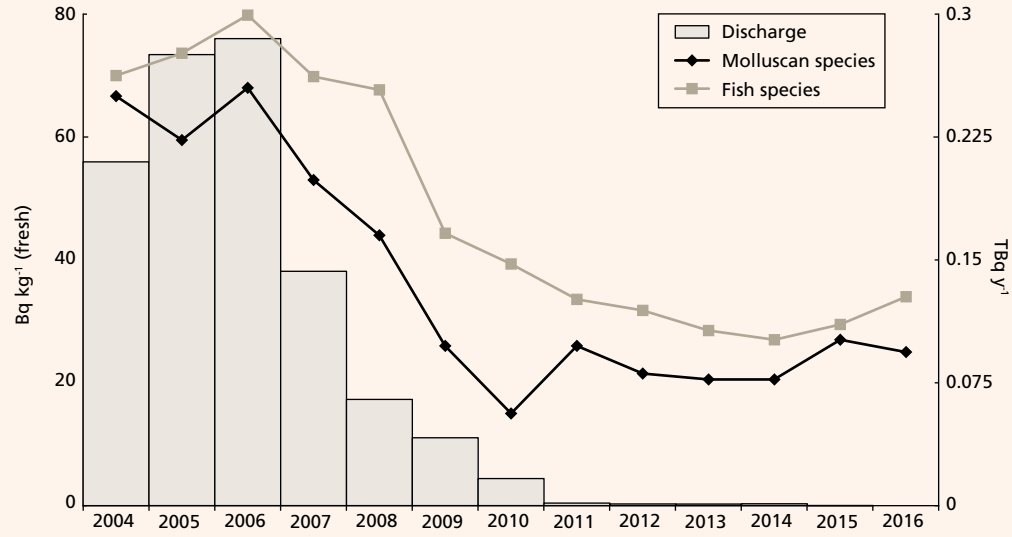



**Figure 6.5.** Carbon-14 liquid discharge from Cardiff and mean concentrations in fish and molluscs near Cardiff, 2004-2016 (species include all those reported in RIFE for the given year)

## Table 6.1 Individual doses – radiochemical sites, 2016

| Site | Representative person[a] | Exposure, mSv per year | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Total | Fish and shellfish | Other local food | External radiation from intertidal areas or river banks[e] | Intakes of sediment or water | Gaseous plume related pathways | Direct radiation from site |
| Amersham | | | | | | | | |
| ***Total dose* – all sources** | **Local adult inhabitants (0–0.25km)** | **0.15[d]** | **–** | **<0.005** | **<0.005** | **–** | **0.005** | **0.14** |
| Source specific doses | Anglers | <0.005 | <0.005 | - | <0.005 | – | – | – |
| | Infant inhabitants and consumers of locally grown food | 0.009[d] | – | <0.005 | – | – | 0.008 | – |
| | Workers at Maple Lodge STW | <0.005 | – | – | <0.005 | <0.005 | – | – |
| Cardiff | | | | | | | | |
| ***Total dose* – all sources** | **Infant milk consumers** | **<0.005** | **–** | **<0.005** | **–** | **–** | **–** | **–** |
| Source specific doses | Prenatal children of seafood consumers | <0.005 | <0.005 | – | <0.005 | - | - | – |
| | Recreational users of River Taff | <0.005 | – | – | <0.005 | <0.005 | - | – |
| | Infant inhabitants and consumers of locally grown food | <0.005 | – | <0.005 | – | – | <0.005 | – |

[a] *The* total dose *is the dose which accounts for all sources including gaseous and liquid discharges and direct radiation. The* total dose *for the representative person with the highest dose is presented. Other dose values are presented for specific sources, either liquid discharges or gaseous discharges, and their associated pathways. They serve as a check on the validity of the* total dose *assessment. The representative person is an adult unless otherwise stated*

[b] *External radiation from raw sewage and sludge*

[c] *Intakes of resuspended raw sewage and sludge*

[d] *Includes a component due to natural sources of radionuclides*

[e] *Doses (*total dose *and source specific doses) only include estimates of anthropogenic inputs (by substracting background and cosmic sources from measured gamma dose rates)*

## Table 6.2(a) Concentrations of radionuclides in food and the environment near Amersham, 2016

| Material | Location | No. of sampling observations | Mean radioactivity concentration (fresh)[a], Bq kg$^{-1}$ | | | | |
|---|---|---|---|---|---|---|---|
| | | | $^{3}$H | $^{131}$I | $^{137}$Cs | Gross alpha | Gross beta |
| **Freshwater samples** | | | | | | | |
| Flounder | Woolwich Reach | 1 | <25 | * | 0.05 | | |
| Sediment | River Colne (Grand Union Canal) | 2[E] | | <4.5 | 4.8 | 200 | 350 |
| Sediment | Upstream of outfall (Grand Union Canal) | 2[E] | | <4.0 | 4.1 | 150 | 240 |
| Freshwater | Downstream of outfall (Grand Union Canal) | 1[E] | <3.2 | <0.35 | <0.24 | <0.080 | 0.47 |
| Freshwater | River Chess | 1[E] | <3.4 | <0.33 | <0.24 | <0.082 | 0.20 |
| Freshwater | River Misbourne – downstream | 1[E] | <3.3 | <0.34 | <0.24 | <0.033 | 0.085 |
| Crude effluent[d] | Maple Lodge Sewage Treatment Works | 2[E] | <7.1 | | <0.24 | <0.075 | 0.69 |
| Digested sludge[e] | Maple Lodge Sewage Treatment Works | 2[E] | <7.9 | 2.8 | <0.14 | <2.7 | 5.5 |
| Final effluent[f] | Maple Lodge Sewage Treatment Works | 2[E] | <6.6 | | <0.22 | <0.069 | 0.87 |

| Material | Location or selection[b] | No. of sampling observations[c] | Mean radioactivity concentration (fresh)[a], Bq kg$^{-1}$ | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | $^{3}$H | $^{35}$S | $^{125}$I | $^{131}$I | $^{137}$Cs | Gross alpha | Gross beta |
| **Terrestrial samples** | | | | | | | | | |
| Milk | | 1 | <5.7 | <0.33 | <0.0068 | <0.0022 | <0.06 | | |
| Apples | | 1 | <2.0 | <0.20 | <0.033 | | <0.04 | | |
| Wheat | | 1 | <4.2 | 1.0 | <0.051 | | <0.04 | | |
| Grass | Next to site | 1[E] | | | | <0.85 | <0.56 | <1.7 | 130 |
| Grass | Orchard next to site | 1[E] | | | | <1.1 | <0.78 | <2.9 | 190 |
| Grass | Water Meadows (River Chess) | 1[E] | | | | <1.3 | <0.89 | <2.7 | 220 |
| Soil | Orchard next to site | 1[E] | | | | <0.51 | 4.4 | 340 | 510 |
| Soil | Water Meadows (River Chess) | 1[E] | | | | <2.0 | 12 | 230 | 360 |

* *Not detected by the method used*

[a] *Except for milk, water and effluent where units are Bq l$^{-1}$ and for sediment and soil where dry concentrations apply*

[b] *Data are arithmetic means unless stated as 'max' in this column. 'Max' data are selected to be maxima. If no 'max' value is given the mean value is the most appropriate for dose assessments*

[c] *The number of farms from which milk is sampled. The number of analyses is greater than this and depends on the bulking regime*

[d] *The concentration of $^{3}$H as tritiated water was <4.0 Bq l$^{-1}$*

[e] *The concentration of $^{3}$H as tritiated water was <4.0 Bq l$^{-1}$*

[f] *The concentration of $^{3}$H as tritiated water was <4.0 Bq l$^{-1}$*

[E] *Measurements labelled "E" are made on behalf of the Environment Agency, all other measurements are made on behalf of the Food Standards Agency*

## Table 6.2(b) Monitoring of radiation dose rates near Amersham, 2016

| Location | Ground type | No. of sampling observations | µGy h$^{-1}$ |
|---|---|---|---|
| **Mean gamma dose rates at 1m over substrate** | | | |
| Bank of Grand Union Canal (downstream) | Grass | 2 | 0.058 |
| Downstream of outfall (Grand Union Canal) | Grass | 2 | 0.057 |
| Upstream of outfall (Grand Union Canal) | Grass | 2 | 0.056 |
| Water Meadows (River Chess) | Grass | 1 | 0.050 |
| Orchard next to site | Grass | 1 | 0.069 |
| Next to site | Grass | 1 | 0.084 |

## Table 6.3(a) Concentrations of radionuclides in food and the environment near Cardiff, 2016

| Material | Location | No. of sampling observations | Mean radioactivity concentration (fresh)[a], Bq kg$^{-1}$ | | | | |
|---|---|---|---|---|---|---|---|
| | | | Organic $^{3}H$[d] | $^{3}H$ | $^{3}H$[e] | $^{14}C$ | $^{137}Cs$ |
| **Marine samples** | | | | | | | |
| Flounder | East of new pipeline | 2 | 31 | 35 | | 31 | 0.24 |
| Lesser spotted dogfish | Off Orchard Ledges | 1 | <25 | 34 | | 37 | 0.21 |
| Limpets | Lavernock Point | 1 | <25 | <25 | | 25 | 0.24 |
| Seaweed | Orchard Ledges | 2[E] | | <14 | | <10 | |
| Sediment | East of sewage outfall | 1[E] | | 18 | | 28 | |
| Sediment | West of sewage outfall | 1[E] | | 25 | | 28 | |
| Seawater | West of sewage outfall | 2[E] | | <12 | <3.8 | <6.2 | |

| Material | Location or selection[b] | No. of sampling observations[c] | Mean radioactivity concentration (fresh)[a], Bq kg$^{-1}$ | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Organic $^{3}H$[e] | $^{3}H$ | $^{3}H$[f] | $^{14}C$ | $^{35}S$ | $^{125}I$ | $^{137}Cs$ |
| **Terrestrial samples** | | | | | | | | | |
| Milk[f] | | 3 | <3.0 | <3.0 | | 16 | <0.46 | <0.0069 | <0.06 |
| Milk[f] | max | | <3.6 | <3.6 | | 18 | 0.55 | <0.0080 | |
| Jerusalem artichokes | | 1 | <2.9 | <2.9 | | 20 | 0.90 | <0.033 | <0.05 |
| Grass | | 1 | <3.2 | <3.2 | | 10 | 2.7 | <0.045 | 0.06 |
| Grass | 0.5km north east of site | 1[E] | | <7.1 | | 12 | | | |
| Grass | 0.5km north west of site | 1[E] | | <8.2 | | <10 | | | |
| Sediment | Glamorgan canal | 1[E] | | 45 | | 59 | | | |
| Freshwater | Outfall to River Taff | 1[E] | | <7.9 | <3.6 | <5.6 | | | |
| Freshwater | River Taff upstream | 2[E] | | <8.0 | | <10 | | | |
| Freshwater | River Taff downstream | 1[E] | | <7.6 | <3.3 | <14 | | | |
| Freshwater | Glamorgan canal | 2[E] | | <12 | <3.4 | <7.0 | | | |

[a] *Except for milk, water and effluent where units are Bq l$^{-1}$ and for sediment where dry concentrations apply*
[b] *Data are arithmetic means unless stated as 'max' in this column. 'Max' data are selected to be maxima. If no 'max' value is given the mean value is the most appropriate for dose assessments*
[c] *The number of farms from which milk is sampled. The number of analyses is greater than this and depends on the bulking regime*
[d] *The organic fraction may be higher than the total tritium value for some analyses due to uncertainties in the analytical methods for tritium. For dose assessments in this report, the higher of the two values has been used*
[e] *As tritiated water*
[f] *The concentration of $^{32}P$ was <0.12 (max <0.13) Bq l$^{-1}$*
[E] *Measurements labelled "E" are made on behalf of the Environment Agency, all other measurements are made on behalf of the Food Standards Agency*

## Table 6.3(b) Monitoring of radiation dose rates near Cardiff, 2016

| Location | Ground type | No. of sampling observations | µGy h$^{-1}$ |
|---|---|---|---|
| **Mean gamma dose rates at 1m over substrate** | | | |
| East of Pipeline | Mud | 2 | 0.078 |
| West of Pipeline | Rock and mud | 1 | 0.086 |
| West of Pipeline | Rock and shingle | 1 | 0.081 |
| Peterstone Wentlooge | Mud | 2 | 0.070 |

# 7. Industrial and landfill sites

This section considers the effects of (i) the main disposal site on land for solid radioactive wastes in the UK, at the LLWR near Drigg in Cumbria, as well as other landfill sites which have received small quantities of solid wastes and (ii) other sites where industries or incidents may have introduced radioactivity into the environment.

## Key points

- Planning permission was granted enabling waste disposal at the LLWR in 2016
- Doses (dominated by the effects of legacy discharges from other sources) decreased at the LLWR in 2016
- Doses (dominated by the effects of naturally occurring radionuclides from legacy discharges) decreased at Whitehaven in 2016
- Doses at landfill sites (excluding the LLWR) were less than 0.5 per cent of the dose limit in 2016

## 7.1 Low Level Waste Repository near Drigg, Cumbria

The LLWR is the UK's national facility for the disposal of lower activity waste and is located on the west Cumbrian coast, south east of Sellafield. The main function of the LLWR is to receive low activity solid radioactive wastes from all UK nuclear licensed sites (except Dounreay, where the adjacent disposal facility began accepting waste in April 2015) and many non-nuclear sites. Where possible the waste is compacted, and then most waste is grouted within containers before disposal. Wastes may be disposed of in engineered concrete vaults on land, whereas prior to the early 1990s waste was disposed of in open clay lined trenches. The site is owned by the NDA and operated on their behalf by LLWR Limited. From 2008, a consortium, UK Nuclear Waste Management Limited (UKNWM), took over as the PBO for LLWR Limited. A plan setting out the long-term future of the site through to its final closure, currently planned for 2079, has been published (LLWR Limited, 2015). Final site clearance is expected to be achieved by 2080 (NDA, 2017).

The disposal permit allows for the discharge of leachate from the site through a marine pipeline. These discharges are small compared with those discharged from the nearby Sellafield site (Appendix 2). Marine monitoring of the LLWR is therefore subsumed within the Sellafield programme, described in Section 2. The contribution to exposures due to LLWR discharges is negligible compared with that attributable to Sellafield and any effects of LLWR discharges in the marine environment could not, in 2016, be distinguished from those due to Sellafield.

The most recent habits survey was published in 2013 and the results have been included in the dose assessments for the site (Clyne *et al*., 2013).

Site operators were granted a new permit to allow for continued waste disposal at the site, effective from 1 November 2015. This permit included granting permission to dispose of further radioactive waste beyond Vault 8 in accordance with the conditions of the permit, the environmental safety case and waste acceptance criteria for the Low Level Waste Repository. It also included removal of annual radiological limits on disposals by burial, and instead limits disposals against a lifetime capacity for the site. Planning permission, covering waste disposal, the construction of future disposal vaults and final capping of the site was granted by Cumbria County Council in July 2016. As a consequence of the issuing of a varied environmental permit and the successful planning permission, the site is commencing a Repository Development Programme which will include the emplacement of waste in its final location in Vault 8 and the capping of this waste.

As emplacement of waste in its final disposal location, and its capping progresses, in future it is intended to report the quantity of solid radioactive waste finally disposed at the site. In the meantime, while development work progresses on the final waste disposal location and capping arrangements, Table A2.3 records, for financial year 2016/17, both solid radioactive waste already disposed in Vault 8 and the solid radioactive wastes accepted by the site with the intention to dispose and currently stored within Vault 8 and 9 pending disposal. 3,350 $m^3$ of waste was received by the site with the intention of disposal in financial year 2016/17, bringing the cumulative total to 244,000 $m^3$. The radiological data are given in Table A2.3, but unlike previous years, data are recorded by financial year instead of calendar year. All activities in terms of either disposal and receipt of solid radioactive waste with the intention of disposal have been within the lifetime capacity for the site.

Although the permit for disposal to the Drigg Stream has been revoked, reassurance monitoring of samples of water and sediment has continued. The results are given in Table 7.2. The tritium, gross alpha and gross beta concentrations in the stream were below the investigation levels for drinking water in the European Directive

2013/51. Although the stream is not known to be used as a source of drinking water, it is possible that occasional use could occur, for example by campers. If the stream was used as a drinking water supply for three weeks, the dose would be less than 0.005 mSv. Concentrations of radionuclides in sediment from the Drigg stream were similar to those in 2015. They reflect the legacy of direct discharges of leachate from the disposal site into the stream (BNFL, 2002). This practice stopped in 1991.

In the past, groundwater from some of the trenches on the LLWR site migrated eastwards towards a railway drain that runs along the perimeter of the site. Radioactivity from the LLWR was detected in the drain water. The previous operators of the site (BNFL) took steps in the early 1990s to reduce migration of water from the trenches by building a "cut-off wall" to reduce lateral migration of leachate. The results of monitoring in the drain in 2016 have shown that the activity concentrations are now very low and have reduced significantly since the "cut-off wall" was constructed. Tritium, gross alpha and gross beta concentrations were below or just above the investigation levels for drinking water in the European Directive 2013/51.

The monitoring programme of terrestrial foodstuffs at the site was primarily directed at the potential migration of radionuclides from the waste burial site via groundwater since the disposals of gaseous wastes are very small. Results for 2016 are given in Table 7.2. Evidence in support of the proposition that radioactivity in leachate from the LLWR might be transferring to foods was very limited in 2016 (as in 2015). In general, concentrations of radionuclides detected were similar to, or lower than, those found near Sellafield (Section 2). The *total dose* from all pathways and sources, including a component due to Chernobyl and weapon test fallout, was 0.41 mSv (values are rounded to two significant figures), or 41 per cent of the dose limit for members of the public of 1 mSv (Table 7.1). This was dominated by the effects of the legacy of discharges into the sea at both Sellafield and Whitehaven, which are near to the LLWR site. If these effects were to be excluded, and the sources of exposure from the LLWR are considered, the representative person was an infant (1 year-old) spending time near the site. Their *total dose* was 0.034 mSv (Table 1.2) in 2016, mostly due to direct radiation. A source specific assessment of exposure for consumers of locally grown terrestrial food gave an exposure of 0.007 mSv. The increase in dose (from <0.005 mSv in 2015) was mostly due to higher carbon-14 concentrations in milk in 2016.

## 7.2 Other landfill sites

Some organisations are granted authorisations or permits by SEPA (in Scotland) or the Environment Agency (in England and Wales)*, respectively to dispose of solid wastes containing low levels of radioactivity to approved landfill sites. In Northern Ireland, this type of waste is transferred to Great Britain for incineration. Waste with very low levels of radioactivity can also be disposed of in general refuse. Radioactivity in wastes can migrate into leachate and in some cases can enter the groundwater. SEPA and the Environment Agency carry out monitoring of leachates. The locations of landfill sites considered in 2016 is shown in Figure 7.1 and the results are presented in Tables 7.3 and 7.4.

The results, in common with previous years, showed evidence for migration of tritium from some of the disposal sites. The reported tritium concentrations vary from year to year. The variation is thought to be related to changes in rainfall quantity and resulting leachate production and the use of different boreholes for sampling. A possible source of the tritium is thought to be due to disposal of Gaseous Tritium Light Devices (Mobbs *et al*., 1998). Inadvertent ingestion of leachate (2.5 l per year) from the site with the highest observed concentration of tritium would result in a dose of less than 0.005 mSv or less than 0.5 per cent of the dose limit for members of the public of 1 mSv (Table 7.1). Similarly, the dose from ingestion of uranium isotopes in leachate from Clifton Marsh was also less than 0.005 mSv.

In 2007, the UK Government introduced a more flexible framework for the disposal of certain categories of LLW to landfill. Further details and information are provided on website: **https://www.gov.uk/government/policies/managing-the-use-and-disposal-of-radioactive-and-nuclear-substances-and-waste/supporting-pages/providing-policy-for-the-safe-and-secure-disposal-of-radioactive-waste**.

In England and Wales, disposal of LLW at landfill sites requires both landfill companies and nuclear operators to hold permits to dispose of LLW and VLLW. The 2007 Government policy led to applications from landfill operators for permits to dispose of LLW at their sites. The landfill sites were:

- Waste Recycling Group Limited at the Lillyhall Landfill Site in Cumbria. Their permit, issued in 2011, allows them to dispose of VLLW
- Augean at the East Northants Resource Management Facility (ENRMF), near Kings Cliffe, Northamptonshire. Their permit, issued in 2011, allows them to dispose of low activity LLW and VLLW. In July 2015, the Environment Agency considered a new application by Augean to extend the current landfill area to the west of the site and to introduce a more flexible and robust method of managing the radiological capacity of the site. A revised environmental safety case was also produced. After careful consideration and consultation with the public, and partner organisations a new permit was issued in February 2016. The new

* *The Environment Agency has an agreement with NRW to undertake some specific activities on its behalf in Wales including some environmental monitoring and aspects of radioactive substances regulation*

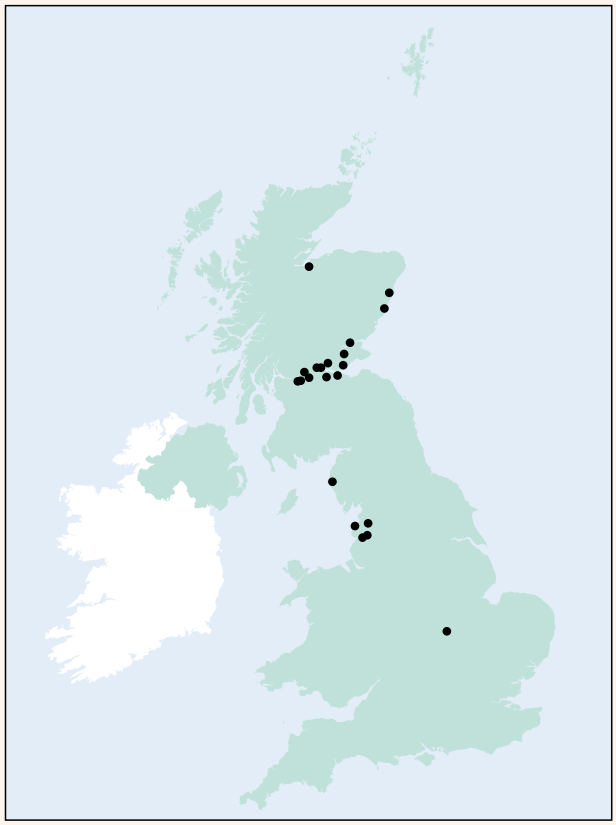


**Figure 7.1.** Landfill sites monitored in 2016

permit requires the operator to carry out periodic environmental monitoring. The results and techniques used are annually audited by the Environment Agency.

- Suez Recycling and Recovery UK Limited (formerly SITA UK) at Clifton Marsh in Lancashire. A permit to dispose of LLW was issued by the Environment Agency in 2012. This permit replaced previous arrangements authorising disposals at Clifton Marsh by operators at the Springfields and Capenhurst nuclear licensed sites, whose permits used to allow disposal of solid LLW at Clifton Marsh in their own right. The varied permits allow those operators to transfer LLW to landfill operators who hold an appropriate EPR 16 (formerly EPR 10) permit.

Disposals of LLW at Clifton Marsh have continued under the new permitting arrangements.

Disposals of LLW at the ENRMF, near Kings Cliffe, site began in 2011 and were from non-nuclear site remediation works. The first consignment from a nuclear licensed site in 2012; this comprised soil, concrete, rubble and clay pipes from the drains on the Harwell site. In parallel, the Environment Agency began a programme of monitoring within and around the ENRMF landfill site, near Kings Cliffe, in order to provide a baseline and allow any future changes to be detected. In 2016, samples were taken and analysed for radiological composition from groundwater boreholes and off-site watercourses. Samples of borehole water and surface water were taken and filtered. Both the filtrate and the particulate were analysed for their radioactivity content, along with some bulk water samples. The results are given in Table 7.5. The results for man-made radionuclides were generally at limits of detection or at low levels expected due to UK-wide fallout from weapon testing and overseas accidents. Naturally occurring radionuclides were present at levels expected due to natural sources. Gross alpha and gross beta concentrations in water were below the investigation levels for drinking water in the European Directive 2013/51 of 0.1 and 1.0 Bq $l^{-1}$, respectively. No use of water for drinking has been observed. Where sampling was repeated, the results were similar to those in previous years. In 2014, leachate samples were analysed and were found to contain tritium levels in excess of 100 Bq $l^{-1}$ (Environment Agency, FSA, FSS, NIEA, NRW and SEPA, 2015). This likely to be due to the disposal of Gaseous Tritium Light Devices. An assessment of exposure based on inadvertent ingestion of borehole or surface water at concentrations presented in Table 7.5 gives a dose of less than 0.005 mSv or less than 0.5 per cent of the dose limit for members of the public of 1 mSv (Table 7.1). The assessment excludes potassium-40 because its presence in the body is homeostatically controlled.

SEPA's monitoring programme at the Stoneyhill Landfill Site in Aberdeenshire which is authorised to dispose of conditioned NORM waste ceased in 2016. Results up to 2015 are included in earlier RIFE reports and show no significant impact.

NORM is found within oil and gas reserves and is consequently extracted along with the oil and gas. The NORM can precipitate onto oil and gas industry equipment creating an insoluble scale (NORM scale). The presence of this scale reduces the efficiency of the equipment and must be removed. Suez Recycling and Recovery UK Limited, who operates Stoneyhill Landfill site, has constructed a descaling facility adjacent to the landfill in partnership with Nuvia Limited. This facility descales oil and gas industry equipment (such as pipes) using pressurised water. The solid scale removed from the equipment is then grouted into drums and can be consigned to Stoneyhill Landfill site in accordance with their authorisation granted in May 2012.

## 7.3 Metals Recycling Facility, Lillyhall, Cumbria

The Metals Recycling Facility (MRF), operated by the license holder, Cyclife UK Limited (formerly Studsvik UK Limited), is a small low hazard facility located at the Lillyhall Industrial Estate near Workington in Cumbria. The MRF receives metallic waste items contaminated with low levels of radiological contamination from clients within the UK nuclear industry. These items are processed on a batch basis that includes size reduction (if required) using conventional hot and cold cutting techniques with subsequent decontamination using industrial grit blasting equipment.

A permit for disposal of radioactive waste from the site was issued by the Environment Agency in March 2008, although no radioactive waste disposals were made until September 2009. The permit allows discharges of gaseous waste to the environment via a main stack and aqueous waste to the sewer. Low discharge limits are set for both aqueous and gaseous discharges. Very small discharges were made during 2015 (Appendix 2). The permit includes conditions requiring Cyclife UK Limited to monitor discharges and undertake environmental monitoring.

## 7.4 Phosphate processing, Whitehaven, Cumbria


An important historical man-made source of naturally occurring radionuclides in the marine environment has been the chemical plant at Whitehaven in Cumbria, which used to manufacture phosphoric acid (for use in detergents) from imported phosphate ore (Rollo *et al*., 1992). Phosphogypsum, containing thorium, uranium and their daughter products, was discharged as a liquid slurry by pipeline to Saltom Bay. Processing of phosphate ore ceased in 1992 and processing of phosphoric acid at the plant ceased at the end of 2001. However, an environmental legacy has occurred from these past operations and discharges. Such sources are said to give rise to Technologically enhanced Naturally Occurring Radioactive Material (TNORM). Decommissioning of the plant was undertaken in 2002 and released small quantities of uranium to sea, but discharges were very much lower than in previous years. The plant was subsequently demolished in 2004 and the permit to discharge radioactive wastes revoked by the Environment Agency.

The results of routine monitoring for naturally occurring radioactivity near the site in 2016 are shown in Table 7.6. Analytical effort has focused on lead-210 and polonium-210, which concentrate in marine species and are the important radionuclides in terms of potential dose to the public. Concentrations of polonium-210 and other naturally occurring radionuclides were slightly enhanced near Whitehaven but quickly reduce to background levels further away. Figures 7.2 and 7.3 show how concentrations of polonium-210 in winkles and crabs have generally decreased since 1998. Concentrations in the early 1990s were in excess of 100 Bq $kg^{-1}$ (fresh weight). There were some variations in concentrations of polonium-210 in local samples in 2016 compared with 2015. In particular, there were small increases in concentrations in crabs and lobsters. However, polonium-210 concentrations in these samples continued to be within or close to the expected range due to natural sources in 2016. For these and other seafood samples, it is now difficult to distinguish between the measured radionuclide concentrations and the range of concentrations normally expected from naturally sourced radioactivity. The latter are shown in Figures 7.2 and 7.3 and in Appendix 1 (Annex 4). There were small enhancements for some samples at other locations above the expected natural background median levels for marine species, but the majority were within the ranges observed in the undisturbed marine environment. It is considered prudent to continue to estimate doses at Whitehaven based on the positive difference, if any, between observed concentrations and median levels indicative of natural background. A recent analysis has confirmed that this approach is unlikely to underestimate doses (Dewar *et al.,* 2014).

The exposure pathway considered for the assessment at Whitehaven was internal irradiation, due to the ingestion of naturally occurring radioactivity in local fish and shellfish. The representative person was a consumer who, centred on the Sellafield site to the south of Whitehaven, obtained their sources of seafood from locations such as Whitehaven, Nethertown and Parton. This consumer is also considered in the assessment of the marine impacts of the Sellafield and LLWR (near Drigg) sites (Sections 2 and 7). The estimated contribution due to background median concentrations of naturally occurring radionuclides is subtracted. Consumption rates for people who eat at high-rates were reviewed and revised in 2016 (Garrod and Clyne, 2017). The dose coefficient for polonium-210 is based on a value of the gut transfer factor of 0.5 for all foods.

The *total dose* to a local high rate consumer of seafood was 0.41 mSv in 2016 (Table 7.1), below the dose limit for members of the public of 1 mSv. The value for 2015 was 0.42 mSv. The dose includes the effects of all sources near the site: enhanced naturally occurring radionuclides from the non-nuclear industrial activity (i.e. TNORM) and Sellafield operations. The source specific assessment of dose, targeted directly at a high-rate seafood consumer confirms the *total dose* assessment and gives a similar result of 0.43 mSv in 2016.

The contribution to the *total dose* from enhanced natural radionuclides was 0.34 mSv in 2016, compared with 0.35 mSv in 2015. This small decrease in dose was due to small changes in the consumption rate and types of crustacean species consumed, although the concentration of polonium-210 in lobster increased slightly (in comparison to 2015). Polonium-210 is an important radionuclide in that small increases in net levels (after the natural background is subtracted) significantly influences the dose contribution from this radionuclide and similarly the increase in value of the estimated dose. The largest contribution to dose to a seafood consumer near Whitehaven and Sellafield is now from historical discharges from Whitehaven. The longer-term trend in *total dose* over

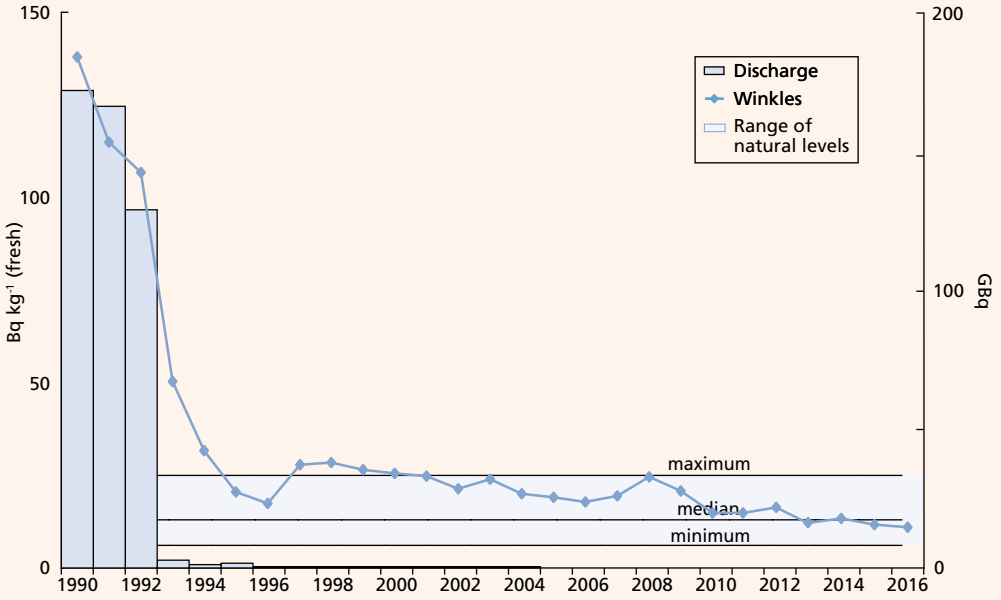



**Figure 7.2.** Polonium-210 discharge from Whitehaven and concentration in winkles at Parton, 1990-2016

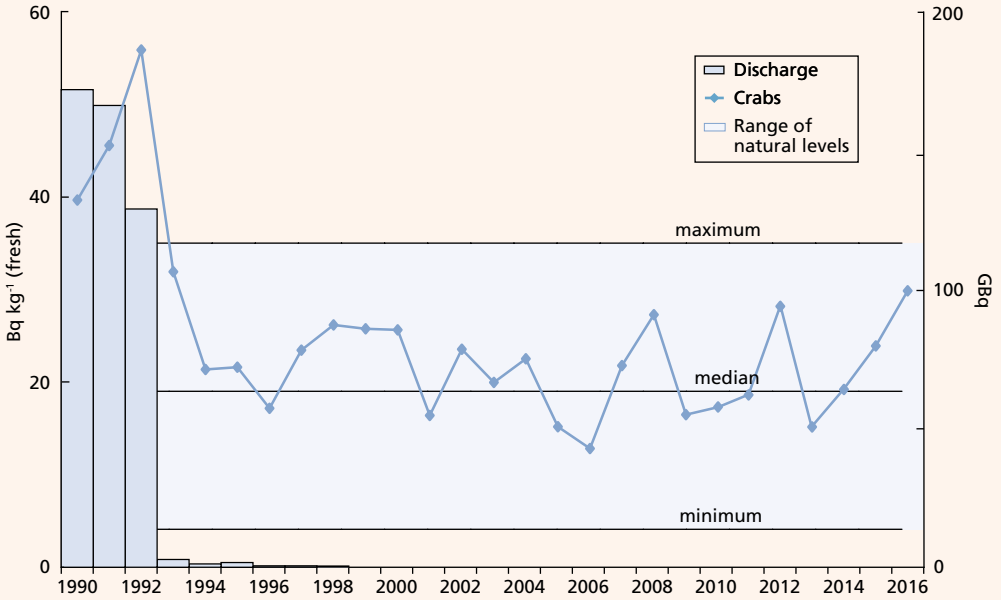



**Figure 7.3.** Polonium-210 discharge from Whitehaven and concentration in crabs at Parton, 1990-2016

the period 2004 – 2016 is shown in Figure 7.4. The overall reduction in *total dose* (with some variability from year to year), up to 2010, reflects changes in both polonium-210 concentrations and consumption rates, primarily of lobsters and molluscs. Thereafter, variations in *total dose* over the period 2011 – 2016 reflect changes in polonium-210 concentrations, consumption rates and the range of seafood species consumed by individuals at high-rates, including that of lobsters and fish.

## 7.5 Aberdeen, Aberdeenshire

Scotoil operates a cleaning facility for equipment from the oil and gas industry contaminated with enhanced concentrations of radionuclides of natural origin. The facility is authorised to discharge liquid effluent to sea with the primary discharge being radium-226 and radium-228, with lead-210 and polonium-210 in smaller quantities. The authorisation includes conditions requiring Scotoil to undertake environmental monitoring. Prior to their operations, a fertiliser manufacturing process was operated on the site, which made discharges to sea.

Seaweed (*Fucus vesiculosus*) from Aberdeen Harbour was monitored in 2016. Technetium-99 was detected in seaweed (18 Bq $kg^{-1}$, fresh), in line with the expected effect from Sellafield discharges (as the releases become diluted or mixed in moving further afield). Gamma-emitting radionuclides were all below the LoD. In 2016,

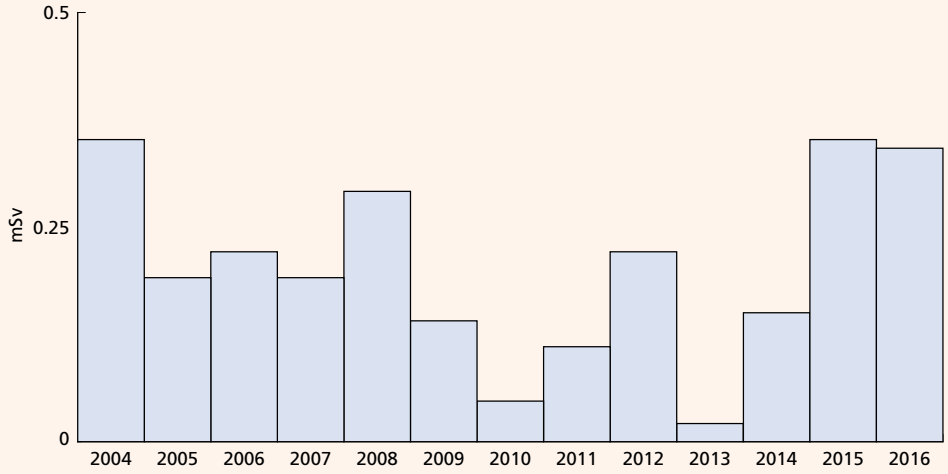



**Figure 7.4.** Trend in *total dose* to seafood consumers from naturally-occurring radionuclides near Whitehaven, 2004-2016

the dose rate on sediment was 0.20 μGy $h^{-1}$ and higher in comparison to those in recent years.

## 7.6 Dalgety Bay, Fife

Radioactive items containing radium-226 and associated daughter products have been detected at Dalgety Bay in Fife since at least 1990. The contamination is associated with historical disposals of waste from past military operations at the Royal Naval Air Station (RNAS) Donibristle, which closed in 1959 and upon which large areas of the town of Dalgety Bay have been built. The air station played a role as an aircraft repair, refitting and salvage yard. It is believed that waste was incinerated and the resultant ash and clinker was disposed of by reclaiming land from the sea. Following years of erosion at the site the contamination is being exposed on and adjacent to the foreshore. Some of the incinerated material contained items such as dials and levers which had been painted with luminous paint containing radium-226.

In 1990, environmental monitoring showed elevated radiation levels in the Dalgety Bay area. The monitoring was undertaken as part of the routine environmental monitoring programme for Rosyth Royal Dockyard conducted in accordance with the dockyard's authorisation to dispose of liquid radioactive effluent to the Firth of Forth. Some material was removed for analysis, which indicated the presence of radium-226. Further investigation confirmed that the contamination could not have originated from the dockyard and was most likely to be associated with past practices related to the nearby former RNAS Donibristle/HMS Merlin military airfield. Since this initial discovery, there have been several monitoring exercises to determine the extent of this contamination.

Following the increased number of particle finds and the discovery of the high activity particles in 2011, additional public protection measures were established and these were maintained during 2015 and into 2016. A monthly beach monitoring and particle recovery programme was adopted in 2012 by a contractor working on behalf of the MoD and this remains in place. The fence demarcating the area where the highest activity particles were discovered remains in place, as well as the information signs advising the public of the contamination and precautions to be taken. In addition, the FEPA Order issued by the Food Standards Agency in Scotland (now FSS) prohibiting the collection of seafood from the Dalgety Bay area remains in force. SEPA undertook a programme of shellfish monitoring between February 2012 and February 2013 during which no particles were detected in the shellfish. All shellfish samples collected were analysed for the presence of radium-226 and all were found to be less than the LoD. During routine monitoring of mussel beds in November 2015 a particle was detected in this area (for the first time since 2011) and retrieved, indicating that the continuation of these protection measures is reducing the risks to members of the public whilst further work continues to address the contamination.

Following the publication of the risk assessment together with the appropriate persons report in 2013, COMARE recommended at its meeting in July 2013 that effective remediation of the affected area is undertaken as soon as is possible. This recommendation, amongst others, was subsequently published in 2014 in COMARE's 15th report. The MoD has progressed with addressing the contamination by initially publishing its Outline Management Options Appraisal Report in January 2014 followed by the publication in July 2014 of its broad management strategy and timescale for implementation of its preferred management option. Copies of these reports are available on the UK Government website.

Work continues towards the implementation of the preferred management option with the convening of the Dalgety Bay Implementation Group. The Dalgety Bay Permitting Authorities Group has also been convened to ensure that any permits or licences required to proceed with the management option can be in place to allow

the addressing of the contamination. The Environmental Impact Assessment (EIA) in support of the Planning Application for the remediation works has been submitted to Fife Council for consideration and will be progressed in line with due process.

For further information on the work at Dalgety Bay please visit the Radioactive Substances pages on SEPA's website (**www.sepa.org.uk**).

## 7.7 Kinloss Barracks (formerly RAF Kinloss), Moray

Radioactive items containing radium-226 and associated daughter products have been detected on an area of land which used to form part of the former RAF Kinloss, now Kinloss Barracks. The contamination is associated with historical disposals of waste from past military operations at the site resulting from the dismantling of aircraft no longer required by the RAF following World War II. During the late 1940s, the aircraft were stripped for their scrap metal, with the remains being burnt and/or buried at the site. The source of the radium-226 and associated daughter products are the various pieces of aircraft instrumentation which were luminised with radium paint.

SEPA has undertaken monitoring surveys at the site which positively identified the presence of radium-226 and has published an assessment of the risks posed to the public. Currently, the site is largely undeveloped open land covered in gorse, with a number of wind turbines and access tracks. The area has a number of informal paths crossing the land that is used by visitors and dog walkers. The contamination detected at the site is all currently buried at depth. Current uses of the site do not involve intrusion into the ground to any significant depth; thus, there is no current pathway for exposure via skin contact, ingestion or inhalation. Exposure via external gamma irradiation is possible but is significantly below the relevant dose criteria detailed in the Radioactive Contaminated Land (RCL) Statutory Guidance.

The risk assessment of the series of monitoring surveys concluded that, under its current use, there are no viable or credible exposure pathways for the public to be exposed to the contamination and that this site does not currently meet the definition of radioactive contaminated land (Natural Scotland and SEPA, 2016). However, SEPA will keep this site under review as a change in land use on the site may alter the potential exposure pathways. To access the full risk assessment report please visit the Radioactive Substances pages on SEPA's website (**www.sepa.org.uk**).

## 7.8 Other non-nuclear sites

Routine discharges of small quantities of radioactive wastes to air and water are made from a wide range of other non-nuclear sites in the UK on land, and from offshore oil and gas installations.

A summary of the most recent data for the quantities discharged under regulation for England, Wales and Northern Ireland is given in Tables 7.7 and 7.8. Data for Scotland are presented in Tables 7.9 and 7.10 in terms of OSPAR regions (Zone II represents the Greater North Sea and Zone III the Celtic Sea). This change in format allows easier trend analysis to be performed for OSPAR and also a direct comparison with the combined UK RIFE Summary/OSPAR BAT report, which will be available in early 2018. The data are grouped according to the main industries giving rise to such wastes in the UK and exclude information for other industries considered in other sections of this report, principally the nuclear sector. The main industries are:

- Oil and gas (off and onshore)
- Education (Universities and Colleges)
- Hospitals
- Other (research, manufacturing and public sector)

Discharges may also occur without an authorisation or permit when the quantities are considered to be below the need for specific regulatory control. For example, discharges of natural radionuclides are made from coal-fired power stations because of the presence of trace quantities of uranium and thorium and their decay products in coal (Corbett, 1983).

As indicated in Section 1, general monitoring of the British Isles as reported elsewhere in this report has not detected any gross effects from non-nuclear sources. Occasionally, routine programmes directed at nuclear licensed site operations detect the effects of discharges from the non-nuclear sector and, when this occurs, a comment is made in the relevant nuclear licensed site text. The radiological impact of the radioactivity from the non-nuclear sector detected inadvertently in this way is very low.

Monitoring of the effects of the non-nuclear sector is limited because of the relatively low impact of the discharges. However, programmes are carried out to confirm that impacts are low and, when these occur, they are described in this report.

In 2016, SEPA undertook a small-scale survey (as part of the annual programme) of the effects of discharges from non-nuclear operators by taking and analysing samples of mussels and other materials from the River Clyde, the Firth of Forth and sludge pellets from a STW. The results are given in Table 7.11. They show the expected effects of Sellafield discharges at this distance and the presence of iodine-131 in sludge pellets, probably from a hospital source. The results were generally similar to those in 2015. An assessment of the dose to a representative high-rate mollusc consumer was undertaken. The dose was less than 0.005 mSv or less than 0.5 per cent of the dose limit.

## Table 7.1 Individual doses – industrial and landfill sites, 2016

| Site | Representative person[a,b] | Exposure, mSv per year | | | | | |
|---|---|---|---|---|---|---|---|
| | | Total | Seafood (nuclear industry discharges) | Seafood (other discharges) | Other local food | External radiation from intertidal areas[e] | Intakes of sediment and water |
| ***Total dose* – all sources** | | | | | | | |
| Whitehaven and LLWR near Drigg | **Adult mollusc consumers** | **0.41[d]** | **0.055** | **0.34** | **–** | **0.019** | **–** |
| **Source specific doses** | | | | | | | |
| LLWR near Drigg | Infant consumers of locally grown food | 0.007 | – | – | 0.007 | – | – |
| | Consumers of water from Drigg stream | <0.005[c] | – | – | – | – | <0.005 |
| Landfill sites for low-level radioactive wastes | Inadvertent leachate consumers (infants) | <0.005 | – | – | – | – | <0.005 |
| Whitehaven (habits averaged 2012-16) | Seafood consumers | 0.43[d] | 0.051 | 0.35 | – | 0.032 | – |

[a] *The* total dose *is the dose which accounts for all sources including gaseous and liquid discharges and direct radiation. The* total dose *for the representative person with the highest dose is presented. Other dose values are presented for specific sources, either liquid discharges or gaseous discharges, and their associated pathways. They serve as a check on the validity of the* total dose *assessment. The representative person is an adult unless otherwise stated*

[b] *None of the people represented in this table were considered to receive direct radiation from the sites listed*

[c] *Includes a component due to natural sources of radionuclides*

[d] *Includes the effects of discharges from the adjacent Sellafield site*

[e] *Doses (*total dose *and source specific doses) only include estimates of anthropogenic inputs (by substracting background and cosmic sources from measured gamma dose rates)*

## Table 7.2 Concentrations of radionuclides in terrestrial food and the environment near Drigg, 2016

| Material | Location or selection[a] | No. of sampling observ-ations[c] | Mean radioactivity concentration (fresh)[b], Bq kg$^{-1}$ | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $^{3}$H | $^{14}$C | $^{60}$Co | $^{90}$Sr | $^{95}$Zr | $^{95}$Nb | $^{99}$Tc | $^{106}$Ru | $^{125}$Sb |
| Milk | | 1 | <3.2 | 19 | <0.07 | 0.032 | <0.13 | <0.09 | <0.015 | <0.62 | <0.17 |
| Deer muscle | | 1 | <3.8 | 29 | <0.08 | <0.051 | <0.23 | <0.19 | <0.10 | <0.54 | <0.11 |
| Eggs | | 1 | <7.7 | 50 | <0.04 | <0.043 | <0.12 | <0.16 | | <0.27 | <0.11 |
| Potatoes | | 1 | <2.2 | 15 | <0.03 | <0.043 | <0.15 | <0.11 | <0.090 | <0.75 | <0.14 |
| Sheep muscle | | 1 | <9.6 | 33 | <0.07 | <0.040 | <0.17 | <0.15 | <0.093 | <0.56 | <0.15 |
| Sheep offal | | 1 | <4.4 | 33 | <0.05 | 0.057 | <0.13 | <0.12 | <0.11 | <0.31 | <0.13 |
| Grass | | 1 | <2.7 | 20 | <0.11 | 0.55 | <0.13 | <0.12 | <0.099 | <0.68 | <0.21 |
| Sediment | Drigg Stream | 4[E] | | | <0.33 | <2.4 | <1.0 | <0.23 | | <2.4 | <1.2 |
| Freshwater | Drigg Stream | 4[E] | <4.0 | | <0.29 | <0.032 | | | | | |
| Freshwater | Railway drain | 1[E] | <4.4 | | <0.24 | 0.20 | | | | | |

| Material | Location or selection[a] | No. of sampling observ-ations[c] | Mean radioactivity concentration (fresh)[b], Bq kg$^{-1}$ | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $^{129}$I | $^{134}$Cs | $^{137}$Cs | Total Cs | $^{144}$Ce | $^{210}$Po | $^{228}$Th | $^{230}$Th | $^{232}$Th |
| Milk | | 1 | <0.0043 | <0.07 | <0.12 | | <0.36 | | | | |
| Deer muscle | | 1 | 0.063 | <0.10 | 1.4 | 1.4 | <0.50 | | | | |
| Eggs | | 1 | <0.027 | <0.06 | <0.04 | 0.035 | <0.32 | | | | |
| Potatoes | | 1 | <0.021 | <0.09 | <0.18 | 0.16 | <0.51 | | | | |
| Sheep muscle | | 1 | <0.019 | <0.07 | 0.26 | 0.35 | <0.38 | | | | |
| Sheep offal | | 1 | <0.016 | <0.04 | 0.09 | 0.16 | <0.30 | | | | |
| Grass | | 1 | <0.021 | <0.10 | 0.41 | 0.34 | <0.40 | | | | |
| Sediment | Drigg Stream | 4[E] | | <0.30 | 72 | | <1.6 | 6.8 | 17 | 12 | 14 |
| Freshwater | Drigg Stream | 4[E] | | <0.29 | <0.23 | | | <0.0025 | <0.0084 | <0.0033 | <0.0027 |
| Freshwater | Railway drain | 1[E] | | <0.24 | <0.19 | | | <0.0021 | <0.0093 | <0.0038 | <0.0029 |

| Material | Location or selection[a] | No. of sampling observ-ations[c] | Mean radioactivity concentration (fresh)[b], Bq kg$^{-1}$ | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $^{234}$U | $^{235}$U | $^{238}$U | $^{238}$Pu | $^{239}$Pu + $^{240}$Pu | $^{241}$Pu | $^{241}$Am | Gross alpha | Gross beta |
| Milk | | 1 | | | | <0.000043 | <0.000037 | <0.11 | <0.000014 | | |
| Deer muscle | | 1 | | | | <0.00014 | <0.00019 | <0.21 | 0.000092 | | |
| Eggs | | 1 | | | | 0.000019 | 0.000071 | <0.21 | 0.00015 | | |
| Potatoes | | 1 | | | | 0.000072 | 0.0018 | <0.23 | 0.0019 | | |
| Sheep muscle | | 1 | | | | <0.000093 | 0.00018 | <0.27 | 0.00063 | | |
| Sheep offal | | 1 | | | | 0.0042 | 0.028 | 0.24 | 0.037 | | |
| Grass | | 1 | | | | 0.0017 | 0.011 | 0.13 | 0.022 | | |
| Sediment | Drigg Stream | 4[E] | 23 | <1.6 | 20 | 4.2 | 29 | <134 | 35 | 190 | 460 |
| Freshwater | Drigg Stream | 4[E] | 0.0097 | <0.0018 | 0.0085 | <0.0022 | <0.0015 | <0.15 | <0.0047 | <0.044 | 0.43 |
| Freshwater | Railway drain | 1[E] | 0.015 | <0.0012 | 0.012 | <0.0028 | <0.0016 | <0.13 | <0.0040 | <0.075 | 0.46 |

[a] *Data are arithmetic means unless stated as 'max'. 'Max' data are selected to be maxima. If no 'max' value is given the mean value is the most appropriate for dose assessments*

[b] *Except for milk and freshwater where units are Bq l$^{-1}$, and for sediment where dry concentrations apply*

[c] *The number of farms from which milk is sampled. The number of analyses is greater than this and depends on the bulking regime*

[E] *Measurements are made on behalf of the Food Standards Agency unless labelled "E". In that case they are made on behalf of the Environment Agency*

## Table 7.3 Concentrations of radionuclides in surface water leachate from landfill sites in Scotland, 2016

| Area | Location | No. of sampling observations | Mean radioactivity concentration, Bq $l^{-1}$ | | | |
|---|---|---|---|---|---|---|
| | | | $^{3}H$ | $^{14}C$ | $^{137}Cs$ | $^{241}Am$ |
| Aberdeen City | Ness landfill | 1 | 25 | <15 | <0.05 | <0.05 |
| City of Glasgow | Summerston landfill | 1 | 58 | <15 | <0.05 | <0.05 |
| City of Glasgow | Cathkin | 1 | 320 | <15 | <0.05 | <0.05 |
| Clackmannanshire | Black Devon | 1 | 10 | <15 | <0.05 | <0.05 |
| Dunbartonshire | Birdston | 1 | <5.0 | <15 | <0.05 | <0.05 |
| Dundee City | Riverside | 1 | 10 | <15 | <0.05 | <0.05 |
| Edinburgh | Braehead | 1 | <5.0 | <15 | <0.05 | <0.05 |
| Fife | Balbarton | 1 | 59 | <15 | <0.05 | <0.05 |
| Fife | Melville Wood | 1 | 280 | <15 | <0.05 | <0.05 |
| Highland | Longman landfill | 1 | <5.0 | <15 | <0.05 | <0.05 |
| North Lanarkshire | Dalmacoulter | 1 | 260 | <15 | <0.05 | <0.05 |
| North Lanarkshire | Kilgarth | 1 | <5.0 | <15 | <0.05 | <0.05 |
| Stirling | Lower Polmaise | 1 | 22 | <15 | <0.05 | <0.05 |

## Table 7.4 Concentrations of radionuclides in water from landfill sites in England and Wales, 2016

| Location | Sample source | No. of sampling observations | Mean radioactivity concentration, Bq $l^{-1}$ | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | $^{3}H$ | $^{40}K$ | $^{60}Co$ | $^{137}Cs$ | $^{228}Th$ | $^{230}Th$ |
| **Lancashire** | | | | | | | | |
| Clifton Marsh | Borehole 6 | 2 | 8.4 | <4.6 | <0.26 | <0.22 | <0.015 | <0.0042 |
| Clifton Marsh | Borehole 19 | 2 | <5.6 | <6.5 | <0.25 | <0.22 | <0.0097 | <0.0027 |
| Clifton Marsh | Borehole 40 | 2 | <4.1 | <4.6 | <0.26 | <0.20 | <0.0090 | <0.0031 |
| Clifton Marsh | Borehole 59 | 2 | <11 | <5.3 | <0.28 | <0.22 | <0.0084 | <0.0028 |

| Location | Sample source | No. of sampling observations | Mean radioactivity concentration, Bq $l^{-1}$ | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | $^{232}Th$ | $^{234}U$ | $^{235}U$ | $^{238}U$ | Gross alpha | Gross beta |
| **Lancashire** | | | | | | | | |
| Clifton Marsh | Borehole 6 | 2 | <0.0032 | 0.051 | <0.0022 | 0.047 | <0.16 | 2.6 |
| Clifton Marsh | Borehole 19 | 2 | <0.0022 | 0.059 | <0.0026 | <0.050 | <1.6 | 8.4 |
| Clifton Marsh | Borehole 40 | 2 | <0.0027 | <0.0023 | <0.0014 | <0.0021 | <0.11 | <1.2 |
| Clifton Marsh | Borehole 59 | 2 | <0.0023 | <0.0026 | <0.0012 | <0.0016 | <0.12 | 1.6 |

**Table 7.5 Concentrations of radionuclides in water near the East Northants Resource Management Facility landfill site, 2016**

| Site reference | Mean radioactivity concentration[a], Bq kg$^{-1}$ | | | | | |
|---|---|---|---|---|---|---|
| | $^{3}$H | $^{40}$K | $^{137}$Cs | $^{226}$Ra | $^{228}$Th | $^{230}$Th |
| K13A Groundwater borehole | <4.2 | <6.1 | <0.25 | 0.01 | <0.011 | <0.0067 |
| K15A Groundwater borehole | <4.7 | <4.4 | <0.19 | 0.01 | <0.015 | <0.0049 |
| K17 Northern perimeter Groundwater borehole | <5.0 | <2.9 | <0.18 | 0.02 | <0.0096 | <0.0037 |
| Horse Water spring | | <6.2 | <0.25 | | | |
| Willow brook | | <4.3 | <0.19 | | | |

| Site reference | Mean radioactivity concentration[a], Bq kg$^{-1}$ | | | | | |
|---|---|---|---|---|---|---|
| | $^{232}$Th | $^{234}$U | $^{235}$U | $^{238}$U | Gross alpha | Gross beta |
| K13A Groundwater borehole | <0.0024 | 0.017 | <0.0016 | 0.015 | <0.13 | 0.092 |
| K15A Groundwater borehole | <0.0021 | 0.036 | <0.0026 | 0.034 | <0.11 | 0.26 |
| K17 Northern perimeter Groundwater borehole | <0.0024 | 0.031 | <0.0025 | 0.027 | <0.31 | 0.54 |
| Horse Water spring | | | | | <0.063 | 0.58 |
| Willow brook | | | | | <0.081 | 0.58 |

[a] *Except for $^{3}$H where units are Bq l$^{-1}$, and soil where dry concentrations apply*

## Table 7.6 Concentrations of naturally occurring radionuclides in the environment, 2016[b]

| Material | Location | No. of sampling observ-ations | Mean radioactivity concentration (fresh)[a], Bq kg$^{-1}$ | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | $^{210}$Po | $^{210}$Pb | $^{228}$Th | $^{230}$Th | $^{232}$Th | $^{234}$U | $^{235}$U | $^{238}$U |
| **Phosphate processing, Whitehaven** | | | | | | | | | | |
| Winkles | Parton | 2 | 11 | 2.9 | | | | | | |
| Winkles | Nethertown | 4 | 13 | 1.9 | 1.1 | 0.88 | 0.69 | 0.87 | 0.030 | 0.80 |
| Mussels | Whitehaven | 2 | 48 | 2.6 | | | | | | |
| Mussels | Ravenglass | 2 | 29 | 1.4 | | | | | | |
| Prawns | Seascale | 2 | 4.0 | <0.076 | | | | | | |
| Crabs | Parton | 2 | 30 | 0.13 | | | | | | |
| Crabs | Sellafield coastal area | 2 | 15 | 0.27 | 0.16 | 0.016 | 0.013 | 0.12 | 0.0045 | 0.11 |
| Lobsters | Parton | 2 | 31 | 0.16 | | | | | | |
| Lobsters | Sellafield coastal area | 2 | 16 | 0.062 | | | | | | |
| *Nephrops* | Whitehaven | 2 | 1.2 | 0.15 | 0.041 | 0.025 | 0.017 | 0.023 | 0.00085 | 0.021 |
| Cod | Parton | 2 | 0.49 | 0.048 | | | | | | |
| Cod | Whitehaven | 2 | 0.71 | 0.20 | | | | | | |
| Plaice | Whitehaven | 2 | 1.6 | 0.24 | 0.068 | <0.000090 | <0.00014 | 0.025 | 0.00070 | 0.023 |
| Plaice | Drigg | 2 | 1.7 | 0.25 | 0.078 | <0.000084 | <0.000084 | 0.022 | 0.00073 | 0.020 |
| **Other samples** | | | | | | | | | | |
| Winkles | South Gare (Hartlepool) | 2 | 7.9 | 0.50 | | | | | | |
| Winkles | Middletons Sands | 2 | 11 | | | | | | | |
| Winkles | Kirkcudbright | 1[S] | 5.4 | | | | | | | |
| Mussels | Morecambe | 2 | 37 | | | | | | | |
| Mussels | Ribble Estuary | 1 | | | 0.25 | 0.22 | 0.130 | | | |
| Limpets | Kirkcudbright | 1[S] | 4.5 | | | | | | | |
| Crabs | Kirkcudbright | 1[S] | 8.6 | | | | | | | |
| Lobsters | Kirkcudbright | 1[S] | 0.55 | | | | | | | |
| Shrimps | Ribble Estuary | 1 | | | 0.012 | 0.0027 | 0.0016 | | | |
| Wildfowl | Ribble Estuary | 1 | | | | 0.016 | 0.0038 | | | |
| Sediment | Kirkcudbright | 2[S] | | | | | | 8.9 | <0.32 | 7.4 |
| Sediment | Rascarrel Bay | 1[S] | | | | | | 5.9 | 0.36 | 4.8 |

[a] *Except for sediment where dry concentrations apply*
[b] *Data for artificial nuclides for some of these samples may be available in the relevant sections for nuclear sites*
[S] *Measurements labelled "S" are made on behalf of the Scottish Environment Protection Agency*

**Table 7.7 Discharges of gaseous radioactive wastes from non-nuclear establishments in England, Northern Ireland and Wales, 2016[a]**

| | Discharges during 2016, Bq | | | | | |
|---|---|---|---|---|---|---|
| | Education (Universities and Colleges) | | Hospitals | | Other (Research, manufacturing and public sector) | |
| | England & Wales | Northern Ireland | England & Wales | Northern Ireland | England & Wales | Northern Ireland |
| $^{3}H$ | | | | | 2.7E+12 | |
| $^{14}C$ | 7.0E+07 | | | | 2.4E+13 | 2.0E+04 |
| $^{18}F$ | 1.8E+11 | | | | 2.8E+11 | |
| $^{35}S$ | | | 1.7E+08 | | 3.4E+08 | |
| $^{85}Kr$ | | | | | 1.3E+08 | |
| $^{99m}Tc$ | | | 2.1E+08 | | 7.3E+04 | |
| $^{125}I$ | 6.0E+05 | | 2.1E+07 | | 2.7E+08 | |
| $^{129}I$ | | | | | 1.1E+06 | |
| $^{131}I$ | | | 2.5E+08 | | 4.3E+08 | |
| $^{131m}Xe$ | | | 1.3E+08 | | | |
| $^{137}Cs$ | | | | | 7.0E+08 | |
| $^{222}Rn$ | | | | | 2.0E+09 | |
| Uranium Alpha | | | | | 1.5E+00 | |
| Plutonium Alpha | | | | | 3.4E+02 | |
| $^{241}Am$ | | | | | 6.4E+02 | |
| Other Alpha particulate | | | 5.6E+07 | | 3.8E+10 | |
| Other Beta/Gamma | | | | 3.4E+11 | | |
| Other Beta/Gamma Particulate | 9.2E+11 | | 1.1E+08 | | 7.3E+12 | |

[a] *Excludes nuclear power, defence and radiochemical manufacturing (Amersham and Cardiff) industries. Excludes discharges which are exempt from reporting. England and Wales discharge data refers to 2015*

**Table 7.8 Discharges of liquid radioactive waste from non-nuclear establishments in England, Northern Ireland and Wales, 2016[a]**

| | Discharges during 2016, Bq | | | | | | |
|---|---|---|---|---|---|---|---|
| | Education (Universities and Colleges) | | Hospitals | | Other (Research, manufacturing and public sector) | | Oil and gas (off-shore) |
| | England & Wales | Northern Ireland | England & Wales | Northern Ireland | England & Wales | Northern Ireland | United Kingdom |
| $^{3}$H | 1.1E+10 | 3.1E+07 | 5.8E+08 | 1.8E+08 | 3.1E+12 | | |
| $^{14}$C | 1.3E+09 | | 6.6E+06 | | 2.6E+11 | 9.0E+05 | |
| $^{18}$F | 3.9E+11 | | 3.6E+12 | 2.1E+11 | 2.2E+12 | | |
| $^{22}$Na | 6.0E+04 | | | | | | |
| $^{32}$P | 5.5E+09 | | 5.6E+09 | 6.6E+08 | 1.7E+09 | | |
| $^{33}$P | 2.0E+08 | | | | 1.9E+09 | | |
| $^{35}$S | 1.1E+10 | | 6.3E+08 | | 4.4E+09 | | |
| $^{51}$Cr | 7.2E+08 | | 4.4E+10 | 5.2E+08 | 1.8E+09 | | |
| $^{57}$Co | 4.1E+04 | | | | 1.8E+01 | | |
| $^{58}$Co | 3.9E+05 | | | | | | |
| $^{60}$Co | 2.6E+00 | | | | | | |
| $^{67}$Ga | 5.3E+08 | | 7.3E+09 | | 2.7E+07 | | |
| $^{75}$Se | 3.8E+07 | | 5.7E+10 | 4.8E+07 | 1.3E+08 | | |
| $^{89}$Sr | | | 6.1E+08 | | | | |
| $^{90}$Sr | 2.0E+05 | | | | 1.1E+01 | | |
| $^{90}$Y | | | 5.7E+11 | 1.1E+09 | 2.8E+08 | | |
| $^{99}$Tc | 4.4E+07 | | | | 8.7E+02 | | |
| $^{99m}$Tc | 4.3E+10 | | 4.9E+13 | 1.6E+12 | 6.9E+11 | | |
| $^{111}$In | 1.3E+09 | | 3.6E+11 | 1.3E+10 | 4.3E+09 | | |
| $^{125}$Sb | | | | | | | |
| $^{123}$I | | | 1.1E+12 | 7.4E+10 | 3.6E+10 | | |
| $^{125}$I | 4.7E+09 | 1.6E+08 | 1.3E+09 | 1.2E+07 | 1.6E+10 | | |
| $^{129}$I | | | | | 2.7E+03 | | |
| $^{131}$I | 7.1E+07 | | 8.8E+12 | 3.0E+11 | 2.2E+11 | | |
| $^{134}$Cs | | | | | 2.4E+07 | | |
| $^{137}$Cs | 1.6E+06 | | | | 2.1E+09 | | |
| $^{153}$Sm | 3.0E+03 | | 1.0E+10 | 1.8E+09 | | | |
| $^{201}$Tl | | | 1.8E+10 | | | | |
| $^{230}$Th | 2.7E+00 | | | | 4.0E+00 | | |
| $^{232}$Th | | | | | 8.8E+09 | | |
| Uranium Alpha | 3.2E+04 | | | | 1.6E+10 | | |
| $^{237}$Np | | | | | 2.0E-01 | | |
| $^{241}$Pu | | | | | 1.1E+04 | | |
| Plutonium Alpha | 1.0E+06 | | | | 3.1E+03 | | |
| $^{241}$Am | 1.2E+05 | | | | 6.3E+03 | | |
| $^{242}$Cm | | | | | 7.0E+00 | | |
| Total Alpha | 8.2E+06 | | 1.2E+10 | 7.4E+08 | 3.7E+10 | | 1.1E+08 |
| Total Beta/Gamma (Excl Tritium) | 6.7E+11 | | 6.0E+13 | | 3.1E+12 | | 5.9E+07 |
| Other Alpha particulate | 6.0E+06 | | 7.3E+09 | | 2.5E+07 | | |
| Other Beta/Gamma[b] | 3.2E+10 | | 4.3E+12 | 2.5E+06 | 3.2E+11 | | |
| Other Beta/Gamma particulate | | | | | 1.4E+09 | | |

[a] *Excludes nuclear power, defence and radiochemical manufacturing (Amersham and Cardiff) industries. Excludes discharges which are exempt from reporting. England and Wales discharge data refers to 2015*

[b] *Excluding specific radionuclides*

## Table 7.9 Discharges of gaseous radioactive wastes from non-nuclear establishments in Scotland by OSPAR region, 2016[a]

| | Discharges during 2016, Bq | | | | | |
|---|---|---|---|---|---|---|
| | OSPAR Region II – Greater North Sea | | | OSPAR Region III – Celtic Seas | | |
| | Education (Universities and Colleges) | Hospitals | Other (Research, manufacturing and public sector) | Education (Universities and Colleges) | Hospitals | Other (Research, manufacturing and public sector) |
| $^{3}H$ | Nil | | | Nil | | |
| $^{14}C$ | | Nil | | | 6.59E+07 | |
| $^{18}F$ | | Nil | | | 4.55E+10 | |
| Other Alpha | | | 1.00E+03 | | | 5.57E+02 |
| Other Beta/Gamma | 1.10E+11 | Nil | 2.17E+04 | 2.49E+03 | | 6.64E+03 |

[a] *Excludes nuclear power and defence industries. Excludes discharges which are exempt from reporting.*

## Table 7.10 Discharges of liquid radioactive waste from non-nuclear establishments in Scotland by OSPAR region, 2016[a]

| | Discharges during 2016, Bq | | | | | | |
|---|---|---|---|---|---|---|---|
| | OSPAR Region II - Greater North Sea | | | | OSPAR Region III - Celtic Seas | | |
| | Education (Universities and Colleges) | Hospitals | Other (Research, manufacturing and public sector) | Oil and gas (on-shore) | Education (Universities and Colleges) | Hospitals | Other (Research, manufacturing and public sector) |
| $^{3}H$ | 1.78E+09 | | 1.21E+09 | | 3.23E+07 | | 9.94E+07 |
| $^{14}C$ | 1.26E+08 | 2.18E+07 | 6.02E+09 | | 2.13E+06 | 2.96E+07 | 2.77E+06 |
| $^{18}F$ | | 1.31E+11 | | | | 3.10E+11 | |
| $^{22}Na$ | 1.00E+06 | | | | | | 4.54E+06 |
| $^{32}P$ | 1.67E+09 | 2.15E+08 | 5.57E+07 | | 5.25E+07 | 4.61E+08 | 5.83E+08 |
| $^{33}P$ | 4.28E+09 | | 8.52E+09 | | | | |
| $^{35}S$ | 9.03E+09 | | 1.01E+08 | | 4.11E+08 | | |
| $^{51}Cr$ | 4.50E+07 | 1.13E+09 | | | | 1.45E+08 | |
| $^{67}Ga$ | | 1.97E+08 | | | | 9.00E+07 | |
| $^{75}Se$ | | 4.96E+07 | | | | 2.22E+06 | |
| $^{90}Y$ | | 5.15E+08 | | | | 4.33E+08 | 2.20E+07 |
| $^{99m}Tc$ | 1.26E+08 | 2.52E+12 | | | | 1.89E+12 | |
| $^{111}In$ | | 1.48E+10 | | | | 3.27E+10 | |
| $^{123}I$ | | 3.81E+10 | | | 3.86E+07 | 3.74E+10 | |
| $^{125}I$ | 5.02E+07 | 6.23E+06 | 1.46E+07 | | 6.06E+07 | 4.40E+07 | 2.14E+05 |
| $^{131}I$ | 2.24E+09 | 3.93E+11 | | | 1.63E+08 | 3.74E+11 | |
| $^{201}Tl$ | | 2.40E+07 | | | | 1.86E+10 | |
| $^{210}Pb$ | | | 4.62E+04 | 1.85E+08 | | | |
| $^{210}Po$ | | | 4.62E+04 | 1.85E+08 | | | |
| $^{226}Ra$ | | | 3.22E+04 | 8.43E+08 | 1.32E+02 | | |
| $^{228}Ra$ | | | 1.74E+04 | 1.87E+09 | | | |
| $^{232}Th$ | | | | | | | 1.48E+06 |
| Uranium Alpha | | | | | 3.10E+00 | | |
| Plutonium Alpha | | | | | 6.27E-01 | | |
| Other Alpha | | 1.88E+08 | | | | | 3.28E+05 |
| Other Beta/Gamma[b] | 1.31E+11 | 7.47E+09 | 3.61E+03 | | 2.41E+08 | 3.78E+10 | 6.75E+05 |

[a] *Excludes nuclear power and defence industries. Excludes discharges which are exempt from reporting.*
[b] *Excluding specific radionuclides*

## Table 7.11 Monitoring in the River Firth, Clyde and near Glasgow, 2016[a]

| Location | Material and selection[b] | No. of sampling observ-ations | Mean radioactivity concentration (fresh)[b], Bq kg$^{-1}$ | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | $^{3}$H | $^{14}$C | $^{32}$P | $^{54}$Mn | $^{90}$Sr | $^{95}$Nb | $^{99}$Tc |
| Between Finlaystone and Woodhall | Mussels | 1 | | 18 | <0.89 | <0.10 | | <0.10 | 2.4 |
| Between Finlaystone and Woodhall | *Fucus vesiculosus* | 1 | | | 3.7 | <0.10 | | <0.10 | 27 |
| Dalmuir Clydebank | Sediment | 1 | | <30 | <2.1 | <0.10 | | <0.10 | |
| Downstream of Dalmuir | Freshwater | 4 | | | <0.12 | <0.10 | | <0.10 | |
| River Clyde | Freshwater | 4 | <1.0 | | | | <0.0050 | | |
| Firth of Forth | Freshwater | 4 | <1.0 | | | | <0.0025 | | |
| Daldowie | Sludge pellets | 4 | | | <10 | <0.28 | | <0.34 | |

| Location | Material and selection[b] | No. of sampling observ-ations | Mean radioactivity concentration (fresh)[b], Bq kg$^{-1}$ | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | $^{125}$Sb | $^{131}$I | $^{137}$Cs | $^{155}$Eu | $^{241}$Am | Gross alpha | Gross beta |
| Between Finlaystone and Woodhall | Mussels | 1 | <0.32 | 0.25 | 0.20 | <0.29 | <0.17 | | |
| Between Finlaystone and Woodhall | *Fucus vesiculosus* | 1 | <0.15 | 14 | 0.39 | <0.18 | <0.10 | | |
| Dalmuir Clydebank | Sediment | 1 | <0.21 | <0.10 | 8.4 | <0.33 | <0.37 | | |
| Downstream of Dalmuir | Freshwater | 4 | <0.11 | <0.49 | <0.10 | <0.12 | <0.12 | | |
| River Clyde | Freshwater | 4 | | <0.94 | <0.03 | | | <0.079 | 1.1 |
| Firth of Forth | Freshwater | 4 | | | <0.01 | | | 0.18 | 1.1 |
| Daldowie | Sludge pellets | 4 | <0.24 | 310 | <2.8 | <1.6 | <0.66 | | |

[a] *Results are available for other radionuclides detected by gamma spectrometry, All such results are less than the limit of detection*

[b] *Except for water where units are Bq l$^{-1}$, and sludge pellets and sediment where dry concentrations apply*

# 8. Regional monitoring

Regional monitoring in areas remote from nuclear licensed sites has continued in 2016:

i) to establish long distance transport of radioactivity from UK and other nuclear licensed sites
ii) to indicate general contamination of the food supply and the environment
iii) to provide data under UK obligations under Article 36 of the Euratom Treaty and the OSPAR Convention

The routine component parts of this programme are: sampling of seafood and environmental samples from the Channel Islands and Northern Ireland; monitoring UK ports of entry for foodstuffs from Japan and for other non-specific contamination; sampling of the UK food supply, air, rain and drinking water and seawater and sediments.

## Key points

- **Doses for the representative person were approximately 0.010 mSv (or less), or approximately 1 per cent (or less) of the dose limit**

## 8.1 Channel Islands

Samples of marine environmental materials provided by the Channel Island States have been analysed for levels of radioactivity. The programme monitors the effects of radioactive discharges from the French reprocessing plant at La Hague and the power station at Flamanville. It also monitors any effects of historical disposals of radioactive waste in the Hurd Deep, a natural trough in the western English Channel. Fish and shellfish are monitored to determine exposure from the internal radiation pathway; sediment is analysed for external exposures. Seawater and seaweeds are sampled as environmental indicator materials and, in the latter case, because of their use as fertilisers. A review of marine radioactivity in the Channel Islands from 1990 to 2009 has been published (Hughes *et al*., 2011).

The results of monitoring for 2016 are given in Table 8.1. There was evidence of routine releases from the nuclear industry in some food and environmental samples (e.g. cobalt-60, strontium-90, technetium-99 and iodine-129). However, activity concentrations in fish and shellfish were low and similar to those in previous years. It is generally difficult to attribute the results to different sources, including fallout from weapon testing, due to the low levels detected. No evidence for significant releases of activity from the Hurd Deep site was found.

An assessment of the dose to a representative person who consumes large amounts of fish and shellfish was carried out. In 2016, the representative person was estimated to receive less than 0.005 mSv, which is less than 0.5 per cent of the dose limit for members of the public. The assessment included a contribution from external exposure. The concentrations of artificial radionuclides in the marine environment of the Channel Islands and the effects of discharges from local sources, therefore, continued to be of negligible radiological significance.

Milk and crop samples from the Channel Island States ceased in 2014. Results up to 2013 are included in earlier RIFE reports and they show no significant effects of UK or other nuclear installations.

## 8.2 Isle of Man

The Environment Agency has carried out a review of their environmental monitoring programmes. Following this review, the Environment Agency's marine monitoring programme of the Isle of Man ceased in 2016. Results up to 2015 are included in earlier RIFE reports (e.g. Environment Agency, FSA, FSS, NIEA, NRW and SEPA, 2016). Previous results have demonstrated that there has been no significant impact on the Isle of Man from discharges to sea from mainland nuclear installations in recent years. The Government of the Isle of Man undertakes their own independent radioactivity monitoring programme and provide an indication of the far-field effects of current and historical discharges from Sellafield and other UK nuclear sites. These are reported annually: **www.gov.im/about-the-government/departments/environment-food-and-agriculture/government-laboratory/environmental-radioactivity/**

## 8.3 Northern Ireland

NIEA monitors the far-field effects of liquid discharges from Sellafield into the Irish Sea. The programme involves sampling fish, shellfish and indicator materials from a range of locations along the coastline (Figure 8.1). The external exposure pathway is studied by monitoring gamma dose rates over intertidal areas. The results are presented in Tables 8.2(a) and (b).

In 2016, the main effect of discharges from Sellafield was observed in concentrations of technetium-99 in shellfish and seaweed samples. These were similar to those in

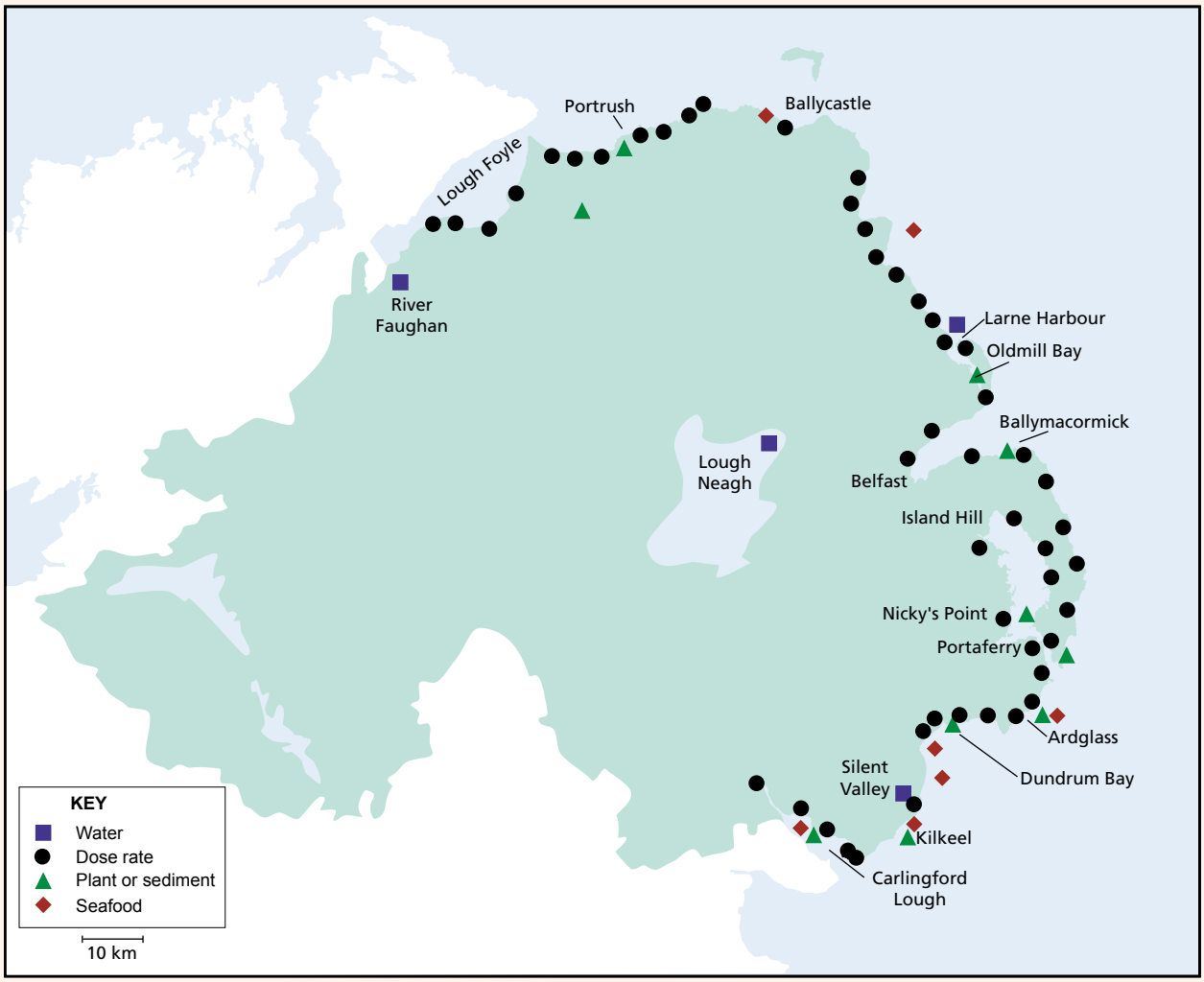



**Figure 8.1.** Monitoring locations in Northern Ireland, 2016

2015 and in recent years, reflecting the considerably decreased inputs to the Irish Sea (see also Section 2.3.3). Caesium-137 concentrations were low and similar to those in 2015, although levels of caesium-137 were higher in sediments at Oldmill Bay and trace amounts of transuranic nuclides were detected in 2016. Observed concentrations were less than those found nearer to Sellafield and continued at the low levels seen in recent years (Figure 8.2). Further information on the trends in radioactivity in the marine environment of Northern Ireland is described in Ly *et al.*, (2015). The gamma dose rates over intertidal areas were similar to those in previous years.

A survey of consumption and occupancy in coastal regions of Northern Ireland (Smith *et al.*, 2002) established habits representative of people consuming large quantities of fish and shellfish. Based on the monitoring results from the marine environment in 2016, the dose to the most exposed person was 0.011 mSv (Table 2.16), which is approximately 1 per cent of the dose limit for members of the public.

Monitoring results for the terrestrial environment of Northern Ireland are included in the following parts of Section 8.

## 8.4 Overseas incidents

Two overseas accidents have had direct implications for the UK: Chernobyl (1986) and Fukushima Dai-ichi (2011). Earlier RIFE reports have provided detailed results of monitoring by the environment agencies and FSA (Environment Agency, FSA, NIEA and SEPA, 2013).

For Chernobyl, the main sustained impact on the UK environment was in upland areas, where heavy rain fell in the days following the accident, but levels have now reduced substantially. The results of monitoring and estimated doses to consumers are available in earlier RIFE reports (e.g. Environment Agency, FSA, NIEA and SEPA, 2013).

In March 2011, the EC implemented controls (Regulation EU/297/2011) on the import of food and feed originating in or consigned from Japan following the Fukushima Dai-ichi accident (EC, 2011b).

Thereafter, imports of all feed and food originating in or consigned from Japan could only enter the UK through specific ports and airports where official controls will be carried out. Products of animal origin can only enter

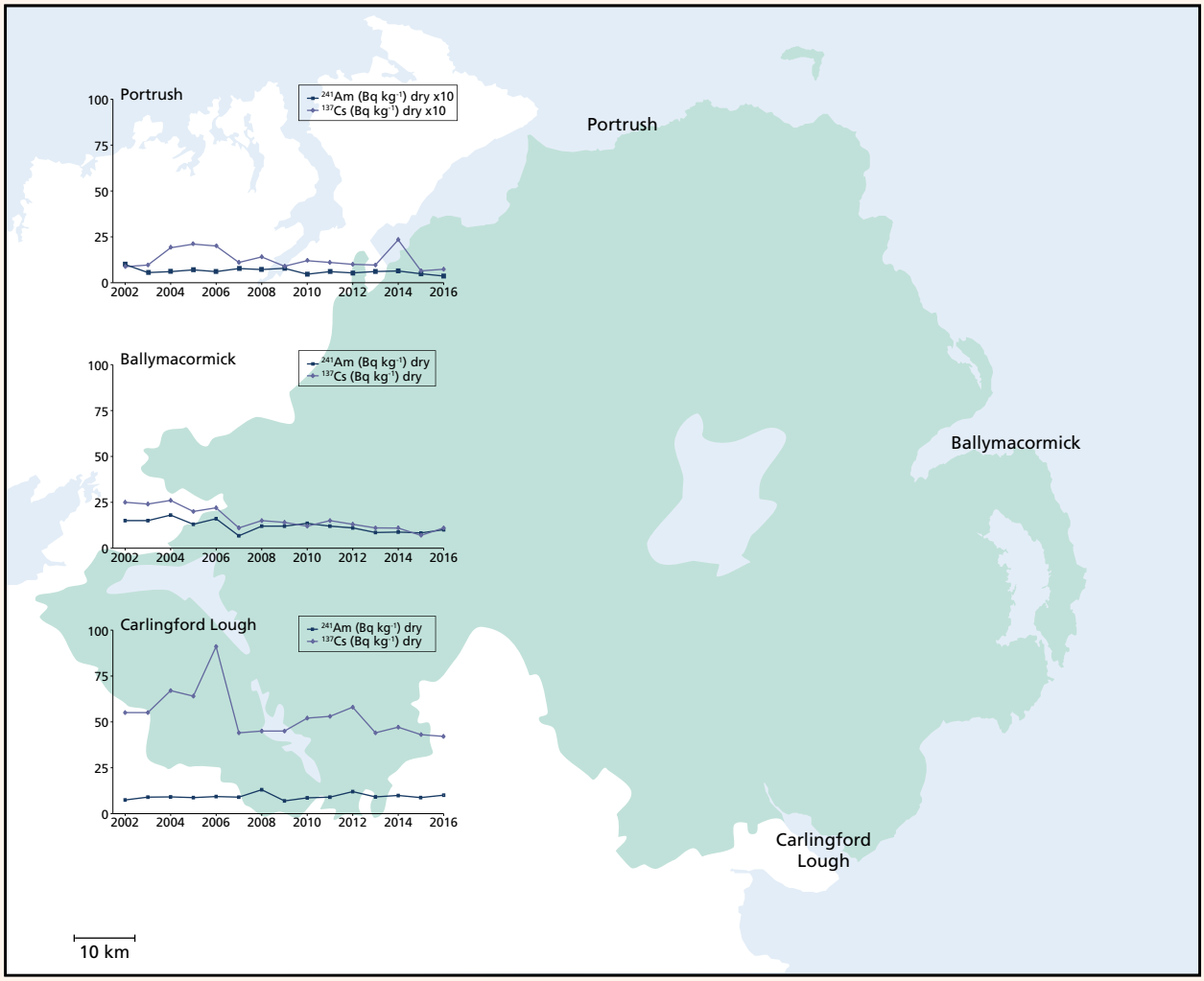



**Figure 8.2.** Concentrations of americium-241 and caesium-137 in coastal sediments in Northern Ireland, 2002-2016

through Border Inspection Posts (BIPs) and products of non-animal origin can only enter through Designated Points of Entry (DPE).

The legislation has been updated in 2016 (Regulation EU/6/2016 (EC, 2016)). Certain measures apply to some feed and food originating in or consigned from 13 prefectures of Japan. The list of applicable feeds and foods from the prefectures can be found in Annex II to the legislation. Applicable feed and food products from these prefectures intended to be imported to the EU must be tested before leaving Japan and are subject to random testing in the EU. The exceptions are for certain personal consignments of feed and food. The main requirements of the regulation for imports of feed and food destined for the EU are that:

- Each consignment of food or feed listed in Annex II of the legislation, from the 13 prefectures must be accompanied by a declaration – signed by the Japanese authorities, attesting that the product complies with legislation in force in Japan, as regards the maximum levels for the sum of the radionuclides: caesium-134 and caesium-137. The declarations must be accompanied by the results of analysis
- Importers are required to notify the BIP or DPE at the port of entry two working days before the arrival of each consignment of food and feed from Japan
- Each consignment should be identified by a code on the declaration, analytical report, common entry documents and the sanitary certificate accompanying the consignment

Identity and physical checks, including laboratory analysis, on less than 5 per cent of the consignments of food or feed will be undertaken by port officials where the product originates in or is consigned from Japan. Products that are found to exceed the maximum levels should not be placed on the market and are either safely disposed of, or returned to Japan. Further information is available on the FSA's website: **http://food.gov.uk/business-industry/imports/banned_restricted/japan** .

A percentage of Japanese imports into the EU are monitored in the UK and this work continued in 2016. Monitoring is carried out by local Port Health Authorities. Following changes to the Regulations in 2016, the FSA and FSS no longer collate routine data on these samples and are only notified in the event of a non-compliant consignment such as exceeding the maximum permitted

levels. None of the imports to the UK have contained radioactivity exceeding the maximum permitted levels of 100 Bq $kg^{-1}$. The doses received due to the imports were of negligible radiological significance.

Screening instruments are used at importation points of entry to the UK as a general check on possible contamination from unknown sources. In 2016, the instruments were not triggered by a food consignment at any point of entry into the UK.

## 8.5 General diet

As part of the UK Government and Devolved Administrations' general responsibility for food safety, concentrations of radioactivity are determined in regional diets. These data (and data on other dietary components in Sections 8.6 and 8.7) form the basis of the UK submission to the EC under Article 36 of the Euratom Treaty to allow comparison with data from other EU member states (**https://remon.jrc.ec.europa.eu/**). Concentrations of radioactivity in the general diet are reported to the EC by the FSA (for England, Northern Ireland and Wales), and by SEPA (for Scotland).

In 2016, the concentrations found in a survey of radioactivity in canteen meals and mixed diets collected across the UK were very low or typical of natural sources (Table 8.3). Where comparisons can be made, similar values were observed in 2015.

## 8.6 Milk

The programme of milk sampling across dairies in the UK continued in 2016. Its aim is to collect and analyse samples, on a monthly basis, for their radionuclide content. This programme provides useful information with which to compare data from farms close to nuclear licensed sites and other establishments that may enhance concentrations above background levels. Milk data are reported by FSA (for England, Northern Ireland and Wales) and SEPA (for Scotland) as part of the UK submission to the EC under Article 36 of the Euratom Treaty (**https://remon.jrc.ec.europa.eu/**).

The results are summarised in Table 8.4. The majority of measurements, where comparable, are similar to those in previous years. The mean carbon-14 concentrations in Northern Ireland and Scotland are similar (maximum concentration of 14 Bq $l^{-1}$ and < 18 Bq $l^{-1}$, respectively) and close to the expected background concentration in milk (see Appendix 1, Annex 4). Alternatively, the mean carbon-14 concentrations in England and Wales (maximum concentrations of 34 Bq $l^{-1}$ and 21 Bq $l^{-1}$, respectively) are slightly elevated compared to the expected background. Tritium results were again below detection limits in 2016. Strontium-90 was positively detected at two dairies in Wales, at very low levels close to the expected less than values. The mean concentration of strontium-90 detected in the UK was < 0.034 Bq $l^{-1}$. In the past, the concentrations of radiocaesium in milk were highest from those regions that received the greatest amounts of Chernobyl fallout. However, the concentrations are now very low and it is not possible to distinguish this trend.

Radiation dose from consuming milk at average rates was assessed for various age groups. In 2016, the maximum dose was to an infant (1 year-old). For the range of radionuclides analysed, the dose was less than 0.005 mSv or less than 0.5 per cent of the dose limit. Previous surveys (for example, FSA and SEPA, 2002) have shown that if a full range of nuclides are analysed and assessed, the dose is dominated by naturally occurring lead-210 and polonium-210, whereas man-made radionuclides contribute to less than 10 per cent.

## 8.7 Crops

The programme of monitoring naturally occurring and man-made radionuclides in crops (in England, Wales and the Channel Islands) as a check on general food contamination (remote from nuclear sites) ceased in 2014. Further information on previously reported monitoring is available in earlier RIFE reports (e.g. Environment Agency, FSA, NIEA, NRW and SEPA, 2014).

## 8.8 Airborne particulate, rain, freshwater and groundwater

Radioactivity in rainwater and air was monitored at several UK locations as part of the programme of background sampling managed by the Environment Agency and SEPA. These data are reported on behalf of BEIS, NIEA and the Scottish and Welsh Governments, as part of the UK submission to the EC under Article 36 of the Euratom Treaty (**https://remon.jrc.ec.europa.eu/**). The results are given in Table 8.5. The routine programme is comprised of two components (i) regular sampling and analysis on a quarterly basis and (ii) supplementary analysis on an *ad hoc* basis by gamma-ray spectrometry. Caesium-137 concentrations in air and rainwater are reported as less than values. These levels in air, typical of recent years, remain less than 0.01 per cent of those observed in 1986, the year of the Chernobyl reactor accident.

Concentrations of beryllium-7, a naturally occurring radionuclide formed by cosmic ray reactions in the upper atmosphere, were positively detected at similar levels at all sampling locations. Peak air concentrations of this radionuclide tend to occur during spring and early summer as a result of seasonal variations in the mixing of stratospheric and tropospheric air (Environment Agency, 2002a). Tritium concentrations in rainwater were reported at limits of detection, similar to those in recent years. Activity concentrations of the radionuclides reported in air

and rainwater were very low and do not currently merit radiological assessment.

Sampling and analysis of freshwater from drinking water sources throughout the UK continued in 2016 (Figure 8.3). These water data are reported by the Environment Agency (for England and Wales), NIEA (for Northern Ireland) and SEPA (for Scotland) as part of the UK submission to the EC under Article 36 of the Euratom Treaty (**https://remon.jrc.ec.europa.eu/**). Sampling was designed to represent the main drinking water sources, namely reservoirs, rivers and groundwater boreholes. Most of the water samples were representative of natural waters before treatment and supply to the public water system. The results in Tables 8.6, 8.7 and 8.8 show that concentrations of tritium were all substantially below the investigation level for drinking water of 100 Bq $l^{-1}$ in the European Directive 2013/51. The highest value in Scotland was found at Gullielands Burn, which is near to the Chapelcross nuclear licensed site. Concentrations of gross alpha and gross beta were generally below the investigation levels for drinking water of 0.1 and 1.0 Bq $l^{-1}$, respectively in the European Directive 2013/51.

The mean annual dose from consuming drinking water in the UK was assessed as 0.017 mSv in 2016 (Table 8.9). The highest annual dose was estimated to be 0.019 mSv for drinking water from the River Faughan, County Londonderry. The estimated doses were dominated by naturally occurring radionuclides and are similar to those in recent years. The annual dose from artificial radionuclides in drinking water was less than 0.001 mSv.

Separately, in 2016, SEPA took a series of groundwater samples from across Scotland and the results are given in Table 8.10. All samples contained levels below or near the reported less than value and are generally consistent with those in recent years.

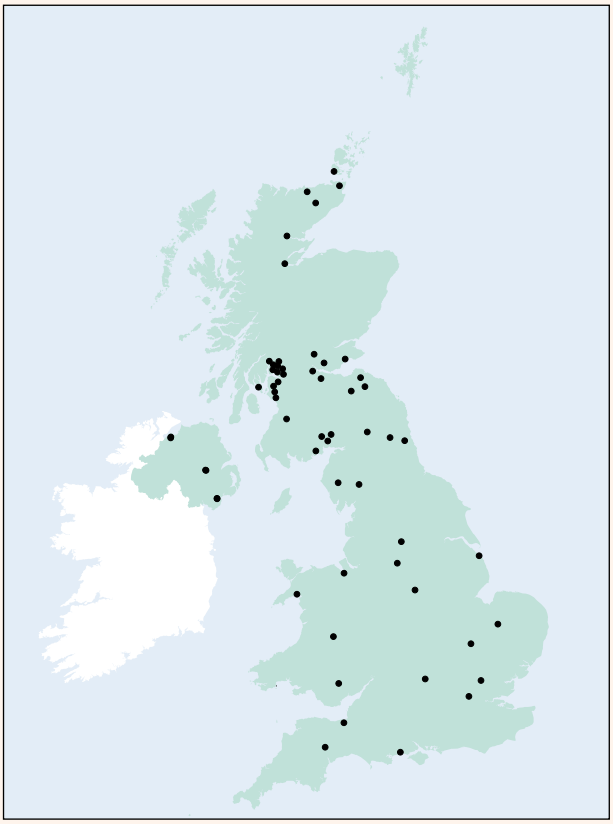


**Figure 8.3.** Drinking water sampling locations, 2016

## 8.9 Seawater surveys

The UK Governments are committed to preventing pollution of the marine environment from ionising radiation, with the ultimate aim of reducing concentrations in the environment to near background values for naturally-occurring radioactive substances, and close to zero for artificial radioactive substances (DECC, Department of the Environment, Northern Ireland, The Scottish Government and Welsh Assembly Government, 2009). Therefore, a programme of surveillance into the distribution of key radionuclides is maintained using research vessels and other means of sampling.

The seawater surveys reported here also support international studies concerned with the quality status of coastal seas (for example, OSPAR, 2010b). A fourth periodic evaluation of progress towards internationally agreed objectives has been published by OSPAR (OSPAR, 2016). The programme of radiological surveillance work provides the source data and, therefore, the means to monitor and assess progress in line with the UK's commitments towards OSPAR's 1998 Strategy for Radioactive Substances target for 2020 (part of the North-east Atlantic Environment Strategy adopted by OSPAR for the period 2010 – 2020). The surveys also provide information that can be used to distinguish different sources of man-made radioactivity (for example, Kershaw and Baxter, 1995) and to derive dispersion factors for nuclear licensed sites (Baxter and Camplin, 1994). In addition, the distribution of radioactivity in seawater around the British Isles is a significant factor in determining the variation in individual exposures at coastal sites, as seafood is a major contribution to food chain doses. Evidence to help gauge progress towards achieving the Government's vision for radionuclides and other hazardous substances is set out in a report (Defra, 2010).

The research vessel programme on radionuclide distribution currently comprises of annual surveys of the Bristol Channel/western English Channel and biennial surveys of the Irish Sea and the North Sea. The results obtained in 2016 are given in Figures 8.4 – 8.8.

A seawater survey of the North Sea was carried out in 2016. Caesium-137 data (given in Figure 8.4) show that the concentrations were very low (up to 0.006 Bq $l^{-1}$) throughout the survey area, and these were only slightly above those observed for global fallout levels in surface seawaters (0.0001- 0.0028 Bq $l^{-1}$, Povinec *et al*., 2005). The overall distribution in the North Sea is characteristic

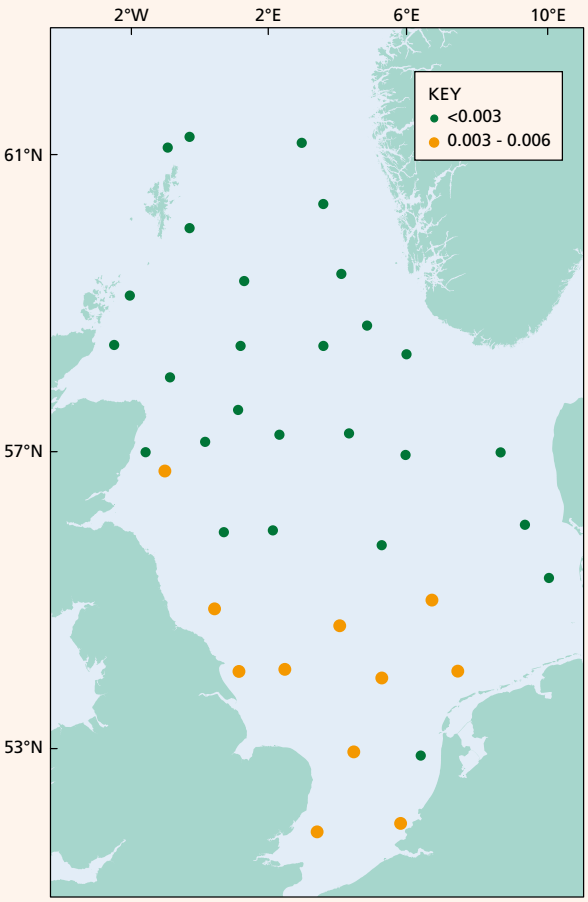



**Figure 8.4.** Concentrations (Bq $l^{-1}$) of caesium-137 in filtered surface water from the North Sea, August–September 2016

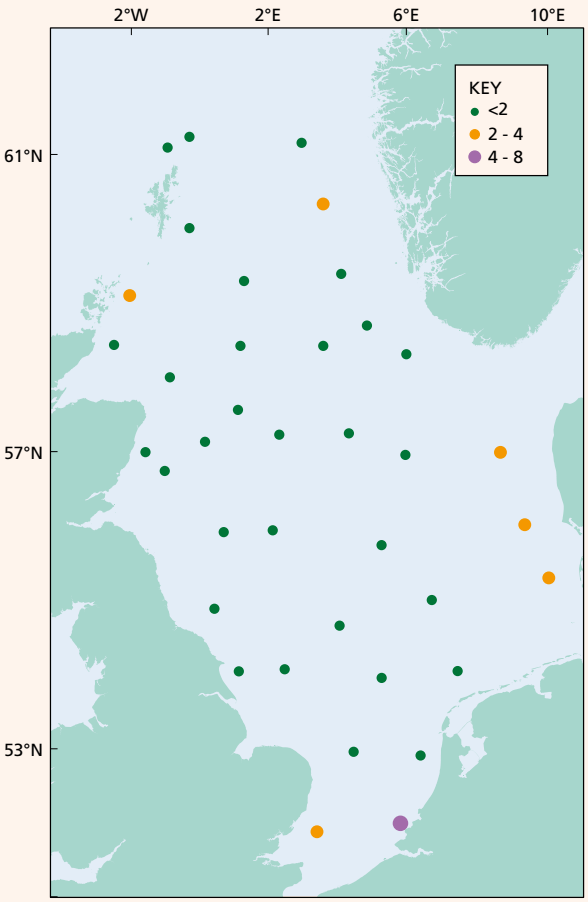



**Figure 8.6.** Concentrations (Bq $l^{-1}$) of tritium in surface water from the North Sea, August–September 2016

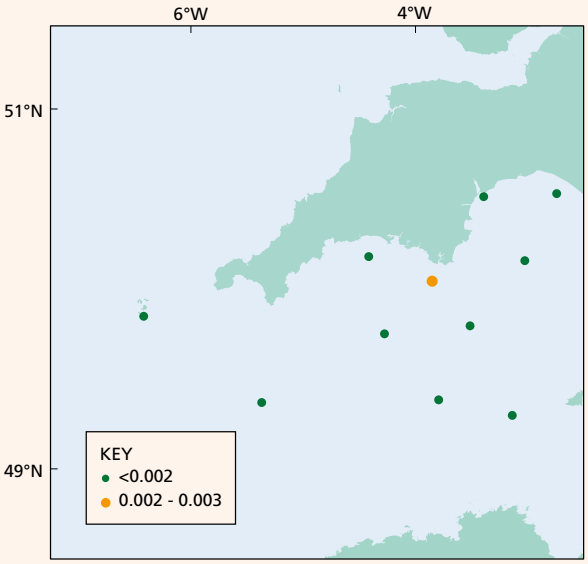



**Figure 8.5.** Concentrations (Bq $l^{-1}$) of caesium-137 in filtered surface water from the English Channel, February-March 2016

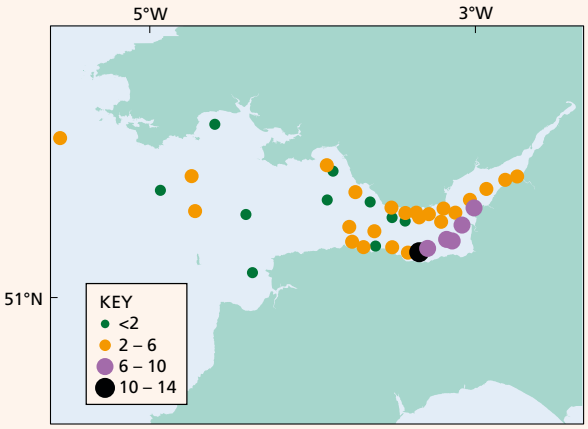



**Figure 8.7.** Concentrations (Bq $l^{-1}$) of tritium in surface water from the Bristol Channel, September 2016

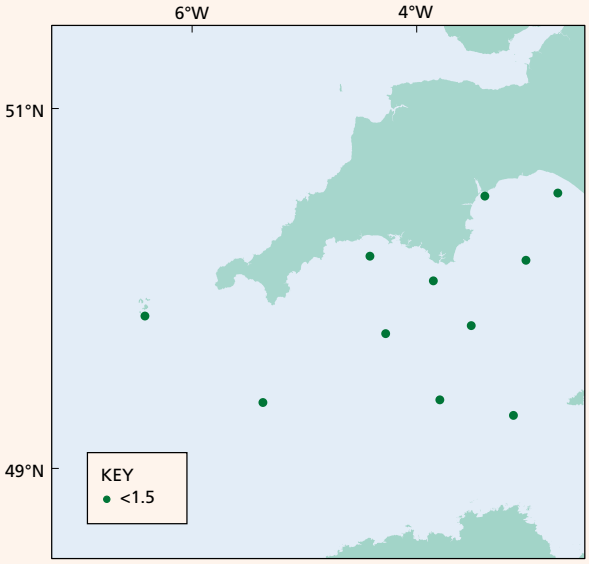



**Figure 8.8.** Concentrations (Bq $l^{-1}$) of tritium in surface water from the English Channel, February–March 2016

of that observed in previous surveys over the last decade, with generally higher values near the coast, due to the long-distance transfer of Sellafield derived activity. The 2016 survey data (as in recent surveys), also shows higher levels at some locations away from the coastline (central and southern North Sea). These were likely to be the outcome of complex water circulation (possibly Sellafield or Chernobyl-derived). In 2016 (and in 2010), there was no evidence of input of Chernobyl-derived caesium-137 from the Baltic (via the Skaggerak) close to the Norwegian Coast.

In the previous three decades the impact of discharges from the reprocessing plants at Sellafield and La Hague has been readily apparent, carried by the prevailing residual currents from the Irish Sea and the Channel, respectively (Povinec *et al*., 2003). Caesium-137 concentrations in the North Sea have tended to follow the temporal trends of the discharges, albeit with a time lag. The maximum discharge of caesium-137 occurred at Sellafield in 1975, with up to 0.5 Bq $l^{-1}$ caesium-137 in the North Sea surface waters in the late 1970s. Due to significantly decreasing discharges after 1978, remobilisation of caesium-137 from contaminated sediments in the Irish Sea was considered to be the dominant source of water contamination for most of the North Sea (McCubbin *et al*., 2002). Recently, trends and observations of caesium-137 concentrations in the waters of the North Sea (and Irish Sea), over the period 1995 – 2015, have been published (Leonard *et al*., 2016).

Caesium-137 concentrations in the Irish Sea were only a small percentage of those prevailing in the late 1970s (typically up to 30 Bq $l^{-1}$, Baxter *et al*., 1992), when discharges were substantially higher. The 2015 seawater survey recorded concentrations of up to 0.06 Bq $l^{-1}$ in the eastern Irish Sea, elsewhere concentrations were generally below 0.02 Bq $l^{-1}$. A recent study has re-confirmed that the predominant source of caesium-137 to the Irish Sea was due to the remobilisation into the water column from activity associated with seabed sediment (Hunt *et al*., 2013). Discharges from Sellafield have decreased substantially since the commissioning of the SIXEP waste treatment process in the mid 1980s, and this has been reflected in a near exponential decrease in shoreline seawater concentrations at St Bees (Figure 8.9). In more recent years, the rate of decline of caesium-137 concentrations with time has been decreasing at St Bees. Longer time series showing peak concentrations in the Irish Sea and, with an associated time-lag, the North Sea are also shown in Figure 8.9

Concentrations of caesium-137 (up to 0.003 Bq $l^{-1}$) in the western English Channel (Figure 8.5) were not distinguishable from the background levels of global fallout (within experimental error) in 2016. Activity concentrations near the Channel Islands were similar in 2016 (compared to those in 2015), and lower than concentrations in both the Irish and North Seas.

A full assessment of long-term trends of caesium-137 in surface waters of Northern European seas is provided elsewhere (Povinec *et al.*, 2003).

Tritium concentrations in North Sea seawater (in 2016) are shown in Figure 8.6, and were generally lower than those observed in the Irish Sea in 2015 (Environment Agency, FSA, NIEA, NRW and SEPA, 2015) due to the influence of discharges from Sellafield and other nuclear licensed sites. As in previous North Sea surveys, tritium concentrations were slightly elevated (but still very low) in a few water samples taken from the most southerly sampling locations of the North Sea. The most probable source of this is from the authorised discharges of tritium from the French nuclear power plants located on the coast of the English Channel.

In the Bristol Channel, the combined effect of tritium discharges from Cardiff, Berkeley, Oldbury and Hinkley Point is shown in Figure 8.7. Overall, the general level of tritium concentrations in the Bristol Channel was very low in 2016. Overall, tritium concentrations were broadly similar to those observed in 2015. However, concentrations were slightly higher than those corresponding values in 2015 from discharges, originating from Hinkley Point. Tritium concentrations in the western English Channel were all below the LoD (Figure 8.8).

Technetium-99 concentrations in seawater are now decreasing following the substantial increases observed from 1994 to their most recent peak in 2003. The results of research cruises to study this radionuclide have been published by Leonard *et al*. (1997a, b; 2004) and McCubbin *et al*. (2002; 2008) and an estimate of the total inventory residing in the sub-tidal sediments of the Irish Sea has also been published (Jenkinson *et al*., 2014). Trends in plutonium and americium concentrations in seawater of the Irish Sea have been considered by Leonard *et al*. (1999). Full reviews of the quality status of the north

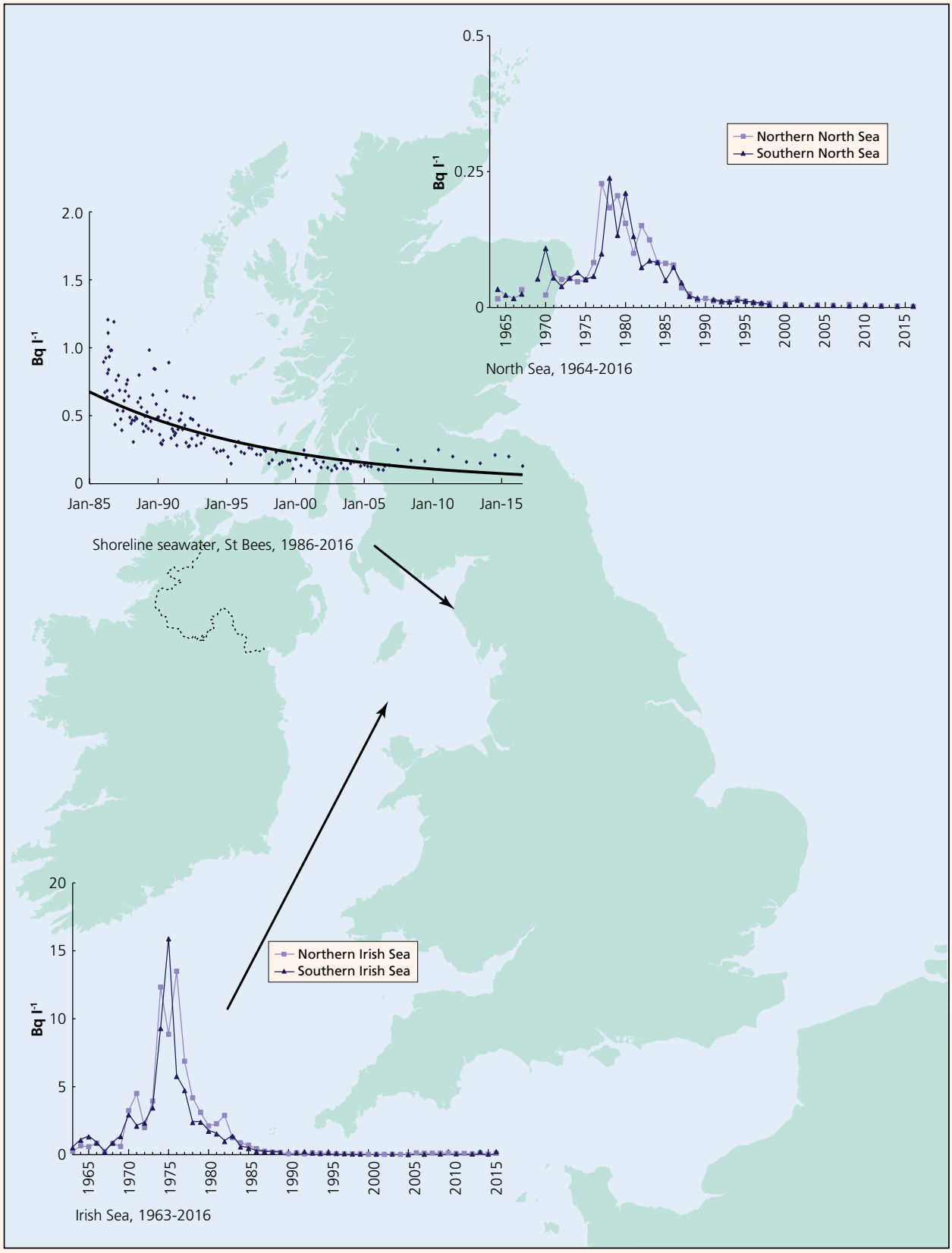



**Figure 8.9.** Concentration of caesium-137 in the Irish Sea, North Sea and in shoreline seawater close to Sellafield at St. Bees
(Note different scales used for activity concentrations)

Atlantic and a periodic evaluation of progress towards internationally agreed targets have been published by OSPAR (2000b; 2009; 2010b).

Shoreline sampling was also carried out around the UK, as part of routine site and regional monitoring programmes. Much of the shoreline sampling was directed at establishing whether the impacts of discharges from individual sites are detectable. Where appropriate, these are reported in the relevant sections of this report, and the analysis results are collated in Table 8.11. Most radionuclides are reported as less than values, and tritium and caesium-137 levels remote from site discharge points are consistent with those in Figures 8.4 – 8.8.

In 2016, SEPA took a series of marine sediment and seawater samples from across Scotland and the results are given in Table 8.12. All radionuclides were reported as less than values in seawater (or close to the less than value). Tritium was positively detected in one seawater sample in the Inner Clyde. In marine sediments, niobium-95, antimony-125, caesium-137, europium-155 and americium-241 were positively detected in samples, albeit at lower levels than reported in Firth of Clyde samples (e.g. Environment Agency, FSA, FSS, NIEA, NRW and SEPA, 2016). The results are generally consistent with those to be expected from measurements at nuclear licensed sites in this report (see, for example, Section 2). Overall, the results support the concept of a reducing trend in concentration with distance from the Sellafield site, albeit confounded by natural variability due to sediment type.

**Table 8.1 Concentrations of radionuclides in seafood and the environment near the Channel Islands, 2016**

| Location | Material | No. of sampling observ-ations | Mean radioactivity concentration (fresh)[a], Bq kg$^{-1}$ | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Organic $^{3}$H | $^{3}$H | $^{14}$C | $^{60}$Co | $^{90}$Sr | $^{99}$Tc | $^{106}$Ru | $^{137}$Cs |
| **Guernsey[c]** | | | | | | | | | | |
| | Mackerel | 1 | | | | <0.09 | | | <0.76 | <0.09 |
| | Bass | 1 | | | | <0.07 | | | <0.56 | 0.21 |
| | Crabs | 1 | | | | <0.05 | | | <0.42 | <0.04 |
| | Lobsters | 1 | | | | <0.05 | | | <0.40 | <0.04 |
| | Limpets | 1 | | | | <0.11 | | | <0.99 | <0.09 |
| | Scallops | 1 | | | | <0.05 | | | <0.43 | <0.04 |
| St. Sampson's Harbour | Mud | 1 | | | | <0.17 | | | <1.7 | 0.51 |
| | Seawater | 4 | | | | | | | | 0.001 |
| **Jersey** | | | | | | | | | | |
| | Crabs | 1 | | | | <0.04 | | | <0.41 | <0.04 |
| | Spiny spider crabs | 1 | | | | <0.04 | | | <0.34 | <0.04 |
| | Lobsters | 1 | | | | <0.06 | | 0.33 | <0.53 | <0.05 |
| La Rocque | Oysters | 1 | | | | <0.03 | | | <0.26 | <0.03 |
| Plemont Bay | *Porphyra* | 2 | | | | <0.11 | | | <0.98 | <0.09 |
| La Rozel | *Fucus vesiculosus* | 4 | | | | <0.07 | <0.035 | 2.5 | <0.54 | <0.06 |
| Gorey | *Ascophyllum nodosum* | 4 | | | | <0.06 | | | <0.50 | <0.06 |
| | | | | | | | | | | |
| **Alderney[b]** | | | | | | | | | | |
| | Crabs | 2 | <25 | <26 | 54 | <0.04 | | <0.38 | <0.35 | <0.04 |
| | Spiny spider crabs | 1 | | | | 0.17 | | | <0.55 | <0.06 |
| | Lobsters | 1 | | | | <0.04 | | | <0.31 | <0.04 |
| | Toothed winkles | 1 | <25 | <25 | 39 | <0.19 | <0.095 | | <1.7 | <0.16 |
| Quenard Point | *Fucus serratus* | 4 | | | | <0.11 | 0.019 | 0.76 | <0.82 | <0.09 |
| Quenard Point | *Laminaria digitata* | 4 | | | | <0.09 | | | <0.70 | <0.07 |
| Little Crabbe Harbour | Sand | 1 | | | | <0.23 | | | <2.2 | 1.3 |
| | Seawater | 4 | | <2.9 | | | | | | 0.002 |

**Table 8.1 continued**

| Location | Material | No. of sampling observ-ations | Mean radioactivity concentration (fresh)[a], Bq kg$^{-1}$ | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | $^{155}$Eu | $^{238}$Pu | $^{239}$Pu + $^{240}$Pu | $^{241}$Am | $^{242}$Cm | $^{243}$Cm+ $^{244}$Cm | Gross beta |
| **Guernsey**[c] | | | | | | | | | |
| | Mackerel | 1 | <0.14 | 0.000033 | 0.000031 | 0.000065 | * | * | 110 |
| | Bass | 1 | <0.14 | 0.000013 | 0.000038 | 0.000073 | * | * | 150 |
| | Crabs | 1 | <0.08 | 0.00024 | 0.00082 | 0.0019 | * | 0.00019 | 94 |
| | Lobsters | 1 | <0.08 | | | 0.06 | | | 110 |
| | Limpets | 1 | <0.15 | | | <0.08 | | | 66 |
| | Scallops | 1 | <0.09 | 0.00054 | 0.0028 | 0.0013 | * | 0.000049 | 90 |
| St. Sampson's Harbour | Mud | 1 | <0.65 | 0.028 | 0.13 | 0.15 | * | 0.010 | 580 |
| | Seawater | 4 | | | | | | | |
| **Jersey** | | | | | | | | | |
| | Crabs | 1 | <0.12 | 0.00023 | 0.00084 | 0.0015 | * | 0.00017 | 100 |
| | Spiny spider crabs | 1 | <0.10 | | | <0.10 | | | 110 |
| | Lobsters | 1 | <0.14 | 0.00020 | 0.0006 | 0.0072 | * | 0.00058 | 89 |
| La Rocque | Oysters | 1 | <0.05 | 0.00082 | 0.0025 | 0.0023 | * | 0.00017 | 63 |
| Plemont Bay | *Porphyra* | 2 | <0.16 | | | <0.09 | | | 70 |
| La Rozel | *Fucus vesiculosus* | 4 | <0.14 | 0.0057 | 0.0170 | 0.0071 | 0.000054 | 0.00057 | 220 |
| Gorey | *Ascophyllum nodosum* | 4 | <0.14 | | | <0.13 | | | 220 |
| | | | | | | | | | |
| **Alderney**[b] | | | | | | | | | |
| | Crabs | 2 | <0.09 | 0.00023 | 0.00075 | 0.0021 | * | 0.00021 | 89 |
| | Spiny spider crabs | 1 | <0.15 | 0.0013 | 0.0028 | 0.0041 | * | 0.00049 | 90 |
| | Lobsters | 1 | <0.07 | 0.00011 | 0.00048 | 0.0032 | * | 0.00032 | 90 |
| | Toothed winkles | 1 | <0.40 | 0.0084 | 0.029 | 0.047 | * | 0.0039 | 67 |
| Quenard Point | *Fucus serratus* | 4 | <0.19 | 0.0022 | 0.0080 | 0.0036 | * | 0.00035 | 220 |
| Quenard Point | *Laminaria digitata* | 4 | <0.14 | | | <0.10 | | | 270 |
| Little Crabbe Harbour | Sand | 1 | <0.45 | | | 0.94 | | | 700 |

* *Not detected by the method used*

[a] *Except for seawater where units are Bq l$^{-1}$, and for sediment where dry concentrations apply*

[b] *The concentration of $^{129}$I based on two observations in* Fucus vesiculosus *is 0.81 Bq kg$^{-1}$*

[c] *The concentration of Gross Beta in ormers is 95 Bq kg$^{-1}$*

**Table 8.2(a) Concentrations of radionuclides in seafood and the environment in Northern Ireland, 2016[a]**

| Material | Location | No. of sampling observations | Mean radioactivity concentration (fresh)[b], Bq kg$^{-1}$ | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | $^{14}$C | $^{60}$Co | $^{99}$Tc | $^{125}$Sb | $^{134}$Cs | $^{137}$Cs |
| Cod | Kilkeel | 4 | 31 | <0.05 | | <0.12 | <0.05 | 1.1 |
| Plaice | Kilkeel | 4 | | <0.07 | | <0.18 | <0.08 | 1.2 |
| Haddock | Kilkeel | 4 | | <0.06 | | <0.14 | <0.06 | 0.30 |
| Herring | Ardglass | 2 | | <0.11 | | <0.27 | <0.12 | 0.46 |
| Lesser spotted dogfish | North coast | 2 | | <0.19 | | <0.44 | <0.20 | 0.80 |
| Spurdog | North coast | 2 | | <0.18 | | <0.39 | <0.18 | 0.94 |
| Skates / rays | Kilkeel | 4 | | <0.12 | | <0.27 | <0.11 | 0.67 |
| Crabs | Kilkeel | 4 | | <0.06 | | <0.14 | <0.06 | <0.12 |
| Lobsters | Ballycastle | 2 | | <0.06 | 12 | <0.12 | <0.06 | 0.19 |
| Lobsters | Kilkeel | 4 | | <0.08 | 8.0 | <0.18 | <0.08 | 0.14 |
| *Nephrops* | Kilkeel | 4 | | <0.13 | 5.5 | <0.32 | <0.14 | 0.61 |
| Winkles | Minerstown | 4 | | <0.05 | | <0.11 | <0.05 | 0.17 |
| Mussels | Carlingford Lough | 2 | | <0.12 | 1.6 | <0.29 | <0.12 | 0.28 |
| Scallops | Co. Down | 2 | | <0.06 | | <0.14 | <0.06 | 0.17 |
| *Ascophyllum nodosum* | Carlingford Lough | 1 | | <0.08 | | <0.16 | <0.08 | 0.27 |
| *Fucus* spp. | Carlingford Lough | 3 | | <0.06 | 83 | <0.15 | <0.08 | 0.25 |
| *Fucus* spp. | Portrush | 4 | | <0.05 | | <0.11 | <0.05 | 0.12 |
| *Fucus vesiculosus* | Ardglass | 4 | | <0.15 | 29 | <0.33 | <0.16 | 0.38 |
| *Rhodymenia* spp. | Portaferry | 4 | | <0.07 | 0.29 | <0.14 | <0.07 | <0.46 |
| Mud | Carlingford Lough | 2 | | <0.55 | | <1.5 | <0.76 | 42 |
| Mud | Ballymacormick | 1 | | <0.36 | | <0.90 | <0.46 | 10 |
| Mud | Dundrum Bay | 2 | | <0.42 | | <1.2 | <0.60 | 18 |
| Mud | Oldmill Bay | 1 | | <0.33 | | <0.93 | <0.40 | 41 |
| Mud | Strangford Lough – (Nicky's Point) | 2 | | <0.32 | | <0.89 | <0.43 | 13 |
| Mud and sand | Ballymacormick | 1 | | <0.20 | | <0.61 | <0.27 | 12 |
| Mud and sand | Oldmill Bay | 1 | | <0.15 | | <0.38 | <0.17 | 6.4 |
| Sand | Portrush | 2 | | <0.18 | | <0.52 | <0.23 | 0.36 |
| Sand, shells and mud | Carrichue | 2 | | <0.20 | | <0.58 | <0.27 | 2.8 |
| Seawater | North of Larne | 12 | | | 0.0022 | | * | 0.008 |

**Table 8.2(a) continued**

| Material | Location | No. of sampling observ-ations | Mean radioactivity concentration (fresh)[b], Bq kg$^{-1}$ | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | $^{155}$Eu | $^{238}$Pu | $^{239}$Pu + $^{240}$Pu | $^{241}$Am | $^{242}$Cm | $^{243}$Cm + $^{244}$Cm |
| Cod | Kilkeel | 4 | <0.11 | | | <0.10 | | |
| Plaice | Kilkeel | 4 | <0.16 | | | <0.14 | | |
| Haddock | Kilkeel | 4 | <0.14 | | | <0.13 | | |
| Herring | Ardglass | 2 | <0.24 | | | <0.19 | | |
| Lesser spotted dogfish | North coast | 2 | <0.32 | | | <0.27 | | |
| Spurdog | North coast | 2 | <0.30 | | | <0.22 | | |
| Skates / rays | Kilkeel | 4 | <0.19 | | | <0.14 | | |
| Crabs | Kilkeel | 4 | <0.11 | | | <0.10 | | |
| Lobsters | Ballycastle | 2 | <0.09 | | | <0.25 | | |
| Lobsters | Kilkeel | 4 | <0.15 | | | <0.12 | | |
| *Nephrops* | Kilkeel | 4 | <0.25 | 0.0041 | 0.024 | 0.11 | * | 0.000059 |
| Winkles | Minerstown | 4 | <0.10 | 0.029 | 0.17 | 0.13 | * | * |
| Mussels | Carlingford Lough | 2 | <0.18 | | | <0.10 | | |
| Scallops | Co. Down | 2 | <0.14 | | | <0.17 | | |
| *Ascophyllum nodosum* | Carlingford Lough | 1 | <0.17 | | | <0.21 | | |
| *Fucus* spp. | Carlingford Lough | 3 | <0.17 | | | <0.18 | | |
| *Fucus* spp. | Portrush | 4 | <0.12 | | | <0.14 | | |
| *Fucus vesiculosus* | Ardglass | 4 | <0.26 | | | <0.30 | | |
| *Rhodymenia* spp. | Portaferry | 4 | <0.11 | 0.070 | 0.41 | 0.84 | * | * |
| Mud | Carlingford Lough | 2 | <1.6 | 2.1 | 14 | 10 | * | * |
| Mud | Ballymacormick | 1 | <0.76 | | | 12 | | |
| Mud | Dundrum Bay | 2 | <1.1 | | | 6.9 | | |
| Mud | Oldmill Bay | 1 | <0.81 | | | 11 | | |
| Mud | Strangford Lough – (Nicky's Point) | 2 | <0.93 | | | 3.6 | | |
| Mud and sand | Ballymacormick | 1 | <0.78 | | | 7.9 | | |
| Mud and sand | Oldmill Bay | 1 | <0.37 | | | 12 | | |
| Sand | Portrush | 2 | <0.63 | | | <0.75 | | |
| Sand, shells and mud | Carrichue | 2 | <0.69 | 0.18 | 1.2 | 2.3 | 0.0041 | 0.0012 |
| Seawater | North of Larne | 12 | | | | | | |

* *Not detected by the method used*

[a] *All measurements are made on behalf of the Northern Ireland Environment Agency*

[b] *Except for seawater where units are Bq l$^{-1}$, and for sediment where dry concentrations apply*

**Table 8.2(b) Monitoring of radiation dose rates in Northern Ireland, 2016[a]**

| Location | Ground type | No. of sampling observations | Mean gamma dose rate in air at 1m, μGy $h^{-1}$ |
|---|---|---|---|
| Lisahally | Mud | 1 | 0.066 |
| Donnybrewer | Shingle | 1 | 0.054 |
| Carrichue | Mud | 1 | 0.061 |
| Bellerena | Mud | 1 | 0.056 |
| Benone | Sand | 1 | 0.053 |
| Castlerock | Sand | 1 | 0.055 |
| Portstewart | Sand | 1 | 0.053 |
| Portrush, Blue Pool | Sand | 1 | 0.054 |
| Portrush, White Rocks | Sand | 1 | 0.055 |
| Portballintrae | Sand | 1 | 0.051 |
| Giant's Causeway | Sand | 1 | 0.054 |
| Ballycastle | Sand | 1 | 0.058 |
| Cushendun | Sand | 1 | 0.054 |
| Cushendall | Sand and stones | 1 | 0.061 |
| Red Bay | Sand | 1 | 0.065 |
| Carnlough | Sand | 1 | 0.053 |
| Glenarm | Sand | 1 | 0.052 |
| Half Way House | Sand | 1 | 0.058 |
| Ballygally | Sand | 1 | 0.051 |
| Drains Bay | Sand | 1 | 0.052 |
| Larne | Sand | 1 | 0.055 |
| Whitehead | Sand | 1 | 0.055 |
| Carrickfergus | Sand | 1 | 0.056 |
| Jordanstown | Sand | 1 | 0.058 |
| Helen's Bay | Sand | 1 | 0.060 |
| Groomsport | Sand | 1 | 0.068 |
| Millisle | Sand | 1 | 0.067 |
| Ballywalter | Sand | 1 | 0.066 |
| Ballyhalbert | Sand | 1 | 0.068 |
| Cloghy | Sand | 1 | 0.059 |
| Portaferry | Shingle and stones | 1 | 0.090 |
| Kircubbin | Sand | 1 | 0.085 |
| Greyabbey | Sand | 1 | 0.087 |
| Ards Maltings | Mud | 1 | 0.075 |
| Island Hill | Mud | 1 | 0.075 |
| Nicky's Point | Mud | 1 | 0.077 |
| Strangford | Shingle and stones | 1 | 0.10 |
| Kilclief | Sand | 1 | 0.074 |
| Ardglass | Mud | 1 | 0.080 |
| Killough | Mud | 1 | 0.082 |
| Ringmore Point | Sand | 1 | 0.069 |
| Tyrella | Sand | 1 | 0.080 |
| Dundrum | Sand | 1 | 0.078 |
| Newcastle | Sand | 1 | 0.095 |
| Annalong | Sand | 1 | 0.11 |
| Cranfield Bay | Sand | 1 | 0.085 |
| Mill Bay | Sand | 1 | 0.11 |
| Greencastle | Sand | 1 | 0.086 |
| Rostrevor | Sand | 1 | 0.11 |
| Narrow Water | Mud | 1 | 0.093 |

[a] *All measurements are made on behalf of the Northern Ireland Environment Agency*

## Table 8.3 Concentrations of radionuclides in diet, 2016[a]

| Region | No. of sampling observations | Mean radioactivity concentration (fresh), Bq kg$^{-1}$ | | | |
|---|---|---|---|---|---|
| | | $^{14}$C | $^{40}$K | $^{90}$Sr | $^{137}$Cs |
| **Canteen meals** | | | | | |
| England | 8 | | 76 | 0.027 | <0.05 |
| Northern Ireland | 5 | | 93 | 0.027 | <0.05 |
| Scotland | 12 | 39 | 110 | 0.032 | <0.018 |
| Wales | 5 | | 90 | 0.031 | <0.05 |

| Region | No. of farms/ dairies | Mean radioactivity concentration (fresh), Bq kg$^{-1}$ | | | |
|---|---|---|---|---|---|
| | | $^{14}$C | $^{40}$K | $^{90}$Sr | $^{137}$Cs |
| **Mixed diet in Scotland** | | | | | |
| **Dumfriesshire** Dumfries | 4 | | 89 | <0.086 | <0.05 |
| **East Lothian** North Berwick | 4 | | 92 | <0.060 | <0.05 |
| **Renfrewshire** Paisley | 4 | | 86 | <0.088 | <0.05 |
| **Ross-shire** Dingwall | 4 | | 89 | <0.10 | <0.05 |

[a] *Results are available for other artificial nuclides detected by gamma spectrometry All such results were less than the limit of detection*

**Table 8.4 Concentrations of radionuclides in milk remote from nuclear sites, 2016**

| Location | Selection[a] | No. of farms/ dairies[b] | Mean radioactivity concentration , Bq $l^{-1}$ | | | |
|---|---|---|---|---|---|---|
| | | | $^{3}H$ | $^{14}C$ | $^{90}Sr$ | $^{137}Cs$ |
| **Milk** | | | | | | |
| Co. Antrim | | 1 | | 11 | <0.022 | <0.07 |
| Co. Armagh | | 1 | | | <0.023 | <0.05 |
| Ceredigion | | 1 | | | 0.026 | <0.05 |
| Cheshire | | 1 | | 34 | <0.022 | <0.05 |
| Clwyd | | 1 | | 21 | <0.023 | <0.04 |
| Cornwall | | 1 | | 12 | <0.022 | <0.05 |
| Devon | | 1 | | 21 | <0.022 | <0.04 |
| Dorset | | 1 | | 19 | <0.020 | <0.05 |
| Co. Down | | 2 | | | <0.022 | <0.05 |
| | max | | | | | |
| Dumfriesshire | | 1 | <5.1 | <15 | <0.10 | <0.05 |
| Essex | | 1 | | 17 | <0.019 | <0.04 |
| Co. Fermanagh | | 1 | | | <0.022 | <0.04 |
| Gloucestershire | | 1 | | 7.7 | <0.022 | <0.05 |
| Gwynedd | | 1 | | 17 | 0.026 | <0.05 |
| Hampshire | | 1 | | 14 | <0.021 | <0.04 |
| Humberside | | 1 | | 20 | <0.023 | <0.04 |
| Kent | | 1 | | 13 | <0.019 | <0.05 |
| Lanarkshire | | 1 | <5.0 | <16 | <0.032 | <0.02 |
| Lancashire | | 1 | | 13 | <0.023 | <0.04 |
| Leicestershire | | 1 | | 15 | <0.029 | <0.04 |
| Middlesex | | 1 | | 17 | <0.019 | <0.04 |
| Midlothian | | 1 | <5.0 | <16 | <0.10 | <0.06 |
| Nairnshire | | 1 | <5.0 | <18 | <0.10 | <0.05 |
| Norfolk | | 1 | | 24 | <0.027 | <0.05 |
| North Yorkshire | | 1 | | 20 | <0.020 | <0.05 |
| Renfrewshire | | 1 | <5.0 | <15 | <0.10 | <0.05 |
| Suffolk | | 1 | | | <0.023 | <0.05 |
| Co. Tyrone | | 2 | | 14 | <0.021 | <0.06 |
| | max | | | | <0.023 | |
| **Mean Values** | | | | | | |
| England | | | | 18 | <0.022 | <0.05 |
| Northern Ireland | | | | 13 | <0.022 | <0.05 |
| Wales | | | | 19 | <0.025 | <0.05 |
| Scotland | | | <5.0 | <16 | <0.086 | <0.05 |
| United Kingdom | | | <5.0 | <17 | <0.034 | <0.05 |

[a] *Data are arithmetic means unless stated as 'max'. 'Max' data are selected to be maxima If no 'max' value is given the mean value is the most appropriate for dose assessments*

[b] *The number of farms or dairies from which milk is sampled. The number of analyses is greater than this and depends on the bulking regime*

## Table 8.5 Concentrations of radionuclides in rainwater and air, 2016

| Location | Sample | No. of sampling observations | Mean radioactivity concentration[a] | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | $^{3}H$ | $^{7}Be$ | $^{7}Be$[d] | $^{90}Sr$ | $^{137}Cs$ | $^{137}Cs$[d] |
| **Ceredigion** | | | | | | | | |
| Aberporth | Rainwater | 4 | <1.3 | 1.4 | | | <0.012 | |
| | Air | 4 | | 0.0040 | | | <2.9 $10^{-6}$ | |
| **Co. Down** | | | | | | | | |
| Conlig | Rainwater | 4 | | 1.1 | | | <0.010 | |
| | Air | 4 | | 0.0037 | | | <6.0 $10^{-7}$ | |
| **Dumfries and Galloway** | | | | | | | | |
| Eskdalemuir | Rainwater | 12 | <1.0 | 1.1 | | <0.010 | <0.010 | |
| | Air | 12 | | 0.0011 | | | <1.0 $10^{-5}$ | |
| **North Lanarkshire** | | | | | | | | |
| Holytown | Rainwater | 12 | <1.0 | <0.48 | | <0.0057 | <0.84 | |
| | Air | 12 | | 0.0011 | | | <1.0 $10^{-5}$ | |
| **North Yorkshire** | | | | | | | | |
| Dishforth/Leeming | Rainwater | 4 | | 1.2 | | | <0.014 | |
| | Air | 3 | | 0.0031 | | | <7.8 $10^{-7}$ | |
| **Oxfordshire** | | | | | | | | |
| Chilton | Rainwater | 4 | | 1.4 | 2.1 | <0.00036[b] | <0.015 | <0.0042 |
| | Air | 12 | | | 0.0021 | | | <3.2 $10^{-7}$ |
| **Shetland** | | | | | | | | |
| Lerwick | Rainwater | 12 | <1.0 | <1.2 | | <0.0051 | <0.010 | |
| | Air | 12 | | 0.0017 | | | <1.0 $10^{-5}$ | |
| **Suffolk** | | | | | | | | |
| Orfordness | Rainwater | 4 | <1.3 | 1.3 | | | <0.016 | |
| | Air | 4 | | 0.0040 | | | <3.8 $10^{-6}$ | |

| Location | Sample | No. of sampling observations | Mean radioactivity concentration[a] | | | | |
|---|---|---|---|---|---|---|---|
| | | | $^{238}Pu$[c] | $^{239}Pu$ + $^{240}Pu$[c] | $^{241}Am$[c] | Gross alpha | Gross beta |
| **Ceredigion** | | | | | | | |
| Aberporth | Rainwater | 4 | <6.1 $10^{-6}$ | <6.1 $10^{-6}$ | <2.2 $10^{-5}$ | | |
| | Air | 4 | 2.1 $10^{-10}$ | 2.4 $10^{-9}$ | <3.0 $10^{-10}$ | | |
| **Dumfries and Galloway** | | | | | | | |
| Eskdalemuir | Air | 12 | | | | | <0.00020 |
| **North Lanarkshire** | | | | | | | |
| Holytown | Air | 12 | | | | | <0.00020 |
| **Oxfordshire** | | | | | | | |
| Chilton | Rainwater | 4 | | | | 0.038[d] | 0.056[d] |
| **Shetland** | | | | | | | |
| Lerwick | Air | 12 | | | | | <0.00020 |

[a] *Bq $l^{-1}$ for rainwater and Bq $kg^{-1}$ for air. 1.2 kg air occupies 1$m^3$ at standard temperature and pressure*
[b] *Bulked from 4 quarterly samples*
[c] *Separate annual sample for rain, annual bulked sample for air*
[d] *Bulked from 12 monthly samples*

## Table 8.6 Concentrations of radionuclides in sources of drinking water in Scotland, 2016

| Area | Location | No. of sampling observations | Mean radioactivity concentration, Bq $l^{-1}$ | | | | |
|---|---|---|---|---|---|---|---|
| | | | $^{3}H$ | $^{90}Sr$ | $^{137}Cs$ | Gross alpha | Gross beta |
| Angus | Loch Lee | 4 | <1.0 | <0.0050 | <0.01 | <0.012 | 0.027 |
| Argyll and Bute | Auchengaich | 1 | <1.0 | | <0.01 | <0.010 | 0.035 |
| Argyll and Bute | Helensburgh Reservoir | 1 | <1.0 | | <0.01 | <0.010 | 0.025 |
| Argyll and Bute | Loch Ascog | 1 | <1.0 | | <0.01 | <0.010 | 0.110 |
| Argyll and Bute | Loch Eck | 1 | <1.0 | | <0.01 | <0.010 | 0.025 |
| Argyll and Bute | Lochan Ghlas Laoigh | 1 | <1.0 | | <0.01 | <0.010 | 0.026 |
| Argyll and Bute | Loch Finlas | 1 | <1.0 | | <0.01 | <0.010 | 0.023 |
| Clackmannanshire | Gartmorn Dam | 1 | <1.0 | | <0.01 | <0.010 | 0.10 |
| Dumfries and Galloway | Black Esk | 1 | <1.0 | | <0.01 | <0.010 | 0.065 |
| Dumfries and Galloway | Gullielands Burn | 1 | 34 | | <0.01 | 0.020 | 0.15 |
| Dumfries and Galloway | Purdomstone | 1 | <1.0 | | <0.01 | 0.013 | 0.28 |
| Dumfries and Galloway | Winterhope | 1 | <1.0 | | <0.01 | <0.010 | 0.039 |
| East Lothian | Hopes Reservoir | 1 | 1.1 | | <0.01 | <0.010 | 0.017 |
| East Lothian | Thorters Reservoir | 1 | <1.0 | | <0.01 | 0.015 | 0.062 |
| East Lothian | Whiteadder | 1 | <1.0 | | <0.01 | <0.010 | 0.053 |
| East Lothian | Thornton Loch Burn | 1 | <1.0 | | <0.01 | 0.015 | 0.095 |
| Fife | Holl Reservoir | 1 | <1.0 | | <0.01 | <0.010 | 0.018 |
| Highland | Loch Baligill | 1 | <1.0 | | <0.01 | <0.019 | 0.070 |
| Highland | Loch Calder | 1 | <1.0 | | <0.01 | <0.010 | 0.044 |
| Highland | Loch Glass | 4 | <1.0 | <0.0050 | <0.01 | <0.021 | 0.056 |
| Highland | Loch Shurrerey | 1 | <1.0 | | <0.01 | 0.013 | 0.030 |
| North Ayrshire | Camphill | 1 | <1.0 | | <0.01 | 0.017 | 0.047 |
| North Ayrshire | Knockendon Reservoir | 1 | 1.1 | | <0.01 | <0.010 | 0.024 |
| North Ayrshire | Munnoch Reservoir | 1 | <1.0 | | <0.01 | 0.018 | 0.076 |
| North Ayrshire | Outerwards | 1 | <1.0 | | <0.01 | 0.023 | 0.050 |
| Orkney Islands | Heldale Water | 1 | <1.0 | | <0.01 | <0.010 | 0.065 |
| Perth and Kinross | Castlehill Reservoir | 1 | <1.0 | | <0.01 | <0.010 | 0.024 |
| Scottish Borders | Knowesdean | 4 | <1.0 | <0.0050 | <0.01 | <0.010 | 0.036 |
| Stirling | Loch Katrine | 12 | <1.0 | 0.0027 | <0.001 | <0.0081 | 0.032 |
| West Dunbartonshire | Loch Lomond (Ross Priory) | 1 | <1.0 | | <0.01 | <0.010 | 0.036 |
| West Lothian | Morton No 2 Reservoir | 1 | <1.0 | | <0.01 | 0.0046 | 0.040 |

## Table 8.7 Concentrations of radionuclides in sources of drinking water in England and Wales, 2016

| Location | Sample source | No. of sampling observ-ations | Mean radioactivity concentration , Bq $l^{-1}$ | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | $^{3}H$ | $^{40}K$ | $^{90}Sr$ | $^{125}I$ | $^{137}Cs$ | Gross alpha | Gross beta[1] | Gross beta[2] |
| **England** | | | | | | | | | | |
| Cambridgeshire | Grafham Water | 4 | <4.0 | 0.30 | 0.0032 | | <0.0010 | 0.027 | 0.47 | 0.32 |
| Cornwall | River Fowey | 4 | <4.0 | <0.036 | 0.0023 | <0.0023 | <0.0010 | <0.023 | 0.085 | <0.058 |
| County Durham | Honey Hill Water Treatment Works, Consett | 4 | <4.0 | <0.051 | <0.0027 | | <0.0018 | 0.047 | 0.12 | 0.080 |
| County Durham | River Tees, Darlington | 4 | <4.0 | <0.038 | <0.0019 | <0.0023 | <0.0010 | <0.026 | 0.087 | <0.061 |
| Cumbria | Ennerdale Lake | 4 | <4.0 | <0.018 | 0.0029 | | <0.0011 | <0.023 | <0.054 | <0.050 |
| Cumbria | Haweswater Reservoir | 4 | <4.0 | <0.019 | 0.0019 | | <0.0010 | <0.020 | <0.062 | <0.051 |
| Derbyshire | Arnfield Water Treatment Plant | 4 | <4.0 | <0.041 | <0.0015 | | <0.0018 | <0.020 | <0.050 | <0.050 |
| Derbyshire | Matlock, Groundwater | 1 | | | | | | 0.093 | 0.11 | 0.068 |
| Devon | River Exe, Exeter | 4 | <4.0 | <0.088 | 0.0031 | <0.0030 | <0.0037 | <0.021 | 0.10 | 0.067 |
| Devon | Roadford Reservoir, Broadwoodwidger | 4 | <4.0 | <0.056 | <0.0022 | | <0.0010 | <0.020 | 0.088 | 0.058 |
| Greater London | River Lee, Chingford | 4 | <4.0 | 0.30 | <0.0015 | <0.0025 | <0.0010 | 0.024 | 0.42 | 0.28 |
| Hampshire | River Avon, Christchurch | 2 | <4.0 | <0.055 | <0.0010 | | <0.0013 | <0.020 | 0.11 | 0.072 |
| Humberside | Littlecoates, Groundwater | 4 | <4.0 | <0.089 | <0.0011 | | <0.0014 | 0.024 | 0.14 | 0.096 |
| Kent | Denge, Shallow Groundwater | 4 | <4.0 | 0.069 | 0.0043 | | <0.0010 | <0.020 | 0.15 | 0.10 |
| Lancashire | Corn Close, Groundwater | 4 | <4.0 | <0.049 | <0.0010 | | <0.0010 | <0.020 | 0.13 | 0.084 |
| Norfolk | River Drove, Stoke Ferry | 4 | <4.0 | 0.10 | 0.0028 | <0.0030 | <0.0010 | 0.029 | 0.14 | 0.093 |
| Northumberland | Kielder Reservoir | 4 | <4.0 | <0.028 | <0.0021 | | <0.0012 | <0.019 | <0.089 | <0.067 |
| Oxfordshire | River Thames, Oxford | 4 | <4.0 | 0.12 | <0.0023 | <0.0020 | <0.0010 | 0.028 | 0.26 | 0.17 |
| Somerset | Ashford Reservoir, Bridgwater | 2 | <4.0 | <0.063 | <0.0010 | | <0.0015 | 0.028 | 0.12 | 0.079 |
| Somerset | Chew Valley Lake Reservoir, Bristol | 4 | <4.0 | 0.11 | 0.0029 | | <0.0010 | <0.025 | 0.18 | 0.11 |
| Surrey | River Thames, Walton | 4 | <4.0 | 0.20 | <0.0019 | <0.0026 | <0.0010 | <0.024 | 0.31 | 0.20 |
| **Wales** | | | | | | | | | | |
| Gwynedd | Cwm Ystradllyn Treatment Works | 4 | <4.0 | <0.015 | 0.0039 | | <0.0012 | <0.023 | <0.058 | <0.051 |
| Mid-Glamorgan | Llwyn-on Reservoir | 4 | <4.0 | <0.029 | <0.0021 | | <0.0012 | <0.020 | <0.050 | <0.050 |
| Powys | Elan Valley Reservoir | 4 | <4.0 | <0.019 | 0.0035 | | <0.0010 | <0.020 | <0.050 | <0.050 |

[1] *Using $^{137}Cs$ standard*
[2] *Using $^{40}K$ standard*

## Table 8.8 Concentrations of radionuclides in sources of drinking water in Northern Ireland, 2016

| Area | Location | No. of sampling observ-ations | Mean radioactivity concentration, Bq $l^{-1}$ | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $^{3}H$ | $^{90}Sr$ | $^{137}Cs$ | $^{210}Po$ | $^{226}Ra$ | $^{234}U$ | $^{235}U$ | $^{238}U$ | Gross alpha | Gross beta |
| Co. Londonderry | R Faughan | 4 | <1.3 | 0.0030 | <0.038 | 0.007 | <0.01 | 0.006 | <0.0003 | 0.003 | <0.02 | <0.05 |
| Co. Antrim | Lough Neagh | 4 | <1.3 | 0.0029 | <0.027 | 0.005 | <0.01 | 0.003 | <0.0005 | 0.002 | <0.02 | <0.05 |
| Co. Down | Silent Valley | 4 | <1.6 | 0.0031 | <0.027 | 0.006 | <0.01 | 0.008 | <0.0004 | 0.006 | 0.02 | <0.05 |

## Table 8.9 Doses from radionuclides in drinking water, 2016[a]

| Region | Mean exposure, mSv per year | | | Maximum exposure, mSv per year | |
|---|---|---|---|---|---|
| | Man-made radionuclides[b,c] | Naturally occurring radionuclides[b] | All radionuclides | Location | All radionuclides |
| England[d] | <0.001 | | <0.001 | Denge, Shallow Groundwater, Kent | <0.001[d] |
| Wales[d] | <0.001 | | | Cwm Ystradllyn Treatment Works, Gwynedd | <0.001[d] |
| Northern Ireland | <0.001 | 0.017 | 0.017 | R Faughan, Co. Londonderry | 0.019 |
| Scotland[d] | <0.001 | | | Gullielands Burn, Dumfries and Galloway | 0.001[d] |
| UK | <0.001 | 0.017 | 0.017 | R Faughan, Co. Londonderry | 0.019 |

[a] *Assessments of dose are based on some concentration results at limits of detection. Exposures due to potassium-40 content of water are not included here because they do not vary according to the potassium-40 content of water. Levels of potassium are homeostatically controlled*
[b] *Average of the doses to the most exposed age group at each location*
[c] *Including tritium*
[d] *Analysis of naturally occurring radionuclides was not undertaken*

## Table 8.10 Analysis of groundwater in Scotland, 2016

| Location | Sample source | No. of sampling observations | Mean radioactivity concentration, Bq $l^{-1}$ | | | |
|---|---|---|---|---|---|---|
| | | | $^{3}H$ | $^{137}Cs$ | Gross alpha | Gross beta |
| Scottish Borders | Selkirk | 1 | <1.2 | <0.10 | 0.10 | <0.10 |
| East Lothian | Dunbar | 1 | <1.0 | <0.10 | 0.10 | <0.10 |
| West Lothian | Livingston | 1 | <1.0 | <0.10 | 0.10 | 0.28 |
| Fife | St Andrews | 1 | <1.2 | <0.10 | 0.11 | 0.28 |
| Fife | Falkland | 1 | <1.2 | <0.10 | 0.10 | <0.10 |
| Angus | Arbroath | 1 | <1.0 | <0.10 | 0.10 | <0.10 |
| Angus | Forfar | 1 | <1.0 | <0.10 | 0.10 | <0.10 |
| Angus | Montrose | 1 | <1.0 | <0.10 | 0.10 | <0.10 |
| Angus | Brechin | 1 | <1.0 | <0.10 | 0.10 | <0.10 |
| Aberdeenshire | Mintlaw | 1 | <1.2 | <0.10 | 0.10 | <0.10 |
| Aberdeenshire | Huntly | 1 | <1.0 | <0.10 | 0.10 | <0.10 |
| Aberdeenshire | Delgaty | 1 | <1.0 | <0.10 | 0.10 | <0.10 |
| Moray | Fochabers | 1 | <1.2 | <0.10 | 0.10 | 0.22 |
| Highland | Cromarty | 1 | <1.0 | <0.10 | 0.10 | <0.10 |
| Highland | Annat | 1 | <1.2 | <0.10 | 0.10 | <0.10 |
| Glasgow | Lennoxtown | 1 | <1.2 | <0.10 | 0.10 | <0.10 |
| Ayr | Girvan | 1 | <1.2 | <0.10 | 0.10 | <0.10 |
| Dumfries and Galloway | Dumfries | 1 | <1.0 | <0.10 | 0.10 | <0.10 |
| Dumfries and Galloway | Annan | 1 | <1.2 | <0.10 | 0.10 | <0.10 |

## Table 8.11 Concentrations of radionuclides in seawater, 2016

| Location | No. of sampling observ-ations | Mean radioactivity concentration, Bq $l^{-1}$ | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | $^{3}H$ | $^{14}C$ | $^{60}Co$ | $^{90}Sr$ | $^{99}Tc$ | $^{106}Ru$ | $^{110m}Ag$ | $^{129}I$ |
| Dounreay (Sandside Bay) | 2[S] | <3.0 | | <0.10 | | | <0.35 | <0.10 | |
| Dounreay (Brims Ness) | 2[S] | <3.0 | | <0.10 | | | <0.36 | <0.10 | |
| Rosyth | 2[S] | <1.0 | | <0.10 | | | <0.36 | <0.10 | |
| Torness[a] | 2[S] | 9.5 | | <0.10 | | | <0.47 | <0.10 | |
| Hartlepool (North Gare)[b] | 2 | <3.8 | | <0.29 | | | <2.1 | <0.33 | |
| Sizewell | 2 | <3.3 | <3.6 | <0.28 | | | <2.2 | <0.34 | |
| Bradwell (Beach pipeline) | 2 | <3.4 | | <0.23 | | | <2.0 | <0.34 | |
| Bradwell (Marina) | 2 | | | <0.31 | | | <2.5 | <0.45 | |
| Bradwell (Steeple) | 2 | | | <0.21 | | | <2.0 | <0.32 | |
| Bradwell (Maylandsea Bay) | 2 | | | <0.27 | | | <2.2 | <0.37 | |
| Bradwell (Blackwater) | 2 | | | <0.32 | | | <2.5 | <0.45 | |
| Bradwell (Osea Causeway) | 2 | | | <0.28 | | | <2.3 | <0.39 | |
| Bradwell (Maldon) | 2 | <3.2 | | <0.28 | | | <2.3 | <0.39 | |
| Bradwell (Heybridge) | 2 | | | <0.28 | | | <2.2 | <0.38 | |
| Bradwell (Strood Channel) | 2 | <3.3 | | <0.24 | | | <2.0 | <0.33 | |
| Bradwell (Tollesbury boatyard) | 2 | | | <0.28 | | | <2.3 | <0.39 | |
| Bradwell (Tollesbury saltwater pool) | 2 | | | <0.23 | | | <2.0 | <0.31 | |
| Bradwell (Pyefleet) | 2 | <3.3 | | <0.27 | | | <2.3 | <0.38 | |
| Bradwell (Rowhedge) | 2 | | | <0.32 | | | <2.5 | <0.46 | |
| Bradwell (Alresford Creek) | 2 | | | <0.23 | | | <2.1 | <0.35 | |
| Bradwell (Brightlingsea Bateman's Tower) | 2 | | | <0.24 | | | <1.9 | <0.33 | |
| Bradwell (Brightlingsea saltwater pool) | 2 | | | <0.27 | | | <2.1 | <0.39 | |
| Bradwell (St Osyth) | 2 | | | <0.31 | | | <2.5 | <0.43 | |
| Dungeness south | 2 | <3.3 | | <0.21 | | | <1.8 | <0.29 | |
| Winfrith (Lulworth Cove) | 1 | | | <0.33 | | | <2.2 | <0.37 | |
| Alderney | 4[F] | <2.9 | | | | | | | |
| Guernsey | 4[F] | | | | | | | | |
| Devonport (Millbrook Lake) | 1 | <3.0 | <9.1 | <0.23 | | | | | |
| Devonport (Tor Point South) | 1 | <3.3 | 19 | <0.21 | | | | | |
| Hinkley | 1 | 4.2 | | <0.21 | <0.034 | | <1.9 | <0.30 | |
| Berkeley and Oldbury | 2 | <3.3 | | <0.30 | | | <2.3 | <0.40 | |
| Cardiff (West of sewage outfall)[c] | 2 | <3.8 | <6.2 | | | | | | |
| Wylfa (Cemaes Bay) | 2 | <3.2 | | <0.28 | | | <2.0 | <0.33 | |
| Seascale (Particulate)[d] | 1 | | | <0.02 | <0.0075 | | <0.21 | <0.04 | <0.020 |
| Seascale (Filtrate) | 2 | 14 | <6.7 | <0.19 | <0.085 | <0.14 | <1.5 | <0.24 | <0.27 |
| St. Bees (Particulate)[e] | 1 | | | <0.02 | <0.0076 | | <0.19 | <0.03 | <0.044 |
| St. Bees (Filtrate) | 2 | <7.0 | <4.7 | <0.16 | <0.038 | <0.11 | <1.2 | <0.19 | <0.34 |
| Seafield | 2[S] | 2.0 | | <0.10 | | | <0.43 | <0.10 | |
| Southerness | 2[S] | 3.4 | | <0.10 | | | <0.42 | <0.10 | |
| Auchencairn | 2[S] | 4.6 | | <0.10 | | | <0.61 | <0.10 | |
| Port Patrick | 2[S] | <1.2 | | <0.10 | | | <0.32 | <0.10 | |
| Hunterston[f] | 2[S] | 12 | | <0.10 | | | <0.44 | <0.10 | |
| North of Larne | 12[N] | | | | | 0.0022 | | | |
| Faslane (Carnban) | 2[S] | 2.0 | | <0.10 | | | <0.51 | <0.10 | |

**Table 8.11 continued**

| Location | No. of sampling observ-ations | Mean radioactivity concentration, Bq $l^{-1}$ | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | $^{134}$Cs | $^{137}$Cs | $^{144}$Ce | $^{237}$Np | $^{241}$Am | Gross alpha | Gross beta |
| Dounreay (Sandside Bay) | 2[S] | <0.10 | <0.10 | <0.20 | | <0.10 | | |
| Dounreay (Brims Ness) | 2[S] | <0.10 | <0.10 | <0.23 | | <0.10 | | |
| Rosyth | 2[S] | <0.10 | <0.10 | <0.20 | | <0.10 | | |
| Torness[a] | 2[S] | <0.10 | <0.10 | <0.29 | | <0.11 | | |
| Hartlepool (North Gare)[b] | 2 | <0.30 | <0.22 | <0.96 | | <0.27 | <3.6 | 20 |
| Sizewell | 2 | <0.27 | <0.22 | <1.0 | | <0.28 | <4.0 | 12 |
| Bradwell (Beach pipeline) | 2 | <0.26 | <0.19 | <1.0 | | <0.28 | <4.3 | 20 |
| Bradwell (Marina) | 2 | <0.32 | <0.25 | <1.2 | | <0.27 | <4.2 | <11 |
| Bradwell (Steeple) | 2 | <0.24 | <0.19 | <1.1 | | <0.28 | <4.1 | 11 |
| Bradwell (Maylandsea Bay) | 2 | <0.28 | <0.22 | <1.1 | | <0.28 | <4.3 | 13 |
| Bradwell (Blackwater) | 2 | <0.33 | <0.26 | <1.1 | | <0.26 | <4.0 | 12 |
| Bradwell (Osea Causeway) | 2 | <0.30 | <0.23 | <1.1 | | <0.27 | <3.1 | 12 |
| Bradwell (Maldon) | 2 | <0.29 | <0.23 | <1.1 | | <0.27 | <2.4 | <3.2 |
| Bradwell (Heybridge) | 2 | <0.28 | <0.22 | <1.2 | | <0.27 | <3.1 | <9.2 |
| Bradwell (Strood Channel) | 2 | <0.26 | <0.20 | <1.0 | | <0.27 | <3.9 | <9.7 |
| Bradwell (Tollesbury boatyard) | 2 | <0.30 | <0.23 | <1.2 | | <0.28 | <3.9 | 16 |
| Bradwell (Tollesbury saltwater pool) | 2 | <0.24 | <0.19 | <1.1 | | <0.29 | <4.0 | <10 |
| Bradwell (Pyefleet) | 2 | <0.28 | <0.21 | <1.2 | | <0.27 | <3.6 | 16 |
| Bradwell (Rowhedge) | 2 | <0.32 | <0.25 | <1.2 | | <0.27 | <3.0 | 10 |
| Bradwell (Alresford Creek) | 2 | <0.26 | <0.20 | <1.0 | | <0.28 | <3.0 | 11 |
| Bradwell (Brightlingsea Bateman's Tower) | 2 | <0.24 | <0.19 | <1.0 | | <0.28 | <3.9 | 14 |
| Bradwell (Brightlingsea saltwater pool) | 2 | <0.28 | <0.22 | <1.2 | | <0.28 | <4.1 | 13 |
| Bradwell (St Osyth) | 2 | <0.32 | <0.24 | <1.2 | | <0.26 | <1.4 | 5.0 |
| Dungeness south | 2 | <0.24 | <0.17 | <0.98 | | <0.28 | <3.8 | <8.8 |
| Winfrith (Lulworth Cove) | 1 | <0.30 | <0.25 | <0.91 | | <0.26 | <2.4 | <5.0 |
| Alderney | 4[F] | * | 0.002 | | | | | |
| Guernsey | 4[F] | * | 0.001 | | | | | |
| Devonport (Millbrook Lake) | 1 | | | | | | | |
| Devonport (Tor Point South) | 1 | | | | | | | |
| Hinkley | 1 | <0.23 | <0.18 | <0.97 | | <0.29 | <4.3 | 8.7 |
| Berkeley and Oldbury | 2 | <0.33 | <0.25 | <1.0 | | <0.26 | <2.1 | <3.9 |
| Cardiff (West of sewage outfall)[c] | 2 | | | | | | | |
| Wylfa (Cemaes Bay) | 2 | <0.26 | <0.21 | <0.96 | | <0.28 | <3.7 | 13 |
| Seascale (Particulate)[d] | 1 | <0.03 | 0.05 | <0.08 | <0.0010 | 0.18 | 0.49 | 0.23 |
| Seascale (Filtrate) | 2 | <0.20 | <0.17 | <0.74 | <0.055 | <0.22 | <3.3 | <9.5 |
| St. Bees (Particulate)[e] | 1 | <0.02 | <0.02 | <0.09 | <0.00080 | <0.02 | 0.069 | 0.037 |
| St. Bees (Filtrate) | 2 | <0.17 | <0.13 | <0.67 | <0.055 | <0.22 | <3.2 | 10 |
| Seafield | 2[S] | <0.10 | <0.10 | <0.32 | | <0.10 | | |
| Southerness | 2[S] | <0.10 | <0.10 | <0.27 | | <0.11 | | |
| Auchencairn | 2[S] | <0.10 | <0.10 | <0.41 | | <0.13 | | |
| Port Patrick | 2[S] | <0.10 | <0.10 | <0.21 | | <0.10 | | |
| Hunterston[f] | 2[S] | <0.10 | <0.10 | <0.27 | | <0.10 | | |
| North of Larne | 12[N] | * | 0.008 | | | | | |
| Faslane (Carnban) | 2[S] | <0.10 | <0.10 | <0.32 | | <0.10 | | |

* *Not detected by the method used*

[a] *The concentration of $^{35}$S was 0.50 Bq $l^{-1}$*

[b] *The concentration of $^{35}$S was <1.0 Bq $l^{-1}$*

[c] *The concentration of $^{3}$H as tritiated water was <12 Bq $l^{-1}$*

[d] *The concentrations of $^{238}$Pu, $^{239/40}$Pu and $^{241}$Pu were 0.016, 0.086 and 0.57 Bq $l^{-1}$ respectively*

[e] *The concentrations of $^{238}$Pu, $^{239/40}$Pu and $^{241}$Pu were 0.0018, 0.011 and <0.11 Bq $l^{-1}$ respectively*

[f] *The concentration of $^{35}$S was 0.50 Bq $l^{-1}$*

*Results are made on behalf of the Environment Agency unless indicated otherwise*

[F] *Measurements labelled "F" are made on behalf of the Food Standards Agency and the Channel Islands States*

[N] *Measurements labelled "N" are made on behalf of the Northern Ireland Environment Agency*

[S] *Measurements labelled "S" are made on behalf of the Scottish Environment Protection Agency*

**Table 8.12 Concentrations of radionuclides in marine sediments and seawater - background survey in Scotland, 2016[a]**

| Sample location and type | Sample source | No. of sampling observ-ations | Mean radioactivity concentration, Bq kg$^{-1}$ (dry)[b] | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $^{3}$H | $^{60}$Co | $^{95}$Nb | $^{110}$Ag | $^{125}$Sb | $^{137}$Cs | $^{155}$Eu | $^{241}$Am | Gross alpha | Gross beta |
| **Marine Sediments** | | | | | | | | | | | | |
| Forth Estuary | Port Edgar | 1 | <5.0 | <0.10 | 0.57 | <0.10 | 0.25 | 14 | 2.0 | 1.8 | 210 | 1700 |
| Forth Estuary | Swing Bridge | 1 | <5.0 | <0.10 | <2.6 | <0.17 | <0.22 | 3.6 | 1.1 | <0.30 | 130 | 950 |
| Forth Estuary | Dunmore | 1 | <5.0 | <0.17 | <5.4 | <0.39 | <0.50 | 16 | 2.0 | 2.0 | 220 | 1800 |
| Forth Estuary | South Alloa | 1 | <5.0 | <0.10 | 0.36 | <0.11 | <0.10 | 18 | 2.8 | 1.2 | 210 | 1900 |
| Inner Clyde | Partick | 1 | <5.0 | <0.10 | 0.54 | <0.10 | <0.16 | 44 | 2.7 | 2.0 | 240 | 1400 |
| Cart River | Paisley | 1 | <5.0 | <0.10 | 0.22 | <0.10 | <0.11 | 29 | 1.9 | 0.40 | 200 | 1000 |
| **Seawater** | | | | | | | | | | | | |
| Forth Estuary | Port Edgar | 1 | <1.0 | <0.10 | <0.34 | <5.1 | <0.14 | <0.10 | <0.14 | <0.10 | | |
| Forth Estuary | Swing Bridge | 1 | <1.0 | <0.10 | <0.14 | <2.1 | <0.10 | <0.10 | <0.10 | <0.10 | | |
| Forth Estuary | Airth | 1 | <1.0 | <0.10 | <0.15 | <6.1 | <0.10 | <0.10 | <0.10 | <0.10 | | |
| Forth Estuary | Dunmore | 1 | <1.0 | <0.10 | <0.14 | <4.1 | <0.10 | <0.10 | <0.10 | <0.10 | | |
| Forth Estuary | South Alloa | 1 | <1.0 | <0.10 | <0.23 | <3.1 | <0.11 | <0.10 | <0.10 | <0.10 | | |
| Inner Clyde | Partick | 1 | 1.1 | <0.10 | <0.71 | <0.10 | <0.17 | <0.10 | <0.14 | <0.10 | | |
| Cart River | Paisley | 1 | <1.0 | <0.10 | <0.58 | <1.1 | <0.14 | <0.10 | <0.12 | <0.10 | | |

[a] *Results are available for other radionuclides detected by gamma spectrometry, All such results are less than the limit of detection*

[b] *Except for seawater where units are Bq l$^{-1}$*

# 9. References

**(Includes references from Appendix 1: CD supplement; sorted in order of first author and then date)**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# APPENDIX 1. Sampling, measurement, presentation and assessment methods and data

This Appendix contains information on the methods of sampling, measurement, presentation and assessment used in the Radioactivity in Food and the Environment report. It is provided in a separate file to the main report at **www.gov.uk/government/publications/radioactivity-in-food-and-the-environment-2016-rife-22**

# APPENDIX 2. Disposals of radioactive waste*

**Table A2.1 Principal discharges of gaseous radioactive wastes from nuclear establishments in the United Kingdom, 2016**

| Establishment | Radioactivity | Discharge limit (annual equivalent)[a], Bq | Discharges during 2016 | |
|---|---|---|---|---|
| | | | Bq | % of annual limit[b] |
| **Nuclear fuel production and reprocessing** | | | | |
| Capenhurst (CNS Ltd) | Alpha | BAT | 1.71E+05 | NA |
| Other authorised outlets | Beta | BAT | 8.32E+05 | NA |
| Capenhurst | Uranium | 7.50E+06 | 6.30E+05 | 8.4 |
| (Urenco UK Ltd) | Other alpha | 2.40E+06 | Nil | Nil |
| | Technetium-99 | 1.00E+08 | Nil | Nil |
| | Others | 2.25E+09 | Nil | Nil |
| | Alpha (Incinerator) | 2.00E+08 | Nil | Nil |
| | Beta (Incinerator) | 2.50E+08 | Nil | Nil |
| Sellafield[c] | Alpha | 8.80E+08 | 1.10E+08 | 13 |
| | Beta | 4.20E+10 | 1.20E+09 | 3 |
| | Tritium | 1.10E+15 | 1.23E+14 | 11 |
| | Carbon-14 | 3.30E+12 | 4.42E+11 | 13 |
| | Krypton-85 | 4.40E+17 | 8.75E+16 | 20 |
| | Strontium-90 | 7.10E+08 | 2.95E+07 | 4.2 |
| | Ruthenium-106 | 2.30E+10 | 7.02E+08 | 3.1 |
| | Antimony-125 | 3.00E+10 | 1.01E+10 | 34 |
| | Iodine-129 | 7.00E+10 | 1.30E+10 | 19 |
| | Iodine-131 | 3.70E+10 | 4.23E+08 | 1.1 |
| | Caesium-137 | 5.80E+09 | 1.02E+08 | 1.8 |
| | Radon-222 | 5.00E+11 | 4.26E+10 | 8.5 |
| | Plutonium alpha | 1.90E+08 | 1.54E+07 | 8.1 |
| | Plutonium-241 | 3.00E+09 | 1.47E+08 | 4.9 |
| | Americium-241 and curium-242 | 1.20E+08 | 1.36E+07 | 11 |
| Springfields | Uranium | 5.30E+09 | 2.52E+07 | <1 |
| Springfields | Tritium | 1.00E+08 | 8.40E+05 | <1 |
| (National Nuclear Laboratory) | Carbon-14 | 1.00E+07 | 1.98E+04 | <1 |
| | Other alpha radionuclides | 1.00E+06 | Nil | Nil |
| | Other beta radionuclides | 1.00E+07 | 5.91E+03 | <1 |
| **Research establishments** | | | | |
| Dounreay[d] | Alpha[e] | 3.10E+07 | 6.93E+06 | 22 |
| | Non-alpha[f] | 1.70E+09 | 1.12E+08 | 6.6 |
| | Tritium | 1.72E+13 | 4.40E+10 | <1 |
| | Krypton-85[g] | 5.69E+14 | 7.20E+08 | <1 |
| | Iodine-129 | 1.08E+08 | 2.27E+07 | 21 |

**Table A2.1 continued**

| Establishment | Radioactivity | Discharge limit (annual equivalent)[a], Bq | Discharges during 2016 | |
|---|---|---|---|---|
| | | | Bq | % of annual limit[b] |
| Harwell | Alpha | 8.00E+05 | 3.00E+04 | 3.8 |
| (Research Sites Restoration Ltd) | Beta | 2.00E+07 | 6.70E+05 | 3.4 |
| | Tritium | 1.50E+13 | 2.70E+11 | 1.8 |
| | Krypton-85 | 2.00E+12 | Nil | Nil |
| | Radon-220 | 1.00E+14 | 5.20E+12 | 5.2 |
| | Radon-222 | 3.00E+12 | 2.60E+11 | 8.7 |
| | Iodines | 1.00E+10 | Nil | Nil |
| | Other radionuclides | 1.00E+11 | Nil | Nil |
| Winfrith | Alpha | 1.00E+05 | Nil | Nil |
| (Inutec) | Tritium | 1.95E+13 | 1.04E+12 | 5.4 |
| | Carbon-14 | 3.00E+10 | Nil | Nil |
| | Other | 1.00E+05 | Nil | Nil |
| Winfrith | Alpha | 2.00E+06 | 1.21E+03 | <1 |
| (Research Sites Restoration Ltd) | Tritium | 4.95E+13 | 2.20E+11 | <1 |
| | Carbon-14 | 5.90E+09 | 1.93E+08 | 3.3 |
| | Other | 5.00E+06 | 2.29E+04 | <1 |
| **Minor sites** | | | | |
| Imperial College Reactor Centre | Tritium | 3.00E+08 | 4.75E+06 | 1.6 |
| Ascot | Argon-41 | 1.70E+12 | Nil | Nil |
| **Nuclear power stations** | | | | |
| Berkeley[h] | Beta | 2.00E+07 | 2.23E+05 | 1.1 |
| | Tritium | 2.00E+10 | 1.11E+10 | 56 |
| | Carbon-14 | 5.00E+09 | 1.81E+09 | 36 |
| Bradwell | Beta | 6.00E+08 | 5.17E+05 | <1 |
| | Tritium | 6.00E+12 | 9.39E+11 | 16 |
| | Carbon-14 | 9.00E+11 | 3.03E+10 | 3.4 |
| Chapelcross | Tritium | 7.50E+14 | 2.96E+13 | 3.9 |
| | All other nuclides | 2.50E+09 | 9.52E+08 | 38 |
| Dungeness | Beta[i] | 5.00E+08 | 2.67E+06 | <1 |
| A Station | Tritium | 2.60E+12 | 8.32E+09 | <1 |
| | Carbon-14 | 5.00E+12 | 2.84E+08 | <1 |
| Dungeness | Tritium | 1.20E+13 | 1.98E+12 | 17 |
| B Station | Carbon-14 | 3.70E+12 | 1.01E+12 | 27 |
| | Sulphur-35 | 3.00E+11 | 6.93E+10 | 23 |
| | Argon-41 | 7.50E+13 | 1.35E+13 | 18 |
| | Cobalt-60[i] | 1.00E+08 | 2.98E+06 | 3.0 |
| | Iodine-131 | 1.50E+09 | 2.51E+07 | 1.7 |
| Hartlepool | Tritium | 1.00E+13 | 7.67E+11 | 7.7 |
| | Carbon-14 | 4.50E+12 | 1.66E+12 | 37 |
| | Sulphur-35 | 2.30E+11 | 2.50E+10 | 11 |
| | Argon-41 | 1.50E+14 | 8.18E+12 | 5.5 |
| | Cobalt-60[i] | 1.00E+08 | 2.07E+07 | 21 |
| | Iodine-131 | 1.50E+09 | 1.46E+08 | 9.7 |

**Table A2.1 continued**

| Establishment | Radioactivity | Discharge limit (annual equivalent)[a], Bq | Discharges during 2016 | |
|---|---|---|---|---|
| | | | Bq | % of annual limit[b] |
| Heysham | Tritium | 1.00E+13 | 9.80E+11 | 9.8 |
| Station 1 | Carbon-14 | 4.50E+12 | 1.93E+12 | 43 |
| | Sulphur-35 | 2.00E+11 | 5.00E+10 | 25 |
| | Argon-41 | 1.50E+14 | 5.39E+12 | 3.6 |
| | Cobalt-60[i] | 1.00E+08 | 6.51E+06 | 6.5 |
| | Iodine-131 | 1.50E+09 | 7.03E+07 | 4.7 |
| Heysham | Tritium | 1.00E+13 | 1.32E+12 | 13 |
| Station 2 | Carbon-14 | 3.70E+12 | 1.83E+12 | 49 |
| | Sulphur-35 | 2.30E+11 | 1.12E+10 | 4.9 |
| | Argon-41 | 7.50E+13 | 9.32E+12 | 12 |
| | Cobalt-60[i] | 1.00E+08 | 9.31E+06 | 9.3 |
| | Iodine-131 | 1.50E+09 | 7.33E+07 | 4.9 |
| Hinkley Point | Beta | 5.00E+07 | 3.20E+05 | <1 |
| A Station | Tritium | 7.50E+11 | 1.30E+10 | 1.7 |
| | Carbon-14 | 5.00E+10 | 3.80E+08 | <1 |
| Hinkley Point | Tritium | 1.20E+13 | 1.34E+12 | 11 |
| B Station | Carbon-14 | 3.70E+12 | 1.38E+12 | 37 |
| | Sulphur-35 | 3.50E+11 | 7.14E+10 | 20 |
| | Argon-41 | 1.00E+14 | 1.19E+13 | 12 |
| | Cobalt-60[i] | 1.00E+08 | 8.49E+06 | 8.5 |
| | Iodine-131 | 1.50E+09 | 4.82E+06 | <1 |
| Hunterston | Tritium | 2.00E+10 | 7.10E+08 | 3.6 |
| A Station | Carbon-14 | 2.00E+09 | 5.64E+07 | 2.8 |
| | All other radionuclides | 3.00E+06 | 9.78E+05 | 33 |
| Hunterston | Particulate beta | 5.00E+08 | 6.82E+07 | 14 |
| B Station[d] | Tritium | 1.50E+13 | 1.85E+12 | 12 |
| | Carbon-14 | 4.50E+12 | 1.47E+12 | 33 |
| | Sulphur-35 | 5.00E+11 | 8.49E+10 | 17 |
| | Argon-41 | 1.50E+14 | 1.13E+13 | 7.5 |
| | Iodine-131 | 2.00E+09 | 3.78E+06 | <1 |
| Oldbury | Beta | 1.00E+08 | 2.50E+05 | <1 |
| | Tritium | 9.00E+12 | 3.44E+10 | <1 |
| | Carbon-14 | 4.00E+12 | 7.20E+08 | <1 |
| Sizewell | Beta | NA | Nil | Nil |
| A Station | Tritium | 3.50E+12 | 1.60E+10 | <1 |
| | Carbon-14 | 1.00E+11 | 8.30E+08 | <1 |
| Sizewell | Noble gases | 3.00E+13 | 3.05E+12 | 10 |
| B Station | Particulate Beta | 1.00E+08 | 1.00E+07 | 10 |
| | Tritium | 3.00E+12 | 5.99E+11 | 20 |
| | Carbon-14 | 5.00E+11 | 2.31E+11 | 46 |
| | Iodine-131 | 5.00E+08 | 1.50E+07 | 3.0 |
| Torness | Particulate beta | 4.00E+08 | 1.86E+07 | 4.7 |
| | Tritium | 1.10E+13 | 1.19E+12 | 11 |
| | Carbon-14 | 4.50E+12 | 1.32E+12 | 29 |
| | Sulphur-35 | 3.00E+11 | 5.41E+10 | 18 |
| | Argon-41 | 7.50E+13 | 6.99E+12 | 9.3 |
| | Iodine-131 | 2.00E+09 | 5.97E+06 | <1 |

**Table A2.1 continued**

| Establishment | Radioactivity | Discharge limit (annual equivalent)[a], Bq | Discharges during 2016 | |
|---|---|---|---|---|
| | | | Bq | % of annual limit[b] |
| Trawsfynydd | Particulate Beta | 5.00E+07 | 1.30E+06 | 2.6 |
| | Tritium | 3.75E+11 | 3.70E+10 | 9.9 |
| | Carbon-14 | 1.00E+10 | 1.00E+09 | 10 |
| Wylfa | Particulate Beta | 7.00E+08 | 5.60E+06 | <1 |
| | Tritium | 1.80E+13 | 8.80E+11 | 4.9 |
| | Carbon-14 | 2.30E+12 | 1.04E+11 | 4.5 |
| | Sulphur-35 | 4.50E+11 | 3.22E+09 | <1 |
| | Argon-41[1] | 1.00E+14 | Nil | Nil |
| **Defence establishments** | | | | |
| Aldermaston[j] | Alpha | 1.65E+05 | 2.62E+04 | 16 |
| | Particulate Beta | 6.00E+05 | 6.96E+03 | 1.2 |
| | Tritium | 3.90E+13 | 4.70E+11 | 1.2 |
| | Carbon-14 | 6.00E+06 | 6.50E+05 | 11 |
| | Activation products[k] | BAT | 3.69E+05 | NA |
| | Volatile beta | 4.40E+06 | 1.70E+05 | 3.9 |
| Barrow[l] | Tritium | 3.20E+06 | Nil | Nil |
| | Argon-41 | 4.80E+10 | Nil | Nil |
| Burghfield[j] | Tritium | 1.00E+10 | Nil | Nil |
| | Alpha | 5.00E+03 | 1.83E+03 | 37 |
| Coulport | Tritium | 5.00E+10 | 2.94E+09 | 5.9 |
| Derby[m] | Alpha[n] | 3.00E+06 | 5.65E+05 | 19 |
| | Alpha[o,p] | 2.40E+04 | 4.30E+01 | <1 |
| | Beta[o,p] | 1.80E+06 | 4.61E+04 | 2.6 |
| Devonport[q,2] | Beta/gamma[i] | 3.00E+05 | 1.14E+04 | 3.8 |
| | Tritium | 4.00E+09 | 5.40E+08 | 14 |
| | Carbon-14 | 6.60E+10 | 8.60E+08 | 1.3 |
| | Argon-41 | 1.50E+10 | 4.60E+06 | <1 |
| Dounreay[d] | Beta[i] | 5.10E+06 | 1.20E+06 | 24 |
| (Vulcan) | Noble gases | 5.00E+09 | 4.97E+08 | 10 |
| Rosyth[r] | Beta (particulate) | 1.00E+05 | Nil | Nil |
| (January to November 2016)[3] | Tritium | 2.00E+08 | Nil | Nil |
| | Carbon-14 | 5.00E+08 | Nil | Nil |
| Rosyth[r] | Tritium | 1.00E+07 | Nil | Nil |
| (December 2016)[3] | Carbon-14 | 5.00E+07 | Nil | Nil |
| | Other radionuclides | 1.00E+05 | Nil | Nil |
| **Radiochemical production** | | | | |
| Amersham (GE Healthcare) | Alpha | 2.25E+06 | 4.76E+04 | 2.1 |
| | Radionuclides T1/2<2hr | 7.50E+11 | 5.96E+09 | <1 |
| | Tritium | 2.00E+12 | 1.08E+06 | <1 |
| | Radon-222 | 1.00E+13 | 2.05E+12 | 21 |
| | Other including selenium-75 and iodine-131 | 1.60E+10 | 2.09E+07 | <1 |

**Table A2.1 continued**

| Establishment | Radioactivity | Discharge limit (annual equivalent)[a], Bq | Discharges during 2016 | |
|---|---|---|---|---|
| | | | Bq | % of annual limit[b] |
| Cardiff (GE Healthcare)[4] | Tritium | 6.00E+12 | 9.79E+11 | 16 |
| | Carbon-14 | 1.10E+12 | 1.31E+11 | 12 |
| | | | | |
| **Industrial and landfill sites** | | | | |
| LLWR | Alpha | BAT | 7.63E+03 | NA |
| | Beta | BAT | 6.33E+04 | NA |
| Lillyhall (Cyclife UK Limited)[5] | Alpha (particulate) | 5.00E+05 | 3.92E+03 | <1 |
| | Beta (particulate) | 5.00E+05 | 1.42E+04 | 2.8 |

* *As reported to SEPA and the Environment Agency*
[a] *In some cases permits specify limits in greater detail than can be summarised in a single table; in particular, periods shorter than one year are specified at some sites*
[b] *Data quoted to 2 significant figures except where values are <1%*
[c] *Limits for tritium, carbon-14, krypton-85 and iodine-129 vary with the mass of uranium processed by THORP*
[d] *Some discharges are upper estimates because they include 'less than' data derived from analyses of effluents at limits of detection*
[e] *All alpha emitting nuclides taken together*
[f] *All non-alpha emitting radion nuclides, not specifically listed, taken together*
[g] *Krypton-85 discharges are calculated*
[h] *Combined data for Berkeley Power Station and Berkeley Centre*
[i] *Particulate activity*
[j] *Discharges were made by AWE plc*
[k] *Argon-41 is reported under the Activation products total and the limit is the demonstration of Best Available Technique*
[l] *Discharges from Barrow are included with those from MoD sites because they are related to submarine activities. Discharges were made by BAE Systems Marine Ltd*
[m] *Discharges were made by Rolls Royce Marine Power Operations Ltd*
[n] *Discharge limit is for the Nuclear Fuel Production Plant Site*
[o] *Annual limits on beta and alpha derived from monthly and weekly notification levels*
[p] *Discharge limit is for the Neptune Reactor Raynesway Site*
[q] *Discharges were made by Devonport Royal Dockyard Ltd*
[r] *Discharges were made by Rosyth Royal Dockyard Ltd*
[1] *Reactors shutdown in 2015, Argon-41 no longer reported*
[2] *Discharge permit revised September 2016. The limit for Carbon-14 was revised*
[3] *Discharge authorisation revised with effect 1 December 2016*
[4] *Discharge permit revised with effect 1 June 2015*
[5] *Formerly Studsvik UK Limited*
*NA Not applicable under permit*
*BAT Best available technology*

**Table A2.2 Principal discharges of liquid radioactive waste from nuclear establishments in the United Kingdom, 2016**

| Establishment | Radioactivity | Discharge limit (annual equivalent)[a], Bq | Discharges during 2016 | |
|---|---|---|---|---|
| | | | Bq | % of annual limit[b] |
| **Nuclear fuel production and reprocessing** | | | | |
| Capenhurst | Uranium | 7.50E+08 | 3.65E+06 | <1 |
| (Urenco UK Ltd) | Uranium daughters | 1.36E+09 | 7.49E+06 | <1 |
| | Non-uranic alpha | 2.20E+08 | 8.73E+06 | 4.0 |
| | Technetium-99 | 1.00E+09 | 4.62E+06 | <1 |
| Sellafield[c,1] | Alpha | 9.00E+11 | 2.53E+11 | 28 |
| | Beta[2] | 1.80E+14 | 1.30E+13 | 7.2 |
| | Tritium | 1.80E+16 | 2.05E+15 | 11 |
| | Carbon-14 | 2.10E+13 | 4.83E+12 | 23 |
| | Cobalt-60 | 3.60E+12 | 3.53E+10 | <1 |
| | Strontium-90 | 4.50E+13 | 2.01E+12 | 4.5 |
| | Zirconium-95 + Niobium-95 | 2.80E+12 | 9.43E+10 | 3.4 |
| | Technetium-99 | 1.00E+13 | 1.90E+12 | 19 |
| | Ruthenium-106 | 5.10E+13 | 1.09E+12 | 2.1 |
| | Iodine-129 | 2.00E+12 | 5.22E+11 | 26 |
| | Caesium-134 | 1.60E+12 | 6.56E+10 | 4.1 |
| | Caesium-137 | 3.40E+13 | 3.72E+12 | 11 |
| | Cerium-144 | 4.00E+12 | 2.13E+11 | 5.3 |
| | Neptunium-237 | 7.30E+11 | 3.14E+10 | 4.3 |
| | Plutonium alpha | 7.00E+11 | 1.79E+11 | 26 |
| | Plutonium-241 | 2.50E+13 | 2.99E+12 | 12 |
| | Americium-241 | 3.00E+11 | 2.58E+10 | 8.6 |
| | Curium-243+244 | 5.00E+10 | 2.96E+09 | 5.9 |
| | Uranium (in kg)[d] | 2.00E+03 | 3.42E+02 | 17 |
| Springfields | Alpha | 1.00E+11 | 1.50E+10 | 15 |
| | Beta | 2.00E+13 | 1.71E+12 | 8.6 |
| | Technetium-99 | 6.00E+11 | 2.66E+10 | 4.4 |
| | Thorium-230 | 2.00E+10 | 1.45E+09 | 7.3 |
| | Thorium-232 | 1.50E+10 | 1.52E+08 | 1.0 |
| | Neptunium-237 | 4.00E+10 | 3.70E+08 | <1 |
| | Other transuranic radionuclides | 2.00E+10 | 2.01E+09 | 10 |
| | Uranium | 4.00E+10 | 1.08E+10 | 27 |
| **Research establishments** | | | | |
| Dounreay[e] | Alpha[f] | 3.40E+09 | 1.40E+08 | 4.1 |
| | Non-alpha[g] | 4.80E+10 | 1.26E+09 | 2.6 |
| | Tritium | 6.90E+12 | 8.55E+10 | 1.2 |
| | Strontium-90 | 1.77E+11 | 2.40E+10 | 14 |
| | Caesium-137 | 6.29E+11 | 2.57E+09 | <1 |
| Harwell (Lydebank Brook) | Alpha | 3.00E+07 | 4.60E+06 | 15 |
| | Beta | 3.00E+08 | 8.96E+06 | 3.0 |
| | Tritium | 2.00E+10 | 1.02E+09 | 5.1 |
| Harwell (sewer) | Alpha | 1.00E+07 | 9.00E+03 | <1 |
| | Beta | 6.00E+08 | 9.90E+04 | <1 |
| | Tritium | 1.00E+11 | 7.60E+07 | <1 |
| | Cobalt-60 | 5.00E+06 | 3.90E+04 | <1 |
| | Caesium-137 | 2.00E+08 | 1.05E+05 | <1 |

**Table A2.2 continued**

| Establishment | Radioactivity | Discharge limit (annual equivalent)[a], Bq | Discharges during 2016 | |
|---|---|---|---|---|
| | | | Bq | % of annual limit[b] |
| Winfrith (inner pipeline)[h] | Alpha | 2.00E+10 | 6.87E+06 | <1 |
| | Tritium | 2.20E+14 | 1.42E+13 | 6.5 |
| | Caesium-137 | 2.00E+12 | 1.12E+09 | <1 |
| | Other radionuclides | 1.00E+12 | 9.39E+08 | <1 |
| Winfrith (outer pipeline) | Alpha | 2.00E+09 | 2.41E+06 | <1 |
| | Tritium | 1.50E+11 | 9.72E+08 | <1 |
| | Other radionuclides | 1.00E+09 | 7.87E+06 | <1 |
| Winfrith (River Frome) | Tritium | 7.50E+11 | Nil | Nil |
| **Minor sites** | | | | |
| Imperial College Reactor Centre | Tritium | 4.00E+07 | Nil | Nil |
| Ascot | Other radioactivity | 1.00E+07 | Nil | Nil |
| **Nuclear power stations** | | | | |
| Berkeley | Tritium | 1.00E+12 | 4.77E+07 | <1 |
| | Caesium-137 | 2.00E+11 | 2.64E+08 | <1 |
| | Other radionuclides | 2.00E+11 | 6.36E+07 | <1 |
| Bradwell | Tritium | 7.00E+12 | 2.48E+11 | 3.5 |
| | Caesium-137 | 7.00E+11 | 2.00E+08 | <1 |
| | Other radionuclides | 7.00E+11 | 9.30E+09 | 1.3 |
| Chapelcross | Alpha | 1.00E+09 | 4.86E+03 | <1 |
| | Non-alpha[i] | 1.00E+12 | 1.02E+04 | <1 |
| | Tritium | 6.50E+12 | 4.86E+03 | <1 |
| Dungeness A Station | Tritium | 8.00E+12 | 1.30E+10 | <1 |
| | Caesium-137 | 1.10E+12 | 7.18E+09 | <1 |
| | Other radionuclides | 8.00E+11 | 4.93E+09 | <1 |
| Dungeness B Station | Tritium | 6.50E+14 | 3.06E+14 | 47 |
| | Sulphur-35 | 2.00E+12 | 5.46E+11 | 27 |
| | Cobalt-60 | 1.00E+10 | 8.67E+08 | 8.7 |
| | Caesium-137 | 1.00E+11 | 1.15E+09 | 1.2 |
| | Other radionuclides | 8.00E+10 | 3.55E+09 | 4.4 |
| Hartlepool | Tritium | 6.50E+14 | 3.59E+14 | 55 |
| | Sulphur-35 | 3.00E+12 | 1.50E+12 | 50 |
| | Cobalt-60 | 1.00E+10 | 1.26E+08 | 1.3 |
| | Caesium-137 | 1.00E+11 | 1.93E+09 | 1.9 |
| | Other radionuclides | 8.00E+10 | 4.54E+08 | <1 |
| Heysham Station 1 | Tritium | 6.50E+14 | 4.00E+14 | 62 |
| | Sulphur-35 | 2.00E+12 | 1.12E+12 | 56 |
| | Cobalt-60 | 1.00E+10 | 1.57E+08 | 1.6 |
| | Caesium-137 | 1.00E+11 | 2.15E+09 | 2.2 |
| | Other radionuclides | 8.00E+10 | 3.59E+09 | 4.4 |

**Table A2.2 continued**

| Establishment | Radioactivity | Discharge limit (annual equivalent)[a], Bq | Discharges during 2016 | |
|---|---|---|---|---|
| | | | Bq | % of annual limit[b] |
| Heysham | Tritium | 6.50E+14 | 3.65E+14 | 56 |
| Station 2 | Sulphur-35 | 2.00E+12 | 6.79E+10 | 3.4 |
| | Cobalt-60 | 1.00E+10 | 9.99E+07 | <1 |
| | Caesium-137 | 1.00E+11 | 1.02E+09 | 1.0 |
| | Other radionuclides | 8.00E+10 | 1.28E+10 | 16 |
| | | | | |
| Hinkley Point | Tritium | 1.00E+12 | 1.52E+09 | <1 |
| A Station | Caesium-137 | 1.00E+12 | 3.08E+09 | <1 |
| | Other radionuclides | 7.00E+11 | 2.44E+10 | 3.5 |
| | | | | |
| Hinkley Point | Tritium | 6.50E+14 | 2.39E+14 | 37 |
| B Station | Sulphur-35 | 2.00E+12 | 2.60E+11 | 13 |
| | Cobalt-60 | 1.00E+10 | 1.16E+08 | 1.2 |
| | Caesium-137 | 1.00E+11 | 1.21E+09 | 1.2 |
| | Other radionuclides | 8.00E+10 | 3.70E+09 | 4.6 |
| | | | | |
| Hunterston | Alpha | 2.00E+09 | 6.39E+08 | 32 |
| A Station | All other non-alpha | 6.00E+10 | 1.56E+09 | 2.6 |
| | Tritium | 3.00E+10 | 4.59E+08 | 1.5 |
| | Caesium-137 | 1.60E+11 | 3.09E+08 | <1 |
| | Plutonium-241 | 2.00E+09 | 2.29E+08 | 11 |
| | | | | |
| Hunterston | Alpha | 1.00E+09 | 2.32E+07 | 2.3 |
| B Station | All other non-alpha | 1.50E+11 | 9.87E+09 | 6.6 |
| | Tritium | 7.00E+14 | 2.48E+14 | 35 |
| | Sulphur-35 | 6.00E+12 | 7.20E+11 | 12 |
| | Cobalt-60 | 1.00E+10 | 4.80E+08 | 4.8 |
| | | | | |
| Oldbury | Tritium | 1.00E+12 | 1.57E+11 | 16 |
| | Caesium-137 | 7.00E+11 | 1.66E+11 | 24 |
| | Other radionuclides | 7.00E+11 | 3.48E+10 | 5.0 |
| | | | | |
| Sizewell | Tritium | 5.00E+12 | 1.24E+10 | <1 |
| A Station | Caesium-137 | 1.00E+12 | 4.19E+10 | 4.2 |
| | Other radionuclides | 7.00E+11 | 5.72E+10 | 8.2 |
| | | | | |
| Sizewell | Tritium | 8.00E+13 | 2.21E+13 | 28 |
| B Station | Caesium-137 | 2.00E+10 | 3.47E+08 | 1.7 |
| | Other radionuclides | 1.30E+11 | 4.51E+09 | 3.5 |
| | | | | |
| Torness | Alpha | 5.00E+08 | 9.16E+05 | <1 |
| | All other non-alpha | 1.50E+11 | 1.60E+09 | 1.1 |
| | Tritium | 7.00E+14 | 2.91E+14 | 42 |
| | Sulphur-35 | 3.00E+12 | 1.02E+12 | 34 |
| | Cobalt-60 | 1.00E+10 | 1.24E+08 | 1.2 |
| | | | | |
| Trawsfynydd | Tritium | 3.00E+11 | 1.30E+09 | <1 |
| | Caesium-137 | 1.50E+10 | 3.00E+08 | 2.0 |
| | Other radionuclides[j] | 3.00E+10 | 7.00E+08 | 2.3 |
| | | | | |
| Wylfa | Tritium | 1.50E+13 | 1.17E+11 | <1 |
| | Other radionuclides | 1.10E+11 | 3.37E+09 | 3.1 |

**Table A2.2 continued**

| Establishment | Radioactivity | Discharge limit (annual equivalent)[a], Bq | Discharges during 2016 | |
|---|---|---|---|---|
| | | | Bq | % of annual limit[b] |
| **Defence establishments** | | | | |
| Aldermaston (Silchester)[k] | Alpha | 1.00E+07 | 1.77E+06 | 18 |
| | Other beta emitting radionuclides | 2.00E+07 | 2.35E+06 | 12 |
| | Tritium | 2.50E+10 | 1.10E+08 | <1 |
| Aldermaston (to Stream)[k, l] | Tritium | NA | 3.40E+08 | NA |
| Barrow[m] | Tritium | 1.20E+10 | 9.82E+05 | <1 |
| | Carbon-14 | 2.70E+07 | 2.21E+05 | <1 |
| | Other gamma emitting radionuclides | 3.50E+06 | 3.48E+03 | <1 |
| Derby[n] | Alpha[o] | 2.00E+09 | 6.86E+07 | 3.4 |
| | Alpha[p] | 3.00E+05 | 1.20E+04 | 4.0 |
| | Beta[p] | 3.00E+08 | 2.94E+06 | <1 |
| Devonport (sewer)[q] | Tritium | 2.00E+09 | 5.53E+07 | 2.8 |
| | Cobalt-60 | 3.50E+08 | 2.97E+06 | <1 |
| | Other radionuclides | 6.50E+08 | 8.82E+07 | 14 |
| Devonport (estuary)[q] | Tritium | 7.00E+11 | 1.80E+10 | 2.6 |
| | Carbon-14 | 1.70E+09 | 4.37E+07 | 2.6 |
| | Cobalt-60 | 8.00E+08 | 3.57E+07 | 4.5 |
| | Other radionuclides | 3.00E+08 | 1.16E+07 | 3.9 |
| Faslane | Alpha | 2.00E+08 | 6.60E+04 | <1 |
| | Beta[i,r] | 5.00E+08 | 6.60E+05 | <1 |
| | Tritium | 1.00E+12 | 1.10E+10 | 1.1 |
| | Cobalt-60 | 5.00E+08 | 3.30E+05 | <1 |
| Rosyth[s] (January to November 2016)[3] | Tritium | 3.00E+09 | 5.74E+07 | 1.9 |
| | Cobalt-60 | 3.00E+08 | 1.25E+06 | <1 |
| | Other radionuclides | 3.00E+08 | 1.02E+06 | <1 |
| Rosyth[s] (December 2016)[3] | Tritium | 3.00E+08 | Nil | Nil |
| | Cobalt-60 | 1.00E+08 | Nil | Nil |
| | Other radionuclides | 1.00E+08 | Nil | Nil |
| **Radiochemical production** | | | | |
| Amersham (GE Healthcare)[r] | Alpha | 3.00E+08 | 3.16E+06 | 1.1 |
| | Tritium | 1.41E+11 | 1.20E+06 | <1 |
| | Other radionuclides | 6.50E+10 | 1.89E+08 | <1 |
| **Industrial and landfill sites** | | | | |
| LLWR | Alpha | BAT | 7.68E+07 | NA |
| | Beta | BAT | 8.99E+08 | NA |
| | Tritium | BAT | 7.68E+10 | NA |
| Lillyhall (Cyclife UK Limited)[4] | Alpha | 5.00E+05 | 1.02E+03 | <1 |
| | Beta | 5.00E+05 | 1.00E+04 | 2.0 |

**Table A2.2 continued**

[a] *In some cases permits specify limits in greater detail than can be summarised in a single table; in particular, periods shorter than one year are specified at some sites*
[b] *Data quoted to 2 significant figures except when values are less than 1%*
[c] *Includes discharges made via the sea pipelines, factory sewer and Calder interceptor sewer*
[d] *The limit and discharge data are expressed in kg*
[e] *Some discharges are upper estimates because they include 'less than' data derived from analyses of effluents at limits of detection. Data quoted to 2 decimal places*
[f] *All alpha emitting radionuclides taken together*
[g] *All non-alpha emitting radion nuclides, not specifically listed, taken together*
[h] *Discharges reported include those from INUTEC*
[i] *Excluding tritium*
[j] *Including strontium*
[k] *Discharges were made by AWE plc*
[l] *The discharge limit has been replaced by an activity notification level of 30 Bq $l^{-1}$*
[m] *Discharges from Barrow are included with those from MOD sites because they are related to submarine activities. Discharges were made by BAE Systems Marine Ltd*
[n] *Discharges were made by Rolls Royce Marine Power Operations Ltd*
[o] *Discharge limit is for Nuclear Fuel Production Plant*
[p] *Discharge limit is for Neptune Reactor Raynesway Site*
[q] *Discharges were made by Devonport Royal Dockyard Ltd*
[r] *Excluding cobalt-60*
[s] *Discharges were made by Rosyth Royal Dockyard Ltd*
[1] *Discharge permit revised with effect 1 March 2015, limits for alpha, beta and tritium were revised*
[2] *The discharge permit was revised with effect from 1 December 2016; limit for beta was revised. The discharges for beta are reported for the whole calendar year, however strictly only the discharges from January to November 2016 are compared to the limit of 2.00E+14 Bq in this table. Discharges from 1 December 2016 are compared to the new limit of 1.80E+14 Bq*
[3] *Discharge authorisation revised with effect 1 December 2016*
[4] *Formerly Studsvik UK Limited*

*NA Not applicable under permit*
*BAT Best available technology*

## Table A2.3 Disposals and receipt with the intention of disposal of solid radioactive waste at nuclear establishments in the United Kingdom, Financial Year 2016/17

| Radionuclide or group of radionuclides | Total vault disposed[a] waste FY16/17 (Bq) | Cumulative total vault disposed[a] waste (Bq) |
|---|---|---|
| Tritium | 8.39E+11 | 2.66E+13 |
| Carbon-14 | 1.28E+10 | 4.61E+11 |
| Chlorine-36 | 9.24E+09 | 7.00E+11 |
| Calcium-41 | 3.33E+08 | 1.20E+10 |
| Selenium-79 | Nil | Nil |
| Molybdenum-93 | Nil | 1.40E+06 |
| Zironium-93 | Nil | 3.83E+10 |
| Niobium-84 | 1.02E+08 | 6.63E+09 |
| Technetium-99 | 1.44E+09 | 3.04E+12 |
| Silver-108m | 7.23E+08 | 5.68E+09 |
| Iodine-129 | 8.79E+06 | 3.31E+09 |
| Caesium-135 | 2.63E+07 | 5.14E+08 |
| Radium-226 | 4.43E+08 | 7.32E+10 |
| Thorium-229 | Nil | 5.29E+05 |
| Thorium-230 | 1.53E+05 | 7.04E+09 |
| Thorium-232 | 1.96E+07 | 3.57E+10 |
| Protactinium-231 | 7.17E+06 | 2.44E+09 |
| Uranium-233 | 3.30E+04 | 5.69E+10 |
| Uranium-234 | 4.83E+09 | 4.60E+11 |
| Uranium-235 | 1.31E+08 | 3.17E+10 |
| Uranium-236 | 6.18E+08 | 2.68E+10 |
| Uranium-238 | 4.13E+09 | 5.22E+11 |
| Neptunium-237 | 6.38E+07 | 4.29E+10 |
| Plutonium-238 | 5.31E+09 | 1.92E+11 |
| Plutonium-239 | 1.44E+10 | 4.91E+11 |
| Plutonium-240 | 1.39E+10 | 3.11E+11 |
| Plutonium-241 | 1.68E+11 | 9.60E+12 |
| Plutonium-242 | 5.45E+05 | 9.85E+08 |
| Americium-241 | 3.78E+10 | 1.33E+12 |
| Americium-242m | Nil | 5.87E+10 |
| Americium-243 | 4.41E+06 | 5.53E+08 |
| Curium-243 | 7.42E+06 | 3.30E+09 |
| Curium-244 | 3.53E+08 | 2.00E+10 |
| Curium-245 | 2.18E+05 | 5.19E+06 |
| Curium-246 | Nil | 1.87E+06 |
| Curium-248 | Nil | 4.98E+07 |
| OTHRT** | Nil | 4.81E+06 |
| PUALD** | Nil | 1.10E+11 |
| UALD** | Nil | 1.13E+10 |
| URRM** | 3.17E+09 | 2.35E+10 |
| Others* | 7.24E+11 | 6.37E+13 |

[a] *In this context, 'disposed' includes waste already disposed in Vault 8 and wastes accepted with the intention to dispose and currently in storage in Vault 8 & 9, pending disposal*

* *'Others' includes all radionuclides not listed above and radionuclides with 'no value' listed above, but excludes radionuclides of less than three months half-life.*

** *'OTHRT' is the sum of activity from radium and thorium isotopes other than Ra-226 and Th-232; 'PUALD', 'UALD' and 'URRM' represent plutonium and uranium, respectively, arising from defence-related activities.*

| Year | Actual receipt data[a] | | Projected data | |
|---|---|---|---|---|
| | Total vault disposed waste for financial year ($m^3$) | Cumulative (to financial year end) total vault disposed waste ($m^3$) | Total vault disposed waste for financial year ($m^3$) | Cumulative (to financial year end) total vault disposed waste ($m^3$) |
| 2015/16 | 3.32E+03 | 2.44E+05 | 1.94E+04 | 3.68E+05 |
| 2016/17 | 3.35E+03 | 2.47E+05 | 2.00E+04 | 3.88E+05 |

[a] *In this context, 'disposed' includes waste already disposed in Vault 8 and wastes accepted with the intention to dispose and currently in storage in Vault 8 & 9, pending disposal*

**Table A2.4 Solid waste transfers from nuclear establishments in Scotland, 2016***

| Establishment – transfer from | Volume $m^3$ | Alpha Bq | Beta/Gamma Bq |
|---|---|---|---|
| **Research establishments** | | | |
| Dounreay | 1.90E+03 | 1.68E+10 | 1.42E+11 |
| | | | |
| **Nuclear Power Stations** | | | |
| Chapelcross | Nil | Nil | Nil |
| Hunterston A | 2.03E+02 | 3.90E+08 | 6.51E+09 |
| Hunterston B | 3.72E+02 | 2.40E+07 | 3.81E+10 |
| Torness | 3.51E+01 | 1.20E+07 | 3.13E+11 |
| | | | |
| **Defence establishments** | | | |
| Coulport | Nil | Nil | Nil |
| Dounreay (Vulcan) | 7.20E+00 | Nil | 4.10E+08 |
| Faslane | 9.40E+00 | Nil | 3.00E+07 |
| Rosyth | 6.42E+01 | Nil | 9.60E+05 |

* *As reported by site operators to SEPA*

**Table A2.5 Summary of unintended leakages, spillages, emissions or unusual findings of radioactive substances from nuclear licensed sites in the UK in 2016**

| Site | Month/Year | Summary of incident | Consequences and action taken |
|---|---|---|---|
| Dounreay | July 2016 | DSRL notified SEPA of the identification of the release of unmonitored krypton-85 gaseous discharges through the authorised discharge outlet at the DFR facility. Although the presence of the DFR Reactor Gas Blanket (RGB) pressure balancing system was known to DSRL, DSRL failed to evaluate Krypton-85 discharges from the DFR RGB pressure balancing system and leakage from the reactor and failed to include these within the records for the krypton-85 discharges from the DFR facility. | SEPA sent a Final Warning Letter to DSRL in relation to the site's arrangements for the evaluation of krypton-85 discharges. Details of the revised reported discharges of krypton-85 from the DFR facility, which takes account of DSRL's estimate of the additional krypton-85 discharges from DFR, are provided in the RIFE 22 errata document. |
| Dounreay | July 2016 | DSRL reported to SEPA that bowing/distortion of a lid on a Half-Height ISO (HHISO) container had been noted during routine operations. | DSRL undertook an investigation which identified issues around an area of voidage/ullage between the top of the grouted waste mass and the HHISO container lid. As a result, SEPA requested from DSRL a review of its grouting practices, taking cognisance of national and international best practice and an assessment of the implications of the voidage in terms of settlement, stability and the mechanical loading on the container lids. While this programme of work is ongoing DSRL ceased all disposals to the LLW disposal facility. |
| Dounreay | September 2016 | DSRL notified SEPA of the identification of water ingress into the Wet Silo (ILW storage facility). The source of the water was identified and isolated by DSRL. | SEPA investigated the circumstances of DSRL's actions in response to the water ingress, DSRL's arrangements for the evaluation of the compliance implications of the event and the circumstances surrounding the maintenance of a pump at the wet silo facility. As a result, SEPA sent a Final Warning Letter to DSRL in relation to the site's arrangements for the management of the wet silo storage facility and its maintenance and inspection arrangements. |
| Cyclife MRF, Lillyhall | December 2016 | During the third quarter of 2016, elevated radiation dose was measured at the perimeter fence of the facility. A maximum dose of 1.35 mSv across the quarter was measured at the perimeter line. The elevated dose resulted from storage of waste in the vicinity of the perimeter fence.<br>When the operators became aware of the elevated dose rates, the containers were moved and the dose rate at the perimeter returned to normal. | The EA and Office of Nuclear Regulation (ONR) were notified in line with requirements.<br>The regulators undertook a joint inspection in February 2017.<br>A number of areas for improvement have been identified to control dose rates within the site and at the perimeter which ONR have communicated to Cyclife.<br>The actual and potential risk to employees and members of the public was assessed to be negligible. |
| Longannet | May 2017 | SEPA's Radioactive Substances Team were notified of a concern relating to a cloud of ash over Valleyfield in Fife. Scotland was, unusually, experiencing a prolonged spell of dry and hot weather, which was having an impact on ash lagoons from the recently disused Scottish Power coal fired power station at Longannet. | SEPA was involved in many aspects to the response; from regulatory action with the site to suppress ash resuspension to allow spraying water from the adjacent Firth of Forth; by participating in the Emergency Management Group to look at the overall health impact and by taking samples of ash from the lagoon. The Radioactive Substances Team were involved to respond to concerns raised by Health Protection Scotland on natural radioactivity within coal. The concentrations of natural radionuclides within coal are so low that they pose no realistic risk to human health and for that reason. SEPA formed the view that exposure to dust from the ash lagoon would have negligible effect on human health from the radionuclides present within the ash. SEPA undertook sampling and analysis of the ash in the lagoons. As expected radioactivity was detected in the samples of ash analysed, and these were at very low concentrations. SEPA served Scottish Power with two enforcement notices for the suppression of ash and dust from the lagoons. A fuller account of this incident, together with data from the radioactive analysis, will be published in RIFE 23. |

# APPENDIX 3. Abbreviations and glossary

| | |
|---|---|
| ABL | AWE plc, Babcock and Lockheed Martin UK |
| ABWR | Advanced Boiling Water Reactor |
| AGIR | Advisory Group on Ionising Radiation |
| AGR | Advanced Gas-cooled Reactor |
| AWE | Atomic Weapons Establishment |
| BAT | Best Available Techniques or Best Available Technology |
| BEIS | Department of Business, Energy and Industrial Strategy |
| BIP | Border Inspection Post |
| BNFL | British Nuclear Fuels plc |
| BPEO | Best Practicable Environmental Option |
| BPM | Best Practicable Means |
| BSS | Basic Safety Standards |
| CAR | Water Environment (Controlled Activities) (Scotland) Regulations 2011 |
| CCFE | Culham Centre for Fusion Energy |
| CEC | Commission of the European Communities |
| CEDA | Consultative Exercise on Dose Assessments |
| Cefas | Centre for Environment, Fisheries & Aquaculture Science |
| CNLS | Cardiff Nuclear Licensed Site |
| CNS | Capenhurst Nuclear Services Limited |
| COMARE | Committee on Medical Aspects of Radiation in the Environment |
| COS | Carbonyl Sulphide |
| CoRWM | Committee on Radioactive Waste Management |
| DECC | Department of Energy and Climate Change |
| DAERA | Department of Agriculture Environment and Rural Affairs |
| DEFA | Department of Environment, Food and Agriculture |
| Defra | Department for Environment, Food and Rural Affairs |
| DPE | Designated Port of Entry |
| DETR | Department of the Environment, Transport and the Regions |
| DH | Department of Health |
| DPAG | Dounreay Particles Advisory Group |
| DSRL | Dounreay Site Restoration Limited |
| DSTL | Defence Science and Technology Laboratory |
| Euratom | European Atomic Energy Community |
| EA | Environment Agency |
| EARP | Enhanced Actinide Removal Plant |
| EC | European Commission |
| EDF | Electricité de France |
| EIA | Environmental Impact Assessment |
| ENRMF | East Northants Resource Management Facility |
| EPR 10 | Environment Permitting (England and Wales) Regulations 2010 |
| EPR 16 | Environment Permitting (England and Wales) Regulations 2016 |
| ERICA | Environmental Risk from Ionising Contaminants: Assessment and Management |
| ESC | Environmental Safety Case |
| ESG | Environmental Scientifics Group |
| EU | European Union |
| FEPA | Food and Environment Protection Act |
| FSA | Food Standards Agency |
| FSS | Food Standards Scotland |
| GDA | Generic Design Assessment |
| GDF | Geological Disposal Facility |
| GDL | Generalised Derived Limit |
| GE | General Electric |
| GES | Good Environmental Status |
| GOCO | Government Owned Contractor Operator |
| HMIP | Her Majesty's Inspectorate of Pollution |
| HMNB | Her Majesty's Naval Base |
| HMSO | Her Majesty's Stationery Office |
| HPA | Health Protection Agency |
| HSE | Health & Safety Executive |
| IAEA | International Atomic Energy Agency |
| ICRP | International Commission on Radiological Protection |
| ID | Indicative Dose |
| IRPA | International Radiation Protection Association |
| ISO | International Standards Organisation |
| JET | Joint European Torus |
| LGC | Laboratory of the Government Chemist |
| LLLETP | Low Level Liquid Effluent Treatment Plant |
| LLW | Low Level Waste |
| LLWR | Low Level Waste Repository |
| LoD | Limit of Detection |
| MAC | Medium Active Concentrate |
| MAFF | Ministry of Agriculture, Fisheries & Food |
| MMO | Marine Management Organisation |
| MoD | Ministry of Defence |
| MRF | Metals Recycling Facility |
| MRL | Minimum Reporting Level |
| MRWS | Managing Radioactive Waste Safely |
| ND | Not Detected |
| NDA | Nuclear Decommissioning Authority |
| NDAWG | National Dose Assessment Working Group |
| NFPP | Nuclear Fuel Production Plant |
| NGS | National Geographic Survey |
| NIEA | Northern Ireland Environment Agency |
| NII | Nuclear Installations Inspectorate |
| NMP | Nuclear Management Partners Limited |
| NNB Genco | NNB Generation Company Limited |
| NORM | Naturally Occurring Radioactive Material |
| NRPB | National Radiological Protection Board |
| NRW | Natural Resources Wales |
| NPS | National Policy Statement |
| NRTE | Naval Reactor Test Establishment |
| OBT | Organically Bound Tritium |

| | |
|---|---|
| OECD | Organisation for Economic Co-operation and Development |
| OMAD | Old Main Active Drain |
| ONR | Office for Nuclear Regulation |
| OSPAR | Oslo and Paris Convention |
| PBO | Parent Body Organisation |
| PRAG (D) | Particles Retrieval Advisory Group (Dounreay) |
| PHE | Public Health England |
| PWR | Pressurised Water Reactor |
| RAPs | Reference Animals and Plants |
| REP | RSR Environmental Principle |
| RIFE | Radioactivity in Food and the Environment |
| RRDL | Rosyth Royal Dockyard Limited |
| RRMPOL | Rolls-Royce Marine Power Operations Limited |
| RNAS | Royal Naval Air Station |
| RSA 93 | Radioactive Substances Act 1993 |
| RSR | Radioactive Substances Regulation |
| RSRL | Research Sites Restoration Limited |
| RSS | Radioactive Substances Strategy |
| SEPA | Scottish Environment Protection Agency |
| SFL | Springfields Fuels Limited |
| SIXEP | Site Ion Exchange Plant |
| SLC | Site Licence Company |
| SRP | Society for Radiological Protection |
| STW | Sewage Treatment Works |
| THORP | Thermal Oxide Reprocessing Plant |
| TNORM | Technologically enhanced Naturally Occurring Radioactive Material |
| TRAMP | Terrestrial Radioactive Monitoring Programme |
| UCP | Urenco ChemPlants Limited |
| UKAEA | United Kingdom Atomic Energy Authority |
| UKNWM | UK Nuclear Waste Management Limited |
| UOC | Uranium Ore Concentrate |
| UUK | Urenco UK Limited |
| VLLW | Very Low Level Waste |
| WFD | Water Framework Directive |
| WHO | World Health Organisation |
| WWTW | Waste Water Treatment Works |
| YP | Ystradyfodwg and Pontypridd |

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| Absorbed dose | The ionising radiation energy absorbed in a material per unit mass. The unit for absorbed dose is the gray (Gy) which is equivalent to J $kg^{-1}$. |
| Authorised Premises | This is a premises that has been authorised by the environment agencies to discharge to the environment. |
| Becquerel | One radioactive transformation per second. |
| Bioaccumulation | Excretion may occur, however the rate of excretion is less than the rate of intake + accumulation. |
| Biota | Flora and fauna. |
| Committed effective dose | The sum of the committed equivalent doses for all organs and tissues in the body resulting from an intake (of a radionuclide), having been weighted by their tissue weighting factors. The unit of committed effective dose is the sievert (Sv). The 'committed' refers to the fact that the dose is received over a number of years but it is accounted for in the year of the intake of the activity. |
| Direct shine | Ionising radiation which arises directly from processes or operations on premises using radioactive substances and not as a result of discharges of those substances to the environment. |
| Dose | Shortened form of 'effective dose' or 'absorbed dose'. |
| Dose limits | Maximum permissible dose resulting from ionising radiation from practices covered by the Euratom Basic Safety Standards Directive, excluding medical exposures. It applies to the sum of the relevant doses from external exposures in the specified period and the 50 year committed doses (up to age 70 for children) from intakes in the same period. Currently, the limit has been defined as 1 mSv per year for the UK. |
| Dose rates | The radiation dose delivered per unit of time. |
| Effective dose | The sum of the equivalent doses from internal and external radiation in all tissue and organs of the body, having been weighted by their tissue weighting factors. The unit of effective dose is the sievert (Sv). |

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| Environmental materials | Environmental materials include freshwater, grass, seawater, seaweed, sediment, soil and various species of plants. |
| Equivalent dose | The absorbed dose in a tissue or organ weighted for the type and quality of the radiation by a radiation-weighting factor. The unit of equivalent dose is the sievert (Sv). |
| External dose | Doses to humans from sources that do not involve ingestion or inhalation of the radionuclides. |
| Fragments | 'Fragments' are considered to be fragments of irradiated fuel, which are up to a few millimetres in diameter. |
| Generalised Derived Limit | A convenient reference level against which the results of environmental monitoring can be compared. GDLs are calculated using deliberately cautious assumptions and are based on the assumption that the level of environmental contamination is uniform over the year. GDLs relate the concentrations of a single radionuclide in a single environmental material to the dose limit for members of the public. |
| Indicator materials | Environmental materials may be sampled for the purpose of indicating trends in environmental performance or likely impacts on the food chain. These include seaweed, soil and grass. |
| In-growth | Additional activity produced as a result of radioactive decay of parent radionuclides. |
| Kerma air rate | Air kerma is the quotient of the sum of the kinetic energies of all the charged particles liberated by indirectly ionising particles in a specified mass of air. |
| Millisievert | The millisievert is a 1/1000 of a sievert. A sievert is one of the International System of Units used for the measurement of dose equivalent. |
| Radiation exposure | Being exposed to radiation from which a dose can be received. |
| Radiation weighting | Factor used to weight the tissue or organ absorbed dose to take account Factor of the type and quality of the radiation. Example radiation weighting factors: alpha particles = 20; beta particles = 1; photons = 1. |
| Radioactivity | The emission of alpha particles, beta particles, neutrons and gamma or x-radiation from the transformation of an atomic nucleus. |
| Radionuclide | An unstable form of an element that undergoes radioactive decay. |
| Representative person | Representative person is an approach used in the assessment of radiation exposures (*total doses*) to the public. Direct measurement of doses to the public is not possible under most normal conditions. Instead, doses to the public are estimated using environmental radionuclide concentrations, dose rates and habits data. The estimated doses are compared with dose criteria. In this report, the dose criteria are legal limits for the public. |
| TNORM | Naturally occurring radioactive materials that may have been technologically enhanced in some way. The enhancement has occurred when a naturally occurring radioactive material has its composition, concentration, availability, or proximity to people altered by human activity. The term is usually applied when the naturally occurring radionuclide is present in sufficient quantities or concentrations to require control for purposes of radiological protection of the public or the environment. |
| Tissue weighting factors | Factor used to weight the equivalent dose in a tissue or organ to takes account of the different radiosensitivity of each tissue and organ. Example tissue weighting factors: lung = 0.12; bone marrow = 0.12; skin = 0.01. |
| *Total dose* | An assessment of dose that takes into account all exposure pathways such as radionuclides in food and the environment and direct radiation. |

# APPENDIX 4. Research in support of the monitoring programmes

FSA and the environment agencies have programmes of special investigations and supporting research and development studies to complement the routine monitoring programmes. This additional work is primarily directed at the following objectives:

- To evaluate the significance of potential sources of radionuclide contamination of the food chain and the environment
- To identify and investigate specific topics or pathways not currently addressed by the routine monitoring programmes and the need for their inclusion in future routine monitoring
- To develop and maintain site-specific habit and agricultural practice data, in order to improve the realism of dose assessment calculations
- To develop more sensitive and/or efficient analytical techniques for measurement of radionuclides in natural matrices
- To evaluate the competence of laboratories' radiochemical analytical techniques for specific radionuclides in food and environmental materials
- To develop improved methods for handling and processing monitoring data

Other studies include projects relating to effects on wildlife, emergency response and planning and development of new environmental models and data.

The contents of the research programmes are regularly reviewed and open meetings are held to discuss ongoing, completed and potential future projects. Occasionally specific topics are the subject of dedicated workshops (for example, Ould-Dada, 2000). A summary of all the research and development undertaken by the Environment Agency between 1996 and 2001 was published in 2002 (Environment Agency, 2002b). A review of research funded by FSA was published in 2004 (FSA, 2004).

Information on recently completed extramural research is presented in Table A4.1. Those sponsored by the Environment Agency and FSA are also listed on their websites (**www.environment-agency.gov.uk**, **www.food.gov.uk**, respectively). Copies of the final reports for each of the projects funded by the FSA are available from Aviation House, 125 Kingsway, London WC2B 6NH. Further information on studies funded by SEPA and the Scotland and Northern Ireland Forum for Environmental Research is available from Greenside House, 25 Greenside Place, Edinburgh, EH1 3AA. Environment Agency reports are available from **www.environment-agency.gov.uk**. A charge may be made to cover costs.

**Table A4.1 Extramural Projects**

| Topic | Reference (if applicable) | Further details | Target completion date |
|---|---|---|---|
| Soil and herbage survey | UKRSR01 and SCO00027 | E, S | *In press* |
| Offshore Dose Assessment Model | N/A | S | Q1, 2018 |
| Sewer Dose Assessment Model | N/A | S | Published 2017 |
| Thorium Transfer Work | N/A | S | Q1, 2018 |
| NORM Biota Project | N/A | S | Q1, 2018 |
| PhD research project – Assessing the hazard from radioactive particles in the environment | N/A | S | 2021 |

*E Environment Agency*
*S Scotland and Northern Ireland Forum for Environmental Research or SEPA*

Environment Agency
Reactor Assessment and Radiological Monitoring, Nuclear Regulation Group (North)
Cumbria and Lancashire Area, Lutra House, Preston, Lancashire PR5 8BX

Food Standards Agency
Food Policy Division
Aviation House, 125 Kingsway, London WC2B 6NH

Food Standards Scotland
4th Floor, Pilgrim House,
Old Ford Road, Aberdeen AB11 5RL

Cyfoeth Naturiol Cymru / Natural Resources Wales
Ty Cambria, 29 Newport Road, Cardiff CF29 0TP

Northern Ireland Environment Agency
Industrial Pollution and Radiochemical Inspectorate
Klondyke Building, Cromac Avenue, Lower Ormeau Road, Belfast BT7 2JA

Scottish Environment Protection Agency
Radioactive Substances Unit
Strathallan House, Castle Business Park, Stirling FK9 4TZ

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