RIFE - 23

# Radioactivity in Food and the Environment, 2017

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

2018

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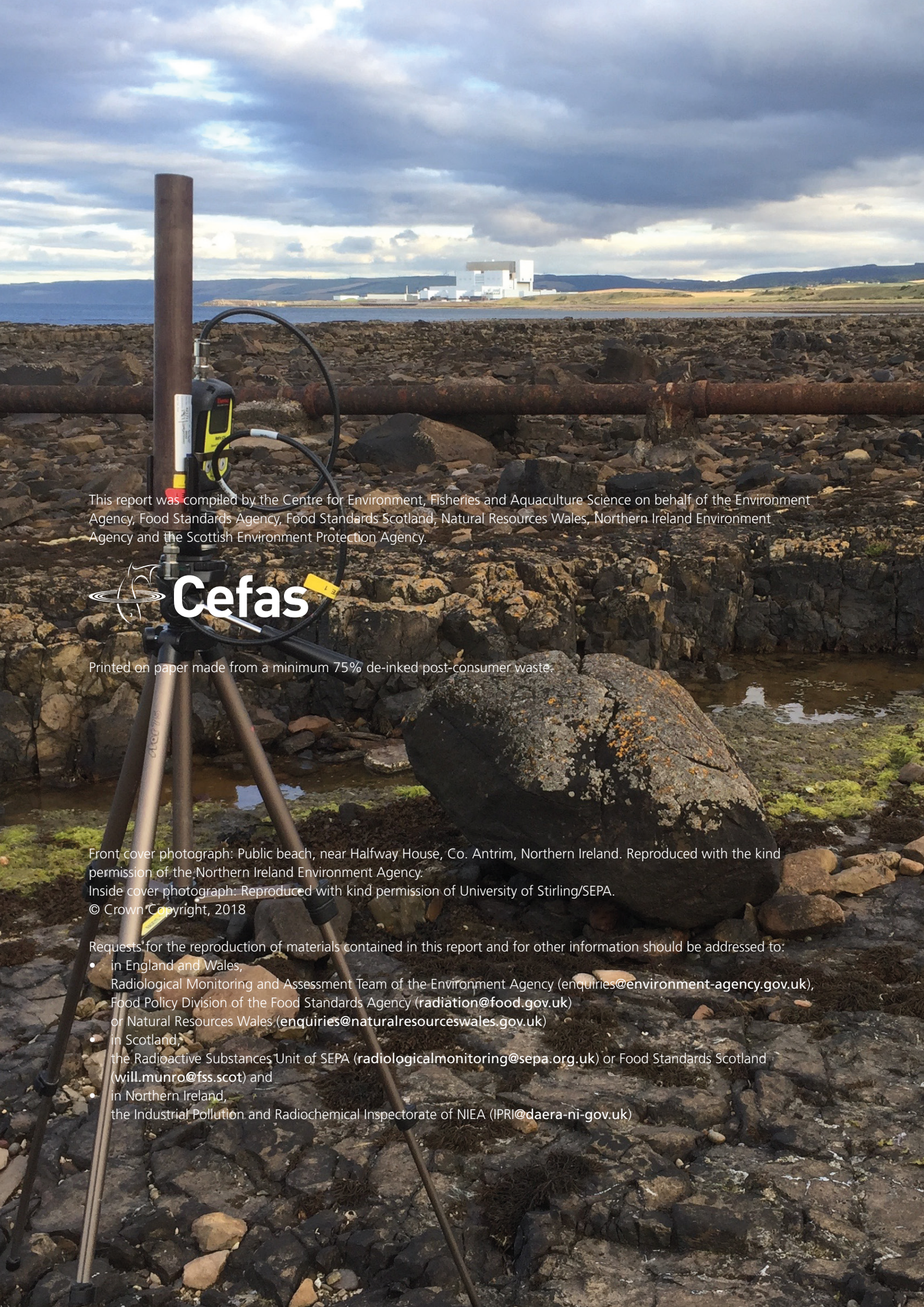
# Radioactivity in Food and the Environment, 2017

## RIFE – 23

October 2018



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 Resources Wales, Northern Ireland Environment Agency and the Scottish Environment Protection Agency.

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- in Northern Ireland,
  the Industrial Pollution and Radiochemical Inspectorate of NIEA (IPRI**@daera-ni-gov.uk**)

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# Preface

This report presents the results of the UK-wide radiological monitoring programmes carried out in 2017. Within these programmes, environmental samples and measurements are taken to analyse radionuclide concentrations and to determine dose rates, respectively. The Environment Agency, Food Standards Agency, Food Standards Scotland, Natural Resources Wales, Northern Ireland Environment Agency and the Scottish Environment Protection Agency work together on the radiological monitoring of food and the environment. These monitoring programmes are independent of, and are also used as a check on, the nuclear site operators' programmes.

This report gives a detailed assessment of radioactivity in food and the environment in the UK and the public's exposure to radiation in 2017. It includes the assessment of radioactivity at sites involved in nuclear fuel production and reprocessing, research establishments, nuclear power production (including both operational and decommissioning sites), defence establishments, radiochemical production, legacy sites and certain industrial and landfill sites.

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 2017. Food in people's general diet and sources of public drinking water were also monitored across the UK. Results showed that artificial radionuclides only contributed a small proportion of the total public radiation dose in people's general diet.

As well as monitoring information, the assessment of exposure to radioactivity requires site specific information on diet and occupancy habits of people living near nuclear licensed sites gathered during habits surveys. In 2017, habits surveys were carried out at Devonport, Hinkley Point and Sellafield in England, and on the Dumfries and Galloway coast and at Hunterston in Scotland.

A summary Radioactivity in Food and the Environment (RIFE) report of recent trends in monitoring data and doses for 2004 – 2016 has been published. This report is combined with the UK report on the application of Best Available Techniques (BAT) in civil nuclear facilities (2012 - 2016) and was prepared for the Radioactive Substances Committee of the OSPAR Commission as the UK statement on the implementation of PARCOM Recommendation 91/4 on Radioactive Substances.

During 2017, regulated radioactive waste disposal in England and Wales was carried out under the Environmental Permitting Regulations 2016 (EPR 16), replacing the previous EPR regulations (EPR 10). In Scotland and Northern Ireland, the Radioactive Substances Act 1993 remained the extant legislation. In 2018, the UK Government published its review of the 2009 UK Strategy for Radioactive Discharges.

The RIFE report and the associated monitoring programmes conform to the requirements of the Euratom Directive (96/29/Euratom) 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. In 2017, the Health and Safety Executive (HSE) consulted on the changes to the Ionising Radiations Regulations 1999 (United Kingdom - Parliament, 1999), in order to transpose the requirements of the revised Euratom Basic Safety Standards Directive (BSSD) (Directive 2013/59/Euratom). The new Ionising Radiations Regulations 2017 came into force on 1 January 2018, replacing the Ionising Radiations Regulations 1999. On 2 May 2018, the Environmental Permitting (England and Wales) (Amendment) Regulations 2018 came into force, also transposing parts of the revised BSSD. In Scotland, the Scottish Environment Protection Agency and the Scottish Government have published consultation documents for the next stages towards an integrated authorisation framework and the Environmental Authorisations (Scotland) Regulations 2018, which came into force on 1 September 2018. In Northern Ireland, the Department of Agriculture, Environment and Rural Affairs has completed a consultation on revised requirements for radiological protection, as part of a UK-wide consultation. It sets out proposals for the transposition of BSSD in relation to public radiation exposures.

As part of its withdrawal from the European Union on 29 March 2019, the UK will also leave the European Atomic Energy Community (Euratom). Euratom provides the framework for cooperation between EU Member States in the civil nuclear sector. While the UK remains a member of the EU and of Euratom, the UK is legally obliged to implement Directives and respect the laws and obligations required by that membership. As such, the UK has continued to negotiate, implement and apply EU legislation to the timelines laid down for transposition and will maintain such standards thereafter.

In July 2018, the UK Government published a White Paper on its vision for the future relationship between the UK and the EU. As part of this, the Government set out its intention to agree a new relationship with Euratom that is broader and more comprehensive than any existing precedent and proposed a comprehensive Nuclear Cooperation Agreement as the mechanism for its delivery.

# 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 a 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 2017 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 the 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 which receives the highest dose.

In 2017, 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 2017 were the same as those in 2016. They were near Sellafield (0.25 mSv), Capenhurst (0.17 mSv) and Amersham (0.15 mSv). The doses received near Capenhurst

* *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'.*

† *As part of its withdrawal from the European Union on 29 March 2019, the UK will also leave the European Atomic Energy Community (Euratom). Euratom provides the framework for cooperation between EU Member States in the civil nuclear sector. While the UK remains a member of the EU and of Euratom, the UK is legally obliged to implement Directives and respect the laws and obligations required by that membership. As such, the UK has continued to negotiate, implement and apply EU legislation to the timelines laid down for transposition and will maintain such standards thereafter. In July 2018, the UK Government published a White Paper on its vision for the future relationship between the UK and the EU. As part of this, the Government set out its intention to agree a new relationship with Euratom that is broader and more comprehensive than any existing precedent and proposed a comprehensive Nuclear Cooperation Agreement as the mechanism for its delivery.*

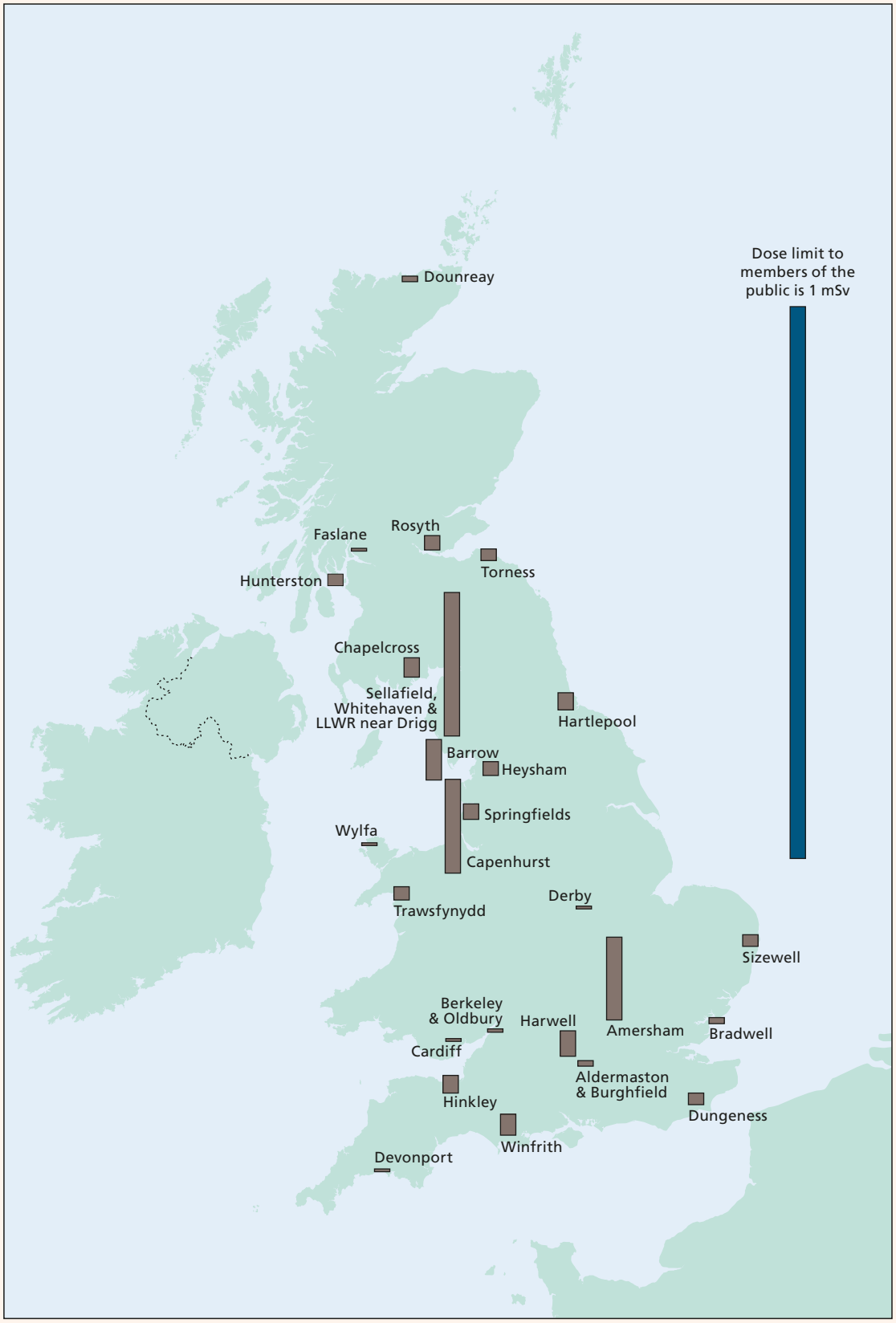



**Figure S.** *Total doses* in the UK due to radioactive waste discharges and direct radiation, 2017
(Exposures at Sellafield, Whitehaven and Drigg receive a significant contribution to the dose from technologically enhanced naturally occurring radionuclides from previous non-nuclear industrial operations)

**Summary Table S *Total doses* due to all sources at major UK sites, 2017[a]**

| Establishment | Exposure, mSv[b] per year | Contributors[c] |
|---|---|---|
| **Nuclear fuel production and processing** | | |
| Capenhurst | 0.17 | Direct radiation |
| Springfields | 0.028 | Gamma dose rate over sediment |
| Sellafield[e] | 0.25 | Crustaceans, molluscs, $^{210}$Po |
| **Research establishments** | | |
| Dounreay | 0.010 | Direct radiation, Potatoes, $^{238}$Pu[d], $^{239/240}$Pu[d] |
| Harwell | 0.046 | Direct radiation |
| Winfrith | 0.038 | Direct radiation |
| **Nuclear power stations** | | |
| Berkeley and Oldbury | <0.005 | Gamma dose rate over sediment |
| Bradwell | 0.011 | Direct radiation |
| Chapelcross | 0.035 | Milk, $^{90}$Sr, $^{241}$Am[d] |
| Dungeness | 0.021 | Direct radiation |
| Hartlepool | 0.031 | Direct radiation, gamma dose rate over sediment |
| Heysham | 0.025 | Direct radiation, gamma dose rate over sediment |
| Hinkley Point | 0.032 | Gamma dose rate over sediment |
| Hunterston | 0.023 | Direct radiation |
| Sizewell | 0.021 | Direct radiation |
| Torness | 0.021 | Direct radiation |
| Trawsfynydd | 0.024 | Exposure over sediment |
| Wylfa | <0.005 | Gamma dose rate over sediment |
| **Defence establishment** | | |
| Aldermaston and Burghfield | 0.010 | Direct radiation |
| Barrow | 0.074 | Gamma dose rate over sediment |
| Derby | <0.005 | Water, $^{60}$Co[d] |
| Devonport | <0.005 | Fish, exposure over sediment, $^{241}$Am[d] |
| Faslane | <0.005 | Fish, $^{137}$Cs, $^{241}$Am[d] |
| Rosyth | 0.026 | Gamma dose rate over sediment |
| **Radiochemical production** | | |
| Amersham | 0.15 | Direct radiation |
| Cardiff | <0.005 | Gamma dose rate over sediment |
| **Industrial and landfill** | | |
| LLWR near Drigg[e] | 0.25 | Crustaceans, molluscs, $^{210}$Po |
| Whitehaven[e] | 0.25 | Crustaceans, molluscs, $^{210}$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 0.077 and 0.18 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*

and Amersham were dominated by direct radiation from sources on the sites.

In 2017, the representative person in the vicinity of the Sellafield site was a high-rate mollusc consumer (who also consumed significant quantities of other seafood). The estimated dose of 0.25 mSv includes a contribution of 0.18 mSv from the past discharges from the former phosphate processing plant near Whitehaven and 0.077 mSv related to the discharges of artificial radionuclides by the nuclear industry. The equivalent local seafood consumer received a dose of 0.41 mSv (including a contribution of 0.34 mSv and 0.074 mSv related to the former phosphate processing plant and the nuclear industry, respectively) in 2016. The decrease in dose near Sellafield was mostly attributable to lower polonium-210 concentrations in crustaceans (lobsters) in 2017. The largest contribution to dose to seafood consumers in the vicinity of Sellafield was from polonium-210. Polonium-210 contributes a significant fraction of the dose to the most exposed members of the public because it has a relatively high dose coefficient (used in converting the activity concentration to a dose value). Polonium-210 is present in the environment from radioactive decay (i.e. as a daughter product) of Naturally Occurring Radioactive Materials (NORM). A secondary source (in this region) has been from the radioactive decay of Technologically enhanced Naturally Occurring Radioactive Material (TNORM). TNORM was discharged from the former phosphate processing plant near Whitehaven. However, polonium-210 concentrations in crustacean samples continued to be within or close to the expected range due to natural sources in 2017. From a radiological assessment perspective, the effects from the Sellafield site and the phosphate processing plant (near Whitehaven) 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 0.011 mSv in 2017, and up from 0.008 mSv (in 2016). The small increase in the dose was attributable to a combination of reasons: the inclusion of a result obtained for a root vegetable (not collected in 2016), and an increase from external exposure over sediments, in 2017. The most exposed age group was adults in 2017 and the dominant contribution to this dose was external exposure over sediments.

In Scotland, the representative person who received the highest dose from authorised releases of radioactivity consumed fish, shellfish and wildfowl from the Dumfries and Galloway coast. The dose in 2017 was 0.035 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 produced food at Trawsfynydd. The dose was 0.024 mSv in 2017.

## 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 2017 compared to those in 2016. The mean concentration of americium-241 in locally harvested molluscs (mussels) near Sellafield was lower in 2017, and is the lowest reported value, in comparison to those in 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.

On occasion, the effects of non-nuclear sites discharges are detected at low levels by the routine monitoring programme for nuclear licensed sites. In 2017, 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.

At Hartlepool, the reported polonium-210 concentration in winkles was enhanced above that value expected due to natural sources. The higher level is not due to discharges from the power station but is believed to be due to the effects of waste slag from local iron and steel industries used in sea defences and the build-up of naturally occurring radionuclides in sediments at this location following degradation of these materials.

In 2018, the Food Standards Agency (FSA) carried out a review of their environmental monitoring programme for the sites at Amersham and Cardiff (operated by GE Healthcare Limited). This programme will be changed to reflect the review outcomes and reported in next year's RIFE report.

In 2018, a review of the 2009 UK Radioactive Discharge Strategy was published (BEIS, 2018). The review demonstrates clear evidence of progress being made by the UK, in meeting the outcomes of the 2009 Strategy and contributing towards the objectives of the OSPAR Radioactive Substances Strategy. Specifically, strong progress has been made towards achieving progressive and

substantial reductions in radioactive discharges. Progress is also being made to work towards achieving progressive reductions in concentrations of radionuclides in the marine environment and achieving progressive reductions in human exposures to ionising radiation, as a result of planned reductions in discharges. From a regulatory perspective, the Environment Agency, Natural Resources Wales (NRW) and the Scottish Environment Protection Agency (SEPA) have continued to support the Strategy. In 2017, the Environment Agency issued new permits, or varied existing ones, at the following sites: Hartlepool, and Sellafield (including Windscale), resulting in one or more of: strengthened conditions, increased/reduced limits or new routes for disposing of radioactive waste. The permit for disposal of radioactive waste, from the site at the Metals Recycling Facility (Lillyhall, Cumbria), was updated to implement a change in company name (following the sale of the company).

## 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 2017 compared with 2016. 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 2017, as a result of an ongoing programme of monitoring by the operator, radioactive items (particles and objects*) from Sellafield were detected on Cumbrian coastline beaches and removed (226 in 2017 calendar year). 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 meet the primary aim of providing reassurance that overall risks to beach users remain at or below those estimated in the PHE risk assessment.

The enhanced monitoring programme at Bradwell continued in 2017. 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 2017.

At Dounreay, the comprehensive beach monitoring programme continued for fragments of irradiated nuclear fuel (particles) and further fragments were recovered from local beaches (similar in number and activity range to that observed in 2016). 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 2017.

## 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 2017, the regular programmes of habits surveys continued, and these give site-specific information on diet and occupancy habits of people near nuclear licensed sites. Surveys were carried out at Devonport, Hinkley Point and Sellafield in England, and on the Dumfries and Galloway coast and at Hunterston 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.

* *"Particles and objects" are terms used which encompass 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). "Objects" are larger radioactive artefacts (e.g. dials) and stones which have radioactive contamination on their surface and are larger than 2 mm in size. 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.*

## 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 the 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 2017. 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 2017. 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 2017, 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 waste slurry containing thorium and uranium was discharged from a phosphate processing plant near Whitehaven (Cumbria) into the Irish Sea. The slurry could be regarded as Technologically enhanced Naturally Occurring Radioactive Material (TNORM). Discharges of TNORM have resulted in an increase in the concentrations of naturally occurring radionuclides in the environment, through the production of the daughter products (from the decay of the long-lived parent radionuclides, previously discharged to sea).

Concentrations of two of the daughter products, polonium-210 and lead-210, in fish and shellfish (near Whitehaven) have been found to be higher than the maximum expected ranges due to naturally sourced radioactivity (i.e. natural background). Concentrations have declined significantly since the plant ceased operations in 1992. Thereafter, the concentrations of polonium-210 and lead-210 were close to the expected ranges of natural background. Estimates of the activity concentrations from the environmental legacy in seafood are made by subtracting the median of the expected natural concentration range of these radionuclides from the measured concentrations. 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 0.25 mSv in 2017 and the most contributing radionuclide was polonium-210. The dose is mostly from the environmental legacy, resulting from these past discharges from the former phosphate processing 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 from hospitals and industrial sites, for example, or 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 2017 and into 2018. This includes a continuing monthly beach monitoring and particle recovery programme. The FEPA Order issued by the FSA in Scotland (now Food Standards Scotland (FSS)), prohibiting the collection of seafood from the Dalgety Bay area, remains in force. Most recently, an Environmental Impact Assessment (EIA), in support of the Planning Application for the remediation works, was submitted to the Fife Council and subsequently approved. In March 2017, SEPA issued guidance on monitoring for heterogeneous radium-226 sources resulting from historic luminising or waste disposal sites (SEPA, 2017a).

Further details can be found in Section 7.5 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 2017 (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.

From the monitoring of artificial radioactivity in Northern Ireland, consumer doses were estimated to be 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.

Disposal of dredge material from harbours and other areas is licensed under the Marine and Coastal Access Act (MCAA), 2009. In 2017, a subsidiary of EDF Energy lodged a MCAA licensing application to carry out a variety of dredging scenarios for the intakes and outfalls jetty application, within which dredging could occur at Hinkley Point C. A specific assessment of doses to workers and members of the public was conducted for the disposal of the dredge material (Leonard *et al*., 2017). The combined doses (from artificial and naturally occurring radionuclides) to individual members of the crew and members of the public were within the IAEA *de minimis* criteria of 0.010 mSv per year.

## 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, Department of Agriculture Environment and Rural Affairs (DAERA), Department of Business, Energy and Industrial Strategy (BEIS), Department for Environment, Food and Rural Affairs (Defra), Natural Resources Wales (NRW) and 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 2017.

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 2017 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 (BSSD)
- 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 2017

## 1.1 Scope and purpose of the monitoring programmes

In England and Wales, the FSA and the Environment Agency* conduct food and non-food (environmental and dose rate) monitoring, respectively. SEPA (working closely with FSS on its programme) and the Northern Ireland Environment Agency (NIEA) both undertake food and non-food monitoring in Scotland and Northern Ireland, respectively. Surveillance of imports through points of entry continued in 2017. 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) are monitored on behalf of BEIS.

FSA has responsibility for food safety in England, Northern Ireland and Wales, whilst FSS has responsibility in Scotland. 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. The UK authorities responsible for the regulation of radioactive discharges and radioactive waste disposal from nuclear sites are the Environment Agency, SEPA and NRW.

Radioactive waste disposal by UK nuclear installations is governed by national legislation. Taking effect from 1 January 2017, the Environment Agency and NRW regulated radioactive waste disposal in England and Wales under the Environmental Permitting Regulations 2016 (EPR 16), (United Kingdom - Parliament, 2016), replacing the previous EPR regulations (EPR 10). 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

* *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.*

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 (BSSD). A revised BSSD was adopted in 2013, that consolidated and updated existing Euratom provisions for protection against the harmful effects of ionising radiation by replacing five existing Directives and a Commission Recommendation into one Directive covering occupational, medical and public exposure (EC, 2014):

- Basic Safety Standards Directive 96/29/Euratom;
- Medical Exposures Directive 97/43/Euratom;
- Outside Workers Directive 90/641/Euratom;
- Control of high-activity sealed radioactive sources and orphan sources 2003/122/Euratom;
- Public Information Directive 89/618/Euratom;
- Radon Commission Recommendation 90/143/Euratom

In 2017, the Health and Safety Executive (HSE) consulted on the changes to the Ionising Radiations Regulations 1999 (HSE, 2017) and provided an analysis of responses received to the consultation, in order to transpose the requirements of the revised BSSD. The new Ionising Radiations Regulations 2017 (United Kingdom - Parliament, 2017) came into force on 1 January 2018, replacing the Ionising Radiations Regulations 1999. The HSE have also provided practical advice (Code of Practice) to help those to comply with their duties under the Ionising Radiations Regulations 2017 (HSE, 2018). On 2 May 2018, the Environmental Permitting (England and Wales) (Amendment) Regulations 2018 (EPR 18) came into force, (United Kingdom - Parliament, 2018), so to also transpose parts of revised BSSD. In Scotland, the Scottish Environment Protection Agency and the Scottish Government have published consultation documents for the next stages towards an integrated authorisation framework and the draft Environmental Authorisations (Scotland) Regulations 2018 (SEPA and Scottish Government, 2017), which came into force on 1 September 2018. In Northern Ireland, the Department of Agriculture, Environment and Rural Affairs has completed a consultation on revised requirements for radiological protection, as part of a UK-wide consultation. It sets out proposals for the transposition of BSSD in relation to public radiation exposures.

In recent years, FSA, SEPA and the Environment Agency 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, 2017). In 2018, the FSA carried out a review of their environmental monitoring programme for the sites at Amersham and Cardiff (operated by GE Healthcare Limited). This part of the programme will be changed to reflect the review outcomes and reported in next year's RIFE report. Reviews are carried out to ensure the monitoring 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 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)
- SOCOTEC UK Limited (formerly Environmental Scientifics Group)
- Public Health England (PHE)
- LGC Limited (LGC)

Building on the information derived from previous RIFE reports (RIFE 10 – 22, inclusive), the Environment Agency, Food Standards Agency, Food Standards Scotland, Natural Resources Wales, Northern Ireland Environment Agency, Scottish Environment Protection Agency and the Department for Business, Energy and Industrial Strategy have published a RIFE summary report (OSPAR, 2018a). This report is combined with the UK report on the application of Best Available Techniques (BAT) in civil nuclear facilities (2012 - 2016) and was prepared for the Radioactive Substances Committee of the OSPAR Commission as the UK statement on the implementation of PARCOM Recommendation 91/4 on Radioactive Substances. This report "Summary of Radioactivity in Food and the Environment in the UK (2004 – 2016)" provides an overview of recent trends in data over this period. The report primarily focuses on time trends associated with radiation exposure (doses) to people living around nuclear sites, disposals of radioactive waste (discharges) to air and water, and radionuclide activity (concentrations) in samples collected around nuclear sites.

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 2017, 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 habits 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 effective doses are calculated and compared with the dose limit of 1 mSv per year for members of the public. 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, 2007) and are consistent with EU legislation (EC, 2014).

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.*, 2013a).

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 2017

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 2017 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 near 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

* *At some locations separate nuclear licensed sites are situated adjacent to one another, for example some EDF Energy operated power stations have a neighbouring decommissioning Magnox station. As these are operated by different employers, workers at one station are considered to be members of the public to the other station. Work has been undertaken this year to consider how direct radiation doses from adjacent nuclear sites to workers at the other site are reported. In future RIFE reports, where this dose is higher than that to a member of the public outside of the combined site boundary, the dose will be reported in an additional footnote.*

| 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 concentrations 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 | Calculate dose from gaseous discharges to people representing those most exposed | Calculate dose from liquid discharges to people representing those most exposed | |
| | Select the highest dose for the person representing the 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

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 - 2017 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 (thereafter decreasing again in 2017).

The estimate of *total dose* at Dounreay has decreased in recent years from the peak value in 2008. The increase in *total dose* at Dounreay in 2016 was mostly due to the inclusion of the concentration of caesium-137 found in venison (game), which had not been sampled in recent years. 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 (in recent years) were mostly due to higher estimates of direct radiation from the individual sites.

### 1.2.4 Source specific dose results for 2017

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 non-nuclear industrial operations resulting in technologically enhanced levels of natural radionuclides, and to a lesser

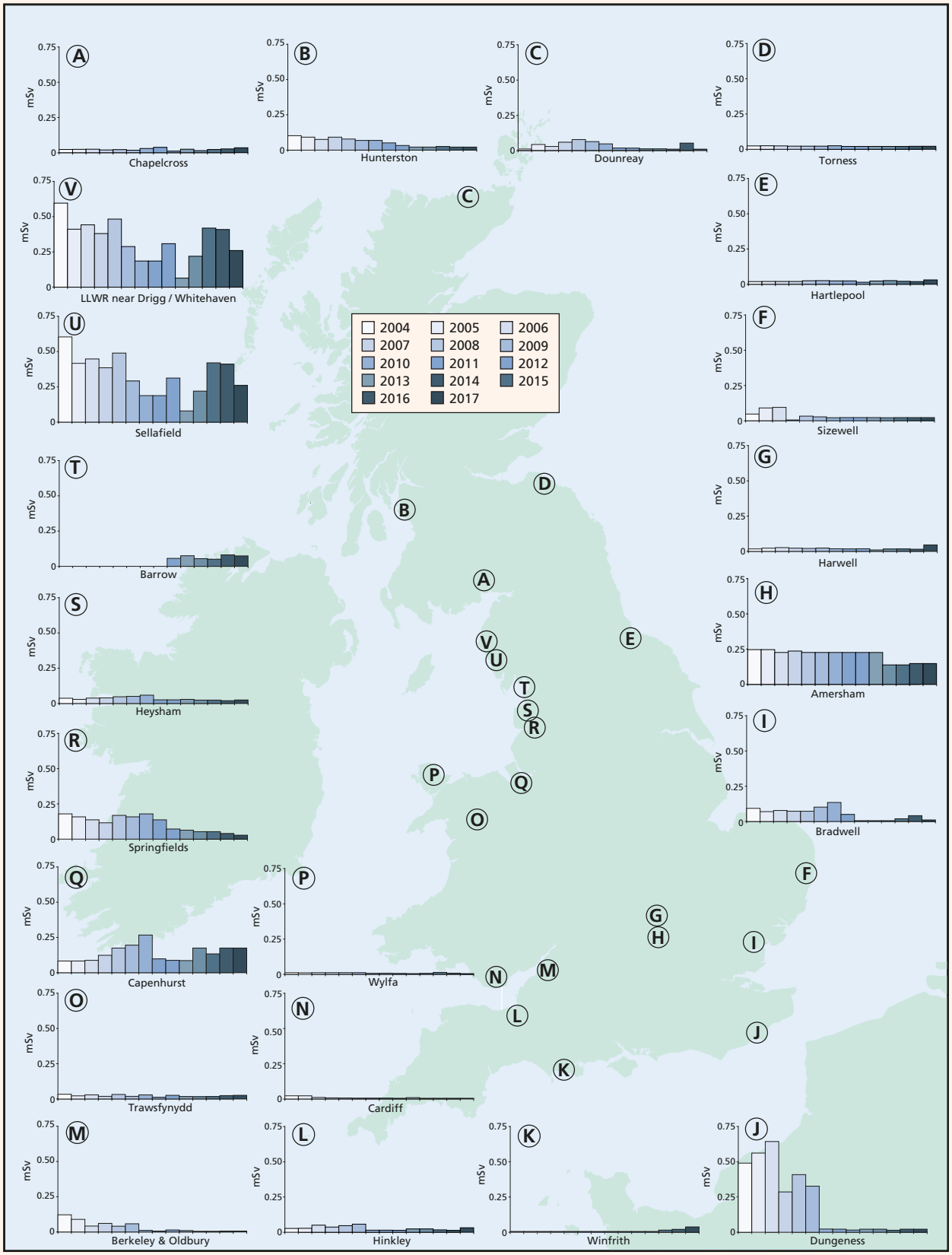



**Figure 1.2.** *Total doses* around the UK's nuclear sites due to radioactive waste discharges and direct radiation (2004-2017). (Exposures at Sellafield/Whitehaven/LLWR receive a significant contribution to the dose from technologically enhanced naturally occurring radionuclides from previous non-nuclear industrial operations)

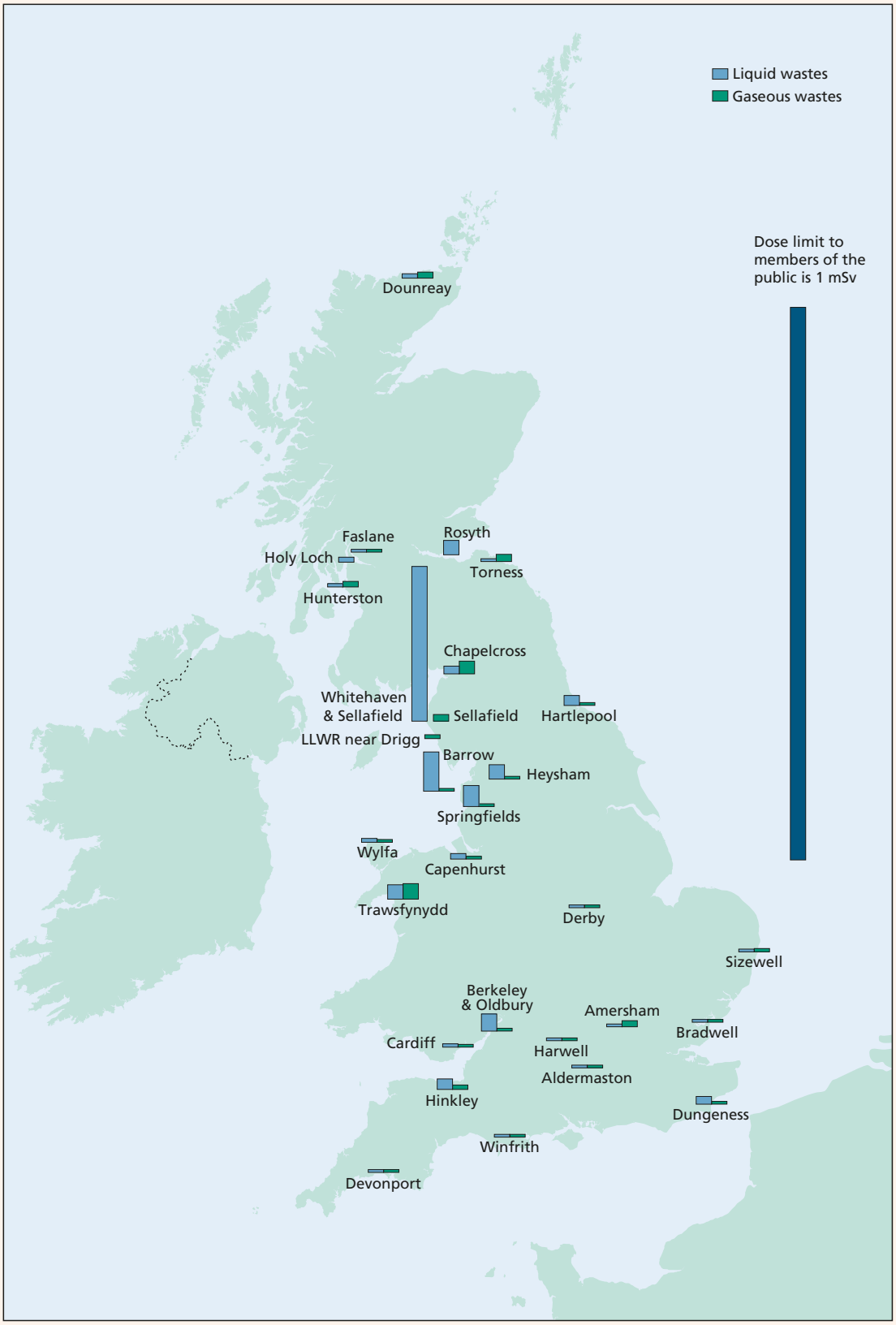



**Figure 1.3.** Source specific doses in the UK, 2017 (Exposures at Whitehaven and Sellafield receive a significant contribution to the dose from technologically enhanced naturally occurring radionuclides from previous non-nuclear industrial operations)

extent, the legacy of historical discharges from Sellafield. 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), which 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 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 regulated radioactive waste discharges, concluding that the worst affected organism was less than the agreed threshold (40 μGy $h^{-1}$) and hence there was no significant impact on the integrity of habitat sites (Environment Agency, 2009a; 2009b). Further information concerning assessment of dose rates to reference organisms is available in earlier RIFE reports (e.g. Environment Agency, FSA, FSS, NIEA, NRW and SEPA, 2017).

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

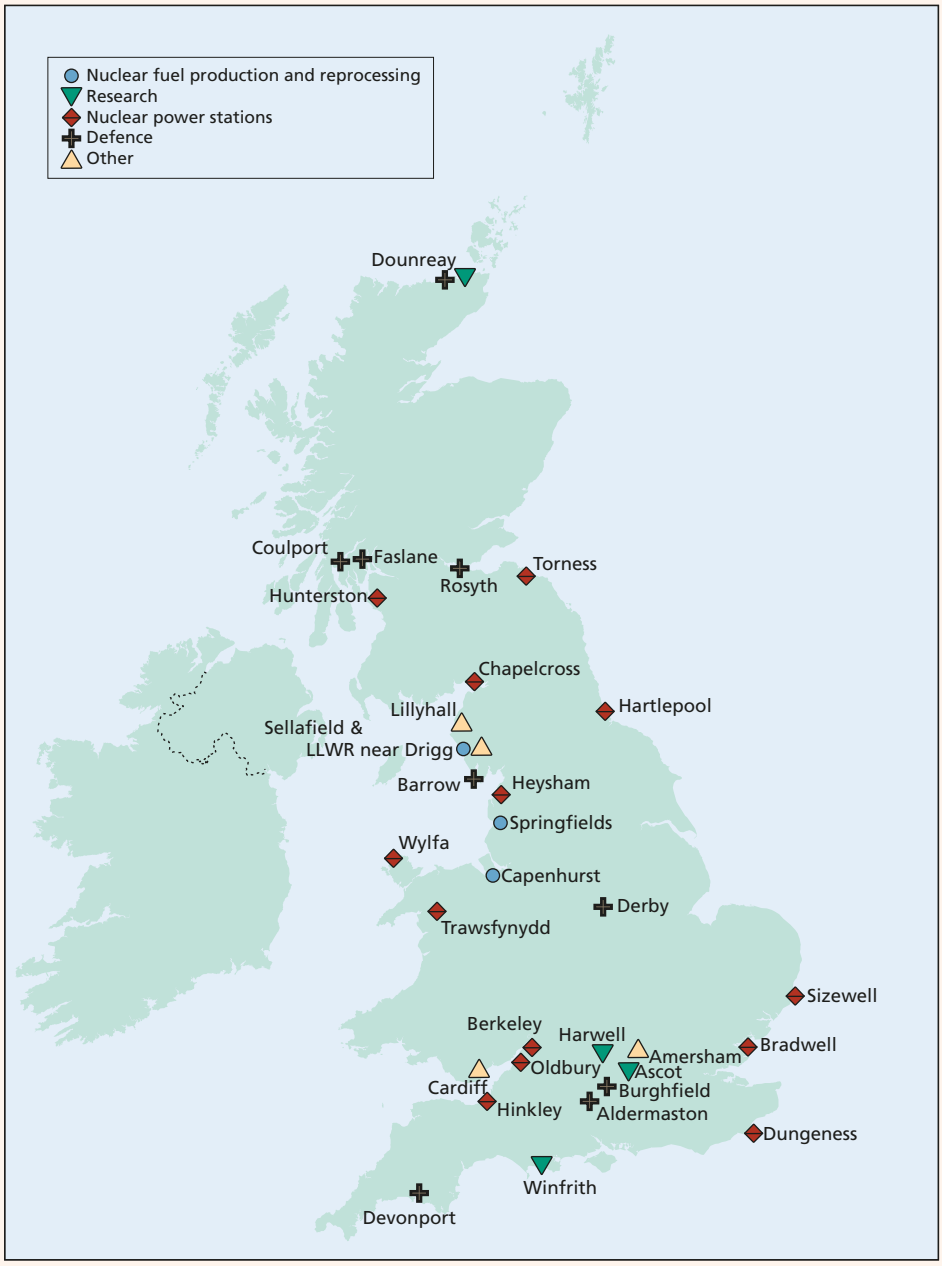
Nuclear licensed sites in the UK discharge liquid and/or gaseous radioactive waste as part of their operations. In addition, solid Low Level Waste (LLW) from nuclear licensed sites can be transferred to the Low Level Waste Repository (LLWR) near Drigg for disposal and solid wastes containing low levels 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. In 2017, these discharges and disposals were 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) and 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 were also regulated under RSA 93 or EPR 16 (formerly EPR 10) in 2017, but not subject to

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

† *In England and Wales, the term 'authorisation' has been replaced by 'permit' with EPR 16 (formerly EPR 10, effective from 6 April 2010) taking effect from 1 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 6 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, 2017 (Showing main initial operation. Some operations are undergoing decommissioning)




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 near 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 and Northamptonshire (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, disposals of radioactive wastes and solid waste transfers from nuclear establishments in 2017, 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 2017, discharges and disposals were all below the limits. In 2017, 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 also considered. In addition, the regulations require Best Available Techniques (BAT), under the Environmental Permitting (England and Wales) Regulations, 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 2017.

### 1.3.2 UK radioactive discharges (International agreements and nuclear new build)

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.

#### International agreements

The UK is a contracting party 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, 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."

A UK Strategy for Radioactive Discharges was published in 2002 to describe how the UK would implement the agreements reached at the 1998 and subsequent meetings of OSPAR (Defra, 2002). In 2009, BEIS and the Devolved Administrations issued a revised Strategy (DECC, Department of the Environment Northern Ireland, the Scottish Government and Welsh Assembly Government, 2009). This revised Strategy included the expansion of 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. A number of objectives (including the UK's obligations, with respect to the OSPAR RSS intermediate objective for 2020) and outcomes were identified in the revised Strategy, that are summarised in earlier RIFE reports (e.g. Environment Agency, FSA, FSS, NIEA, NRW and SEPA, 2016).

To support implementation of UK Government policy concerning the regulation of radioactive discharges into the environment, 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, 2010). 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).

In June 2018, the UK Government published its review of the 2009 UK Strategy for Radioactive Discharges (BEIS, 2018). The 2018 review of the Strategy takes account of developments in UK Government policy, commercial decisions within the nuclear industry, technological advances and improvements in our knowledge of the impacts of radionuclides in the marine environment. This review demonstrates the clear evidence of progress being made by the UK in meeting the outcomes of the 2009 Strategy and contributing towards the objectives of the OSPAR Radioactive Substances Strategy. Further information and a copy of the report is available on the UK Government website:

https://www.gov.uk/government/publications/uk-strategy-for-radioactive-discharges-2018-review-of-the-2009-strategy.

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, 2018b). A revised agreement has been reached on the basis for monitoring of relevance to OSPAR by Contracting Parties (OSPAR, 2017). 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, 2015a; b). The UK submission concerning the implementation of the principle of using BAT has also been published (OSPAR, 2018a). 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 (Department of the Environment Northern Ireland, 2011; Baxter *et al.,* 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, 2010) 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

## Nuclear new build

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 2017 for Hitachi-GE's UK Advanced Boiling Water Reactor (UK ABWR) and Westinghouse's AP1000® reactor (ONR, Environment Agency and NRW, 2017).

In March 2017, ONR, the Environment Agency and NRW completed the GDA of Westinghouse's AP1000® that is intended for construction at NuGen's Moorside site near Sellafield. In December 2017, the regulators completed GDA for Hitachi GE's UK ABWR design that is intended for construction at Horizon's sites at Wylfa Newydd on Anglesey and Oldbury in South Gloucestershire. ONR and the Environment Agency commenced GDA of the China General Nuclear (CGN) designed UK HPR1000 that is intended for deployment at Bradwell B in Essex.

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


The requesting party for this GDA is General Nuclear System (GNS) a joint company of CGN and EDF. This GDA commenced following a request from Government to ONR and the Environment Agency in January 2017. ONR and the Environment Agency began the first assessment step of GDA (step 2) in November 2017 and, with GNS, are targeting completing this step in around 12 months. Construction of NNB GenCo's new twin UK EPR reactor nuclear power station at Hinkley point C in Somerset continues at pace. In March 2017, ONR granted its first consent for the start of nuclear safety related construction at the site and continues to be engaged in conducting safety and security assessment and regulating its construction. The Environment Agency also continues to regulate environmental matters at the site under the environmental permits it has granted including that for construction related discharges. Of interest to both regulators is the growth of the NNB GenCo company so as to ensure that it has the competences and resources required to secure safety, security and environment protection throughout construction and as it prepares itself to be an operator.

ONR and the environment agencies are continuing to work with the companies seeking to construct new nuclear power stations at:

- Oldbury, South Gloucestershire (Horizon Nuclear Power Limited, ABWR design)
- Wylfa Newydd, Anglesey (Horizon Nuclear Power Limited, ABWR design)
- Moorside, Cumbria (NuGen Limited, AP1000® design)
- Sizewell C, Suffolk (NNB GenCo Limited, UK EPR design)
- Bradwell B, Essex (Bradwell B Power Generation Company Limited, UK HPR1000 design)

The possible radiological impact from routine radiological discharges has been assessed for proposed nuclear power stations in England and Wales (Jones *et al*., 2013b).

### 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, 2014b; BEIS, 2017). At the Sixth Review Meeting of the Joint Convention in May 2018, the UK was awarded a Good Practice for its robust approach to implementing the waste management hierarchy, particularly regarding management of LLW which has resulted in major reductions of LLW requiring disposal at the national Low Level Radioactive Waste Repository (LLWR) in Cumbria, thereby extending the lifetime of the facility. 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. The NDA reports to BEIS and is responsible to Scottish ministers. The NDA manages the decommissioning and clean-up of the civil public sector nuclear sites, plus the associated liabilities and assets. In 2016, the NDA took direct ownership of Sellafield Limited, which now operates as a wholly owned subsidiary of the NDA. The role of the 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 2018/21 is available (NDA, 2018). The health and socio-economic impacts of the strategy have been considered (NDA, 2016b). In 2017, the 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, 2017).

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, the NDA was required to develop a UK strategy for the management of solid low level radioactive waste in the nuclear industry. The NDA developed and published the "*UK Strategy for the Management of Solid Low-Level Radioactive Waste from the Nuclear Industry*" in 2010 (NDA, 2010). 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:

- 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 NORM wastes as well as solid wastes. (DECC, Scottish Government, Welsh Government and the Northern Ireland Department of the Environment, 2014).

UK Government policy (excluding Scotland) is that geological disposal is the best available means of managing higher activity radioactive waste in the long term. Scottish Government policy is that the long-term management of higher activity radioactive waste should be in near-surface facilities.

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 the NDA). Three initial actions, National Geological Screening (NGS); Working with Communities; and Land-use Planning, underpin the work to deliver outputs. Further information on these aspects is available on the GOV.UK website: **https://www.gov.uk/government/collections/geological-disposal-facility-gdf-for-high-activity-radioactive-waste**.

No specific sites have been selected or are currently under consideration (DECC, 2016). 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 supports 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 Scottish Government published its Implementation Strategy for Scotland's policy on higher activity radioactive waste following consultation in December 2016 (Scottish Government, 2016).

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 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). BEIS, covering England and Northern Ireland, and the Welsh Government opened separate consultations in January 2018 to seek views on the arrangements for engaging with communities in Wales who may be considering entering discussions.

The Northern Ireland Executive has responsibility for ensuring that any proposed GDF will not have an adverse impact upon the environment, health and safety of Northern Ireland. Northern Ireland 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 annual report for 2016-2017 (CoRWM, 2017a) and proposed work programme for 2017-2020 (CoRWM, 2017b).

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. In May 2017, LLWR Limited published guidance to LLWR customers accessing the Very Low Level Waste Service (LLWR Limited, 2017). 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). SEPA has issued a policy statement which specifies how it will regulate the disposal of LLW from nuclear licensed sites (SEPA, 2012b) and interim guidance on the regulation of in-situ disposals of radioactive waste and residual radioactive contamination on nuclear authorised premises (SEPA, 2014). In January 2017, SEPA issued guidance on the shipment of wastes which contain naturally occurring radioactive material (NORM) (SEPA, 2017b). In September 2017, a joint report by ONR and SEPA published the findings of an inspection of Radioactive Waste Management Limited's (RWM) disposability assessment process for the management of higher activity radioactive waste (HAW) in Scotland (ONR and SEPA, 2017).

Decommissioning of many nuclear sites in Great Britain is underway. In 2016, the environment agencies undertook a consultation process on the 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 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 2016:

https://consultation.sepa.org.uk/operations-portfolio/grr/results/2016_12_14-grr-consultation-agencies-response.pdf. The responses to the consultation and the operational feedback from the trial use of the guidance, at three sites, were used to refine the structure and clarity of the GRR guidance, published on 24 July 2018 (SEPA, Environment Agency and NRW, 2018). This guidance describes what operators must do in order to achieve release from radioactive substances regulation and is also available via: https://www.gov.uk/government/publications/decommissioning-of-nuclear-sites-and-release-from-regulation/decommissioning-of-nuclear-sites-and-release-from-regulation.

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 Marine Management Organisation (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 waters and around the coast of Northern Ireland are the responsibility of the Scottish Government (Marine Scotland) and the Department of Environment (NIEA), respectively. As of 1 April 2013, upon its creation as the lead environmental body for Wales, NRW took over the responsibility from the Welsh Government for issuing licences for Welsh waters.

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). In 2017, NNB GenCo lodged a licensing application to carry out a variety of dredging scenarios, within which dredging could occur at Hinkley Point C. Samples of the dredge material were analysed for radioactivity and a generic assessment of potential radiation doses was made (Leonard *et al*., 2017). The results of the assessment are given in Appendix 5. Estimated doses (from artificial and naturally occurring radionuclides) to individual members of the crew and members of the public were within the International Atomic Energy Agency (IAEA) *de minimis* criterion of 0.010 mSv per year. Therefore, there was no objection to the licence being issued from radiological considerations.

### 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 (e.g. 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 2017. 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: **https://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 the appropriate regulatory regimes control exposures of the public from onshore oil and gas exploration and extraction, including hydraulic fracturing. 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 published by PHE (Kibble *et al*., 2014). The Environment Agency has granted three permits for hydraulic fracturing at the sites: Preston New Road, near Blackpool and Roseacre Wood near Elswick both in Lancashire, and in Kirby Misperton, near Pickering in North Yorkshire. 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. The regime was extended in 2006 to provide a system for identifying and remediating land, in relation to i) contamination causing people to be exposed to lasting exposure to radiation resulting from the after-effects of a radiological emergency, ii) past practice or post work activity, and iii) where intervention is liable to be justified. In the UK there is 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 it has been 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 most significant source of exposure was from 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; and of this, 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 UK and EU law.

## Table 1.1 Individual doses – direct radiation pathway, 2017*

| Site | Exposure, mSv |
|---|---|
| **Nuclear fuel production and reprocessing** | |
| Capenhurst | 0.17 |
| Sellafield | 0.004 |
| Springfields | 0.018 |
| **Research establishments** | |
| Dounreay | 0.006 |
| Harwell | 0.046 |
| Winfrith | 0.038 |
| **Nuclear power stations** | |
| Berkeley | Bgd[a] |
| Bradwell | 0.011 |
| Chapelcross | Bgd[a] |
| Dungeness | <0.020[b] |
| Hartlepool | <0.020 |
| Heysham | <0.020 |
| Hinkley Point | <0.010[c] |
| Hunterston | <0.020[d] |
| Oldbury | Bgd[a] |
| Sizewell | <0.020[e] |
| Torness | <0.020 |
| Trawsfynydd | Bgd[a] |
| Wylfa | Bgd[a] |
| **Defence establishments** | |
| Aldermaston | <0.010 |
| Barrow | Bgd[f] |
| Burghfield | <0.010 |
| Derby | Bgd[a] |
| Devonport | Bgd[f] |
| Faslane | Bgd[f] |
| Rosyth | Bgd[f] |
| **Radiochemical production** | |
| Amersham | 0.14 |
| Cardiff | Bgd[a] |
| **Industrial and landfill sites** | |
| LLWR near Drigg | 0.053 |
| Metals Recycling Facility | 0.001 |

* *At some locations separate nuclear licensed sites are situated adjacent to one another, for example some EDF operated power stations have a neighbouring decommissioning Magnox station. As these are operated by different employers, workers at one station are considered to be members of the public to the other station. Work has been undertaken this year to consider how direct radiation doses from adjacent nuclear sites to workers at the other site are reported. In future RIFE reports, where this dose is higher than that to a member of the public outside of the combined site boundary, the dose will be reported in an additional footnote.*

[a] *Doses not significantly different from natural background*

[b] *Datum for Dungeness B. Dungeness A (0.010) not used*

[c] *Datum for Hinkley B. Hinkley A (Bgd[a]) not used*

[d] *Datum for Hunterston B. Hunterston A (0.001) not used*

[e] *Datum for Sizewell B. Sizewell A (Bgd[a]) not used*

[f] *For MoD sites, habits and dose rate measurements indicate that doses are indistinguishable from natural background*

**Table 1.2 *Total doses* integrated across pathways, 2017**

| Site | Representative person[a] | Exposure, mSv | |
|---|---|---|---|
| | | Total | Dominant contributions[b] |
| **A Gaseous releases and direct radiation from the site** | | | |
| Aldermaston & Burghfield | Local adult inhabitants (0.5–1km) | 0.010[g] | Direct radiation |
| 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 | <0.005 | Milk, $^{14}$C, $^{35}$S[c] |
| Bradwell | Prenatal children of local inhabitants (0–0.25km) | 0.011 | 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 | 0.035 | Milk, $^{90}$Sr, $^{241}$Am[c] |
| Derby | Children potato consumers | <0.005[g] | Potatoes, $^{234}$U, $^{238}$U |
| Devonport | Adult potato consumers | <0.005 | Fish, potatoes, $^{3}$H[c], $^{137}$Cs, $^{241}$Am[c] |
| Dounreay | Adult consumers of wild fruits and nuts | 0.010 | Direct radiation, Potatoes, $^{238}$Pu[c], $^{239/240}$Pu[c] |
| Dungeness | Local adult inhabitants (0–0.25km) | 0.021 | Direct radiation |
| Faslane | Infant honey consumers | <0.005 | Honey, $^{137}$Cs, $^{241}$Am[c] |
| Hartlepool | Local adult inhabitants (0–0.25km) | 0.031 | Direct radiation, gamma dose rate over sediment |
| Harwell | Local adult inhabitants (0–0.25km) | 0.046 | Direct radiation |
| Heysham | Local adult inhabitants (0–0.25km) | 0.024 | Direct radiation, gamma dose rate over sediment |
| Hinkley Point | Prenatal children of local inhabitants (0.5–1km) | 0.012 | Direct radiation, gamma dose rate over sediment |
| Hunterston | Adult other domestic vegetable consumers | 0.023 | Direct radiation |
| LLWR near Drigg | Infant local inhabitants (0.5–1km) | 0.056 | Direct radiation |
| Rosyth[d] | - | - | - |
| Sellafield | Adult other domestic vegetable consumers | 0.011[g] | Direct radiation, gamma dose rate over sediment, root vegetables, $^{241}$Am |
| Sizewell | Local adult inhabitants (0–0.25km) | 0.021 | Direct radiation |
| Springfields | Infant local inhabitants (0.5–1km) | 0.018[g] | Direct radiation |
| Torness | Local adult inhabitants (0.5–1km) | 0.021 | Direct radiation |
| Trawsfynydd | Infant local inhabitants (0.25–0.5km) | 0.015 | Milk, $^{241}$Am |
| Winfrith | Local adult inhabitants (0.25–0.5km) | 0.038 | Direct radiation |
| Wylfa | Infant local inhabitants (0.25–0.5km) | <0.005 | Milk, $^{14}$C, $^{35}$S, $^{137}$Cs |
| **B Liquid releases from the site** | | | |
| Aldermaston & Burghfield | Adult occupants over riverbank | 0.007 | Direct radiation |
| Amersham | Adult occupants over riverbank | <0.005 | Gamma dose rate over riverbank |
| Barrow | Adult occupants on houseboats | 0.074 | Gamma dose rate over sediment |
| Berkeley & Oldbury | Adult occupants over sediment | <0.005 | Gamma dose rate over sediment |
| Bradwell | Adult occupants on houseboats | <0.005 | Gamma dose rate over sediment |
| Capenhurst | Occupants over riverbank aged 10y | 0.008 | Gamma dose rate over sediment |
| Cardiff | Prenatal children of occupants over sediment | <0.005 | Gamma dose rate over sediment |
| Chapelcross | Adult wildfowl consumers | 0.010 | Gamma dose rate over sediment, molluscs, $^{239/240}$Pu, $^{241}$Am |
| Derby | Adult consumers of locally sourced water | <0.005 | Water, $^{60}$Co[c] |
| Devonport | Adult consumers of marine plants and algae | <0.005 | Fish, exposure over sediment, $^{241}$Am[c] |
| Dounreay | Adult occupants over sediment | 0.008 | Gamma dose rate over sediment |
| Dungeness | Adult occupants over sediment | 0.007 | Gamma dose rate over sediment |
| Faslane | Adult fish consumers | <0.005 | Fish, $^{137}$Cs, $^{241}$Am[c] |
| Hartlepool | Adult occupants over sediment | 0.025 | Direct radiation, gamma dose rate over sediment |
| Harwell | Adult occupants over sediment | <0.005 | Gamma dose rate over riverbank |
| Heysham | Adult occupants over sediment | 0.018 | Gamma dose rate over sediment |
| Hinkley Point | Prenatal children of occupants over sediment | 0.032 | Gamma dose rate over sediment |
| Hunterston | Adult mollusc consumers | 0.022 | Direct radiation, molluscs |
| LLWR near Drigg[e] | Adult mollusc consumers | 0.25[f] | Crustaceans, molluscs, $^{210}$Po |

**Table 1.2 continued**

| Site | Representative person[a] | Exposure, mSv | |
|---|---|---|---|
| | | Total | Dominant contributions[b] |
| Rosyth | Adult occupants over sediment | 0.026 | Gamma dose rate over sediment |
| Sellafield[e] | Adult mollusc consumers | 0.25[f] | Crustaceans, molluscs, $^{210}$Po |
| Sizewell | Adult occupants over sediment | 0.008 | Direct radiation, gamma dose rate over sediment |
| Springfields | Adult occupants on houseboats | 0.028 | Gamma dose rate over sediment |
| Torness | Adult mollusc consumers | <0.005 | Fish, molluscs, $^{241}$Am |
| Trawsfynydd | Prenatal children of occupants over sediment | 0.024 | Exposure over sediment |
| Whitehaven[e] | Adult mollusc consumers | 0.25[f] | Crustaceans, molluscs, $^{210}$Po |
| Winfrith | Adult occupants over sediment | 0.014 | Direct radiation, gamma dose rate over sediment |
| Wylfa | Adult occupants over sediment | <0.005 | Gamma dose rate over sediment |
| | | | |
| **C All sources** | | | |
| Aldermaston & Burghfield | Local adult inhabitants (0.5–1km) | 0.010[g] | Direct radiation |
| Amersham | Local adult inhabitants (0–0.25km) | 0.15[g] | Direct radiation |
| Barrow | Adult occupants on houseboats | 0.074 | Gamma dose rate over sediment |
| Berkeley & Oldbury | Adult occupants over sediment | <0.005 | Gamma dose rate over sediment |
| Bradwell | Prenatal children of local inhabitants (0–0.25km) | 0.011 | Direct radiation |
| Capenhurst | Infant local inhabitants (0.25–0.5km) | 0.17[g] | Direct radiation |
| Cardiff | Prenatal children of occupants over sediment | <0.005 | Gamma dose rate over sediment |
| Chapelcross | Infant milk consumers | 0.035 | Milk, $^{90}$Sr, $^{241}$Am[c] |
| Derby | Adult consumers of locally sourced water | <0.005 | Water, $^{60}$Co[c] |
| Devonport | Adult consumers of marine plants and algae | <0.005 | Fish, exposure over sediment, $^{241}$Am[c] |
| Dounreay | Adult consumers of wild fruits and nuts | 0.010 | Direct radiation, Potatoes, $^{238}$Pu[c], $^{239/240}$Pu[c] |
| Dungeness | Local adult inhabitants (0–0.25km) | 0.021 | Direct radiation |
| Faslane | Adult fish consumers | <0.005 | Fish, $^{137}$Cs, $^{241}$Am[c] |
| Hartlepool | Local adult inhabitants (0–0.25km) | 0.031 | Direct radiation, gamma dose rate over sediment |
| Harwell | Local adult inhabitants (0–0.25km) | 0.046 | Direct radiation |
| Heysham | Local adult inhabitants (0.25–0.5km) | 0.025 | Direct radiation, gamma dose rate over sediment |
| Hinkley Point | Prenatal children of occupants over sediment | 0.032 | Gamma dose rate over sediment |
| Hunterston | Adult root vegetable consumers | 0.023 | Direct radiation |
| LLWR near Drigg[e] | Adult mollusc consumers | 0.25[f] | Crustaceans, molluscs, $^{210}$Po |
| Rosyth | Adult occupants over sediment | 0.026 | Gamma dose rate over sediment |
| Sellafield[e] | Adult mollusc consumers | 0.25[f] | Crustaceans, molluscs, $^{210}$Po |
| Sizewell | Local adult inhabitants (0–0.25km) | 0.021 | Direct radiation |
| Springfields | Adult occupants on houseboats | 0.028 | Gamma dose rate over sediment |
| Torness | Local adult inhabitants (0.5–1km) | 0.021 | Direct radiation |
| Trawsfynydd | Prenatal children of occupants over sediment | 0.024 | Exposure over sediment |
| Whitehaven[e] | Adult mollusc consumers | 0.25[f] | Crustaceans, molluscs, $^{210}$Po |
| Winfrith | Local adult inhabitants (0.25–0.5km) | 0.038 | Direct radiation |
| Wylfa | Adult occupants over sediment | <0.005 | Gamma dose rate over sediment |

[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 0.077 and 0.18 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 |
|---|---|---|---|---|---|---|---|---|
| Aldermaston & Burghfield | <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 |
| Barrow | | | | | | | | |
| Berkeley & Oldbury | | *0.12* | *0.090* | *0.042* | 0.061 | 0.041 | 0.058 | 0.011 |
| Bradwell | | *0.09* | *0.067* | *0.075* | 0.070 | 0.070 | 0.098 | 0.13 |
| Capenhurst | | *0.080* | *0.080* | *0.085* | *0.12* | 0.17 | 0.19 | 0.26 |
| Cardiff | 0.038 | 0.023 | 0.023 | 0.011 | 0.008 | 0.007 | 0.006 | 0.006 |
| Chapelcross | | *0.022* | 0.023 | 0.024 | 0.019 | 0.021 | 0.017 | 0.029 |
| Derby | | | | | | | <0.005 | <0.005 |
| Devonport | | <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 |
| Dungeness | | *0.48* | 0.55 | 0.63 | 0.28 | 0.40 | 0.32 | 0.022 |
| Faslane | | *<0.005* | *<0.005* | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 |
| Hartlepool | 0.021 | 0.020 | 0.021 | 0.021 | 0.021 | 0.026 | 0.027 | 0.025 |
| Harwell | | *0.017* | *0.022* | *0.026* | 0.022 | 0.020 | 0.023 | 0.018 |
| Heysham | | *0.036* | *0.028* | 0.037 | 0.038 | 0.046 | 0.049 | 0.057 |
| Hinkley Point | | *0.026* | *0.027* | 0.048 | 0.035 | 0.045 | 0.055 | 0.014 |
| Hunterston | | 0.10 | 0.090 | 0.074 | 0.090 | 0.077 | 0.067 | 0.067 |
| LLWR near Drigg[b] | 0.66 | 0.58 | 0.40 | 0.43 | 0.37 | 0.47 | 0.28 | 0.18 |
| Rosyth | | *<0.005* | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 |
| Sellafield[b] | 0.66 | 0.58 | 0.40 | 0.43 | 0.37 | 0.47 | 0.28 | 0.18 |
| Sizewell | | *0.045* | 0.086 | 0.090 | <0.005 | 0.031 | 0.026 | 0.020 |
| Springfields | | *0.17* | *0.15* | 0.13 | 0.11 | 0.16 | 0.15 | 0.17 |
| Torness | | *0.024* | *0.025* | 0.024 | 0.022 | 0.022 | 0.022 | 0.025 |
| Trawsfynydd | | *0.032* | 0.021 | 0.028 | 0.018 | 0.031 | 0.018 | 0.028 |
| Whitehaven[b] | 0.66 | 0.58 | 0.40 | 0.43 | 0.37 | 0.47 | 0.28 | 0.18 |
| Winfrith | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 |
| Wylfa | | 0.011 | 0.010 | 0.011 | 0.011 | 0.011 | 0.011 | 0.007 |

| Site | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 |
|---|---|---|---|---|---|---|---|
| Aldermaston & Burghfield | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | 0.010 |
| Amersham | 0.22 | 0.22 | 0.22 | 0.14 | 0.14 | 0.15 | 0.15 |
| Barrow | | 0.057 | 0.076 | 0.055 | 0.051 | 0.082 | 0.074 |
| Berkeley & Oldbury | 0.006 | 0.014 | 0.010 | <0.005 | <0.005 | 0.006 | <0.005 |
| Bradwell | 0.048 | <0.005 | <0.005 | <0.005 | 0.017 | 0.036 | 0.011 |
| Capenhurst | 0.095 | 0.085 | 0.080 | 0.17 | 0.13 | 0.17 | 0.17 |
| Cardiff | 0.006 | 0.005 | 0.010 | <0.005 | <0.005 | <0.005 | <0.005 |
| Chapelcross | 0.037 | 0.011 | 0.024 | 0.014 | 0.022 | 0.026 | 0.035 |
| Derby | <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 |
| Dounreay | 0.018 | 0.017 | 0.012 | 0.012 | 0.010 | 0.058 | 0.010 |
| Dungeness | 0.021 | 0.015 | 0.021 | 0.021 | 0.014 | 0.021 | 0.021 |
| Faslane | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | 0.009 | <0.005 |
| Hartlepool | 0.025 | 0.015 | 0.024 | 0.027 | 0.022 | 0.020 | 0.031 |
| Harwell | 0.017 | 0.018 | 0.010 | 0.016 | 0.017 | 0.015 | 0.046 |
| Heysham | 0.025 | 0.025 | 0.028 | 0.023 | 0.023 | 0.019 | 0.025 |
| Hinkley Point | 0.014 | 0.013 | 0.022 | 0.022 | 0.016 | 0.013 | 0.032 |
| Hunterston | 0.050 | 0.032 | 0.021 | 0.021 | 0.025 | 0.021 | 0.023 |
| LLWR near Drigg[b] | 0.18 | 0.30 | 0.061 | 0.22 | 0.42 | 0.41 | 0.25 |
| Rosyth | <0.005 | <0.005 | <0.005 | <0.005 | 0.006 | 0.017 | 0.026 |
| Sellafield[b] | 0.18 | 0.30 | 0.076[c] | 0.22 | 0.42 | 0.41 | 0.25 |
| Sizewell | 0.021 | 0.021 | 0.021 | 0.020 | 0.021 | 0.021 | 0.021 |
| Springfields | 0.13 | 0.068 | 0.060 | 0.050 | 0.050 | 0.038 | 0.028 |
| Torness | 0.020 | 0.020 | 0.020 | 0.020 | 0.020 | 0.021 | 0.021 |
| Trawsfynydd | 0.012 | 0.025 | 0.017 | 0.013 | 0.014 | 0.019 | 0.024 |
| Whitehaven[b] | 0.18 | 0.30 | 0.061 | 0.22 | 0.42 | 0.41 | 0.25 |
| Winfrith | <0.005 | <0.005 | <0.005 | <0.005 | 0.014 | 0.019 | 0.038 |
| Wylfa | 0.008 | 0.006 | <0.005 | 0.007 | 0.013 | 0.008 | <0.005 |

[a] *Where no data is 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, 2017

| 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 | 0.010 | 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 | 0.013 | Ext |
| | Terrestrial foods, external and inhalation near site | G | <0.005[i] | $^{234}U$, $^{238}U$ |
| | External in intertidal areas (children playing)[a,h] | L | <0.005 | Ext |
| | Occupancy of houseboats | L | 0.028 | Ext |
| | External in intertidal areas (farmers) | L | 0.023 | Ext |
| | Wildfowl consumers | L | <0.005 | Ext |
| | External (skin) to fishermen | L | 0.033[g] | Beta |
| Sellafield[f] | Fish and shellfish consumption and external in intertidal areas (2013-2017 surveys) (excluding naturally occurring radionuclides)[l] | L | 0.085 | Ext, $^{241}Am$ |
| | Fish and shellfish consumption and external in intertidal areas (2013-2017 surveys) (including naturally occurring radionuclides)[m] | L | 0.27 | Ext, $^{210}Po$ |
| | Fish and shellfish consumption and external in intertidal areas (2017 surveys) (excluding naturally occurring radionuclides)[l] | L | 0.082 | Ext, $^{241}Am$ |
| | Terrestrial foods, external and inhalation near Sellafield[j] | G | 0.011 | $^{14}C$, $^{90}Sr$, $^{241}Am$ |
| | Terrestrial foods at Ravenglass[j] | G/L | 0.020 | $^{106}Ru^{d}$, $^{144}Ce^{d}$ |
| | External in intertidal areas (Ravenglass)[a] | L | 0.007 | Ext |
| | Occupancy of houseboats (Ribble estuary) | L | 0.028 | Ext |
| | Occupancy of houseboats (Barrow) | L | 0.071 | Ext |
| | External (skin) to bait diggers | L | 0.067[g] | Beta |
| | Handling of fishing gear | L | 0.11[g] | Beta |
| | | | | |
| **Research establishments** | | | | |
| Culham | Water consumption[o] | L | <0.005 | $^{137}Cs^{d}$ |
| Dounreay | Fish and shellfish consumption and external in intertidal areas | L | 0.008 | Ext |
| | Terrestrial foods, external and inhalation near site | G | 0.011 | $^{129}I$, $^{238}Pu^{c}$, $^{239/240}Pu^{c}$, $^{241}Am$ |
| Harwell | Fish consumption and external to anglers | L | <0.005 | Ext |
| | Terrestrial foods, external and inhalation near site[j] | G | <0.005 | $^{3}H^{d}$, $^{222}Rn$ |
| 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 | 0.016 | Ext |
| | Terrestrial foods, external and inhalation near site[j] | G | <0.005 | $^{14}C$, $^{35}S^{d}$ |
| Bradwell | 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 | $^{3}H^{d}$, $^{14}C$ |
| Chapelcross | Wildfowl, fish and mollusc consumption and external in intertidal areas | L | 0.014 | Ext, $^{239/240}Pu$ $^{241}Am$ |
| | Crustacean consumption | L | <0.005 | $^{90}Sr$, $^{106}Ru^{d}$ |
| | Terrestrial foods, external and inhalation near site[j] | G | 0.023 | $^{90}Sr$, $^{241}Am^{d}$ |
| Dungeness | Fish and shellfish consumption and external in intertidal areas | L | 0.006 | Ext, $^{241}Am$ |
| | Occupancy of houseboats | L | 0.014 | Ext |
| | Terrestrial foods, external and inhalation near site[j] | G | <0.005 | $^{14}C$, $^{35}S^{d}$, $^{60}Co^{d}$ |
| Hartlepool | Fish and shellfish consumption and external in intertidal areas | L | 0.019 | Ext, $^{131}I^{d}$, $^{241}Am$ |
| | 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 | 0.026 | Ext, $^{241}Am$ |
| | External in intertidal areas (turf cutters) | L | 0.008 | Ext |
| | Terrestrial foods, external and inhalation near site[j] | G | 0.005 | $^{14}C$, $^{35}S^{d}$, $^{60}Co^{d}$ |
| Hinkley Point | Fish and shellfish consumption and external in intertidal areas | L | 0.019 | Ext |
| | Terrestrial foods, external and inhalation near site[j] | G | 0.007 | $^{14}C$, $^{35}S^{d}$ |
| Hunterston | Fish and shellfish consumption and external in intertidal areas | L | 0.005 | Ext, $^{137}Cs$, $^{239/240}Pu$, $^{241}Am$ |
| | Terrestrial foods, external and inhalation near site[j] | G | 0.016 | $^{14}C$, $^{35}S$, $^{90}Sr$ |
| 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 | <0.005 | $^{14}C$, $^{35}S$ |

**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 | 0.013 | $^{90}$Sr, $^{241}$Am[d] |
| Trawsfynydd | Fish consumption and external to anglers | L | 0.026 | Ext |
| | Terrestrial foods, external and inhalation near site[j] | G | 0.028 | $^{241}$Am |
| Wylfa | Fish and shellfish consumption and external in intertidal areas | L | 0.007 | Ext, $^{241}$Am |
| | Terrestrial foods, external and inhalation near site[j] | G | <0.005 | $^{14}$C, $^{35}$S, $^{137}$Cs |
| **Defence establishments** | | | | |
| Aldermaston & Burghfield | 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] |
| Barrow | Occupancy of houseboats | L | 0.071 | Ext |
| | Terrestrial food consumption | G | <0.005 | $^{3}$H[d], $^{137}$Cs |
| Derby | Water consumption, fish consumption and external to anglers[o] | L | <0.005 | Ext, $^{60}$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 | Ext, $^{241}$Am[d] |
| | Occupancy of houseboats | L | <0.005 | Ext |
| | Terrestrial foods, external and inhalation near site[p] | G | <0.005 | $^{3}$H[d], $^{14}$C |
| Faslane | Fish and shellfish consumption and external in intertidal areas | L | 0.005 | $^{137}$Cs, $^{241}$Am[d] |
| | Terrestrial food consumption | G | <0.005 | $^{137}$Cs, $^{241}$Am[d] |
| Holy Loch | External in intertidal areas | L | 0.009 | Ext |
| Rosyth | Fish and shellfish consumption and external in intertidal areas | L | 0.026 | Ext |
| **Radiochemical production** | | | | |
| Amersham | Fish consumption and external to anglers | L | <0.005 | Ext |
| | Terrestrial foods, external and inhalation near site[j] | G | 0.011 | $^{222}$Rn |
| Cardiff | Fish and shellfish consumption and external in intertidal areas[p] | L | 0.006 | 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 | $^{3}$H[d], $^{14}$C |
| **Industrial and landfill** | | | | |
| LLWR near Drigg | Terrestrial foods[j] | G | 0.005 | $^{14}$C, $^{90}$Sr, $^{106}$Ru[d] |
| | Fish and shellfish consumption and external in intertidal areas (2013-2017 surveys) (including naturally occurring radionuclides)[f,m] | L | 0.27 | Ext, $^{210}$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 (2013-2017 surveys) (excluding artificial radionuclides)[f,k] | L | 0.18 | $^{210}$Po |
| | Fish and shellfish consumption and external in intertidal areas (2013-2017 surveys) (including artificial radionuclides)[f,n] | L | 0.27 | Ext, $^{210}$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 is reprocessed from nuclear power stations.

The Capenhurst site is owned partly by Urenco UK Limited (UUK) and partly by the NDA. UUK holds the Site Licence, and their main commercial business is production of enriched uranium for nuclear power stations. The NDA's legacy storage and decommissioning activities are managed by an Urenco Group company, Capenhurst Nuclear Services Limited (CNS). On 30 October 2017, CNS was renamed as Urenco Nuclear Stewardship Limited (UNS). Another Urenco Group company, Urenco ChemPlants Limited (UCP), is currently building a new facility (Tails Management Facility, planned to be commissioned in late 2018) on a separate part of the site.

Both the Springfields and Sellafield sites are owned by the NDA. The Springfields site is leased long-term to Springfields Fuels Limited and used to carry out nuclear fuel manufacture and other commercial activities. Springfields Fuels Limited have a contract with the 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. In 2016, the 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 the NDA, is located on the Sellafield site. In 2008, the site licence for Windscale was transferred to Sellafield Limited. Following an application from Sellafield Limited, and acceptance by ONR, the site operators were granted a revised permit effective from 1 April 2017, that covers Sellafield only (amalgamating the Sellafield and Windscale nuclear 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.

## Key points

- *Total doses* for the representative person were 25 per cent (or less) of the dose limit for all assessed sites and decreased in 2017

### Capenhurst, Cheshire

- *Total dose* for the representative person was 0.17 mSv and unchanged in 2017
- Liquid discharges of non-uranic alpha radioactivity decreased in 2017

### Springfields, Lancashire

- *Total dose* for the representative person was 0.028 mSv and decreased in 2017
- Liquid discharges of technetium-99, neptunium-237 and "other transuranic radionuclides" increased in 2017

### Sellafield, Cumbria

- *Total doses* for the representative person were 0.25 mSv (or less) of the public dose limit and decreased in 2017
- The highest *total doses* were from seafood, dominated by the effects of naturally occurring radionuclides. Historical discharges from Sellafield made a lesser contribution
- Radiation dose from an environmental legacy of naturally occurring radionuclides (non-nuclear industry) was lower in 2017. The contribution to *total dose* from Sellafield discharges also decreased in 2017
- Gaseous discharges of antimony-125, krypton-85 and iodine-129 decreased, and plutonium alpha increased, in 2017. Liquid discharges of iodine-129 decreased in 2017
- The mean concentrations of americium-241 in locally harvested molluscs in 2017 are the lowest reported values, in comparison to previous years

Gaseous and liquid discharges from each of these sites are regulated by the Environment Agency. In 2017, gaseous and liquid discharges were below permit limits for each of the sites (see Appendix 2).

## 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, UNS (previously CNS) and UCP. UUK operates three plants producing enriched uranium for nuclear power stations. UNS (previously CNS) manages assets owned by the 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 2018. The plant is permitted for Radioactive Substances Activities 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 of radiation was 0.17 mSv (Table 2.1) in 2017, or 17 per cent of the dose limit, and unchanged from 2016. 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. The trend in *total dose* over the period 2004 – 2017 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 for high-rate consumers of locally grown foods, and for children playing in and around Rivacre Brook, give exposures that were less than the *total dose* in 2017 (Table 2.1). The dose for children (10 year-old), who play in and around the brook and may inadvertently ingest water and sediment, was 0.010 mSv in 2017 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 UNS (previously CNS). The focus for terrestrial sampling was the analyses of technetium-99 and uranium in food (including milk), grass and soil. Results for 2017 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. Figure 2.2 shows the trends over time (2004 – 2017) of technetium-99 concentrations in grass. 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 based on data reported as less than values. If the enrichment of reprocessed uranium was to increase in the future, this 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 were similar in 2017 in comparison to those releases in 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. Results for 2017 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. The low concentrations in fish and shellfish reflect the distant effects of discharges from Sellafield. Low concentrations of thorium-234 were detected in mussels and cockles in 2017. As in previous years, sediment samples collected


**Figure 2.1.** *Total dose* at nuclear fuel production and reprocessing sites, 2004-2017
(Exposures at Sellafield/Whitehaven/LLWR receive a significant contribution to the dose from technologically enhanced naturally occurring radionuclides from previous non-nuclear industrial operations)

downstream from the Rivacre Brook contained very low but measurable concentrations of uranium (enhanced above natural levels) and technetium-99. As expected, enhanced concentrations of these radionuclides (and others) were measured close to the discharge point (Rivacre Brook). However, concentrations of technetium-99, thorium-234 and uranium radionuclides from this location were higher in 2017, compared to those in recent years. Permitted discharges from the effluent treatment plant were within the normal range in 2017 and there were no recent activities on site that would have led to elevated activity concentrations in sediments, close to the discharge point. The higher (than usual) radionuclide concentrations in 2017 are therefore thought to be from either the accumulation of older sediment in the site drains (that has then been flushed out), or from natural processes occurring in the brook (in which historical sediment has been disturbed and transported to the surface). Variations in concentrations in sediment from the brook are also to be expected due to differences in the size distribution of the sedimentary particles. Concentrations of radionuclides in freshwaters at the discharge point (and other freshwaters) were very low in 2017, and similar to those in 2016. 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 2016.

Figure 2.2 also shows the trends over time (2004 – 2017) of a number of other permitted radionuclides and activity concentrations in environmental samples. Since 2004, the overall trend was a reduction of liquid discharges over time. Most of the reductions were attributed to progress in decommissioning some of the older plant and equipment. Concentrations of technetium-99 in sediment (Rivacre Brook) from liquid discharges were detectable close to the discharge point. The increase in 2007 was probably due to the discharge occurring at the same time as environmental sampling. Concentrations of caesium-137 and americium-241 in sediments at Rock Ferry on the Irish Sea coast were from past discharges from Sellafield carried into the area by tides and currents. The concentrations were generally similar over most of the time period and any fluctuations were most likely due to normal changes in the environment. The lowest activity concentrations were reported in 2016 at both locations.

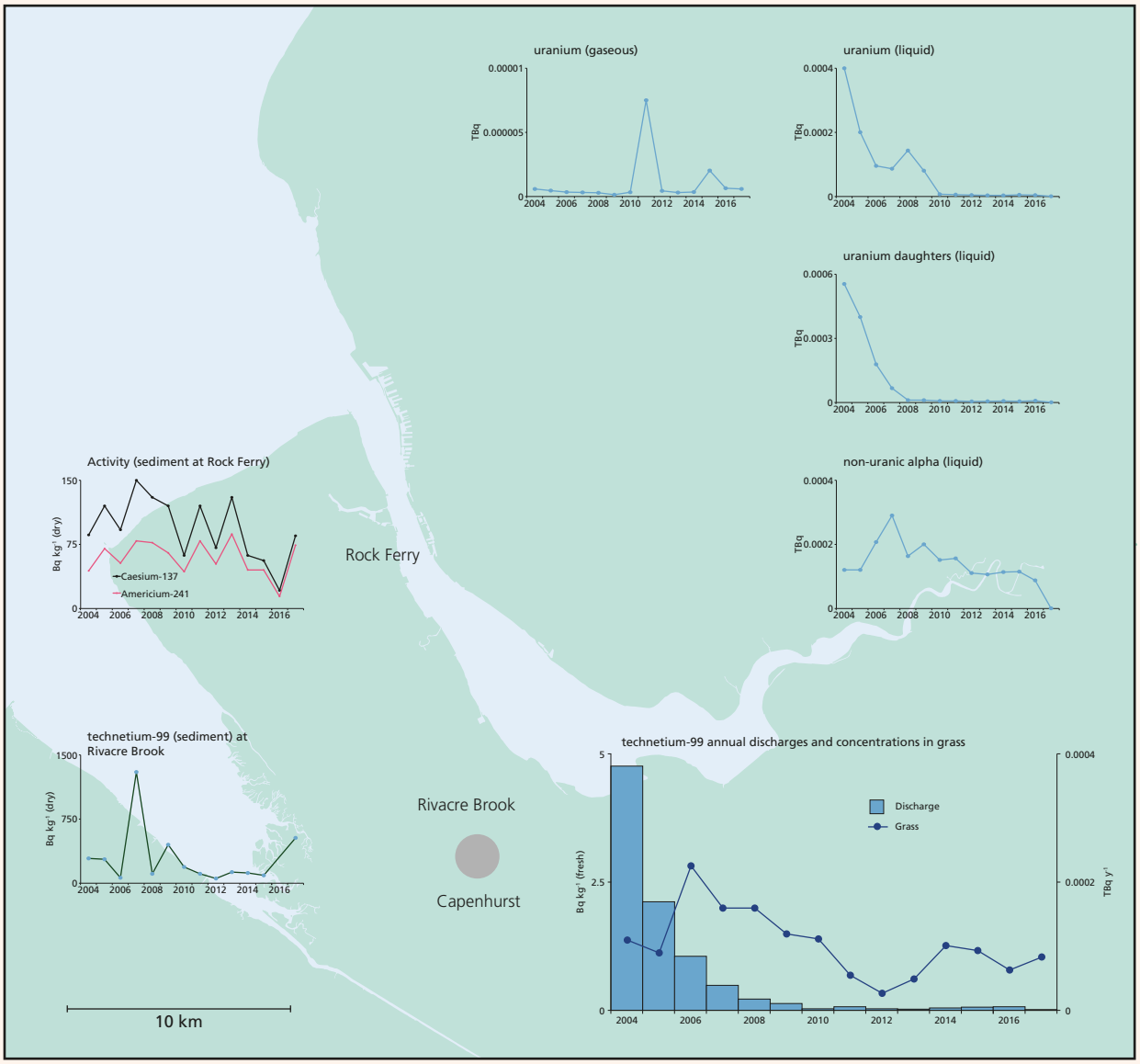



**Figure 2.2.** Discharges of gaseous and liquid radioactive wastes and monitoring of the environment, Capenhurst (2004-2017) (Note different scales used for discharges and activity concentrations)

## 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 the 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 the 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 2017, based on a five-year rolling average (2013 – 2017), the occupancy rate was unchanged for high-rate houseboat dwellers. Figures for consumption rates, together with occupancy and handling rates, are provided in Appendix 1 (Table X2.2).

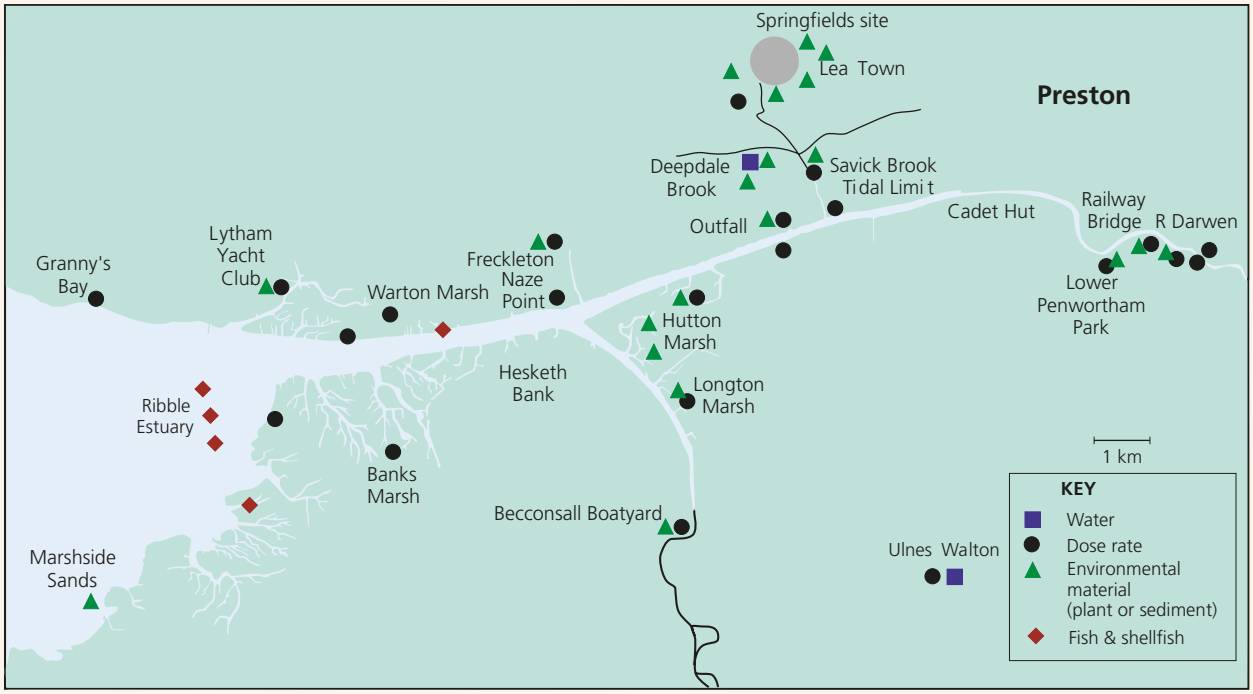



**Figure 2.3.** Monitoring locations at Springfields, 2017 (not including farms)

## Doses to the public

In 2017, the *total dose* from all pathways and sources is assessed to have been 0.028 mSv (Table 2.1), or less than 3 per cent of the dose limit, and down from 0.038 mSv in 2016. 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 2016) 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 underneath a houseboat in 2017. Therefore, dose rates were derived by using measurements outside the houseboat (in 2017), and then adjusting these values by the ratio of on-board and outside dose rates from results reported (and taken underneath 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 – 2017 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 locally grown food and of seafood
- Wildfowlers consuming game obtained from the estuary area
- Farmers spending time on the banks of the estuary
- Children playing on the banks of the estuary

In 2017, the source specific assessment gives an estimated dose to a high-occupancy houseboat dweller of 0.028 mSv, or less than 3 per cent of the dose limit for members of the public of 1 mSv, and was lower than that in 2016 (0.038 mSv). The reason for the decrease in dose in 2017 (from 2016) is the same as that contributing to the maximum *total dose*. This value is identical to the *total dose* (with more realistic assumptions) of 0.028 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 0.013 mSv in 2017. Of this dose, approximately 0.012 mSv was from external exposure and the remainder was from the consumption of fish and shellfish. The dose in 2016 was 0.019 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 0.033 mSv in 2017, 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 also undertaken to determine the dose to: wildfowlers from external exposure over salt marsh and the consumption of game; to farmers from external exposure; to high-rate consumers of locally grown food; and to children playing on the banks of the estuary, at Springfields. The estimated doses in 2017 were less than 0.005 mSv, 0.023 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

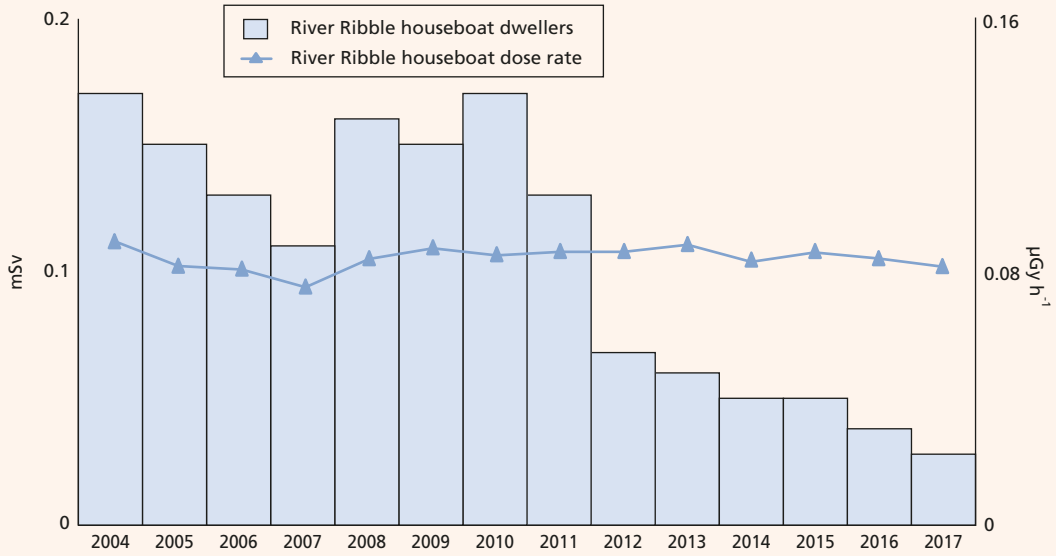



**Figure 2.4.** *Total dose* from all sources and dose rates at Springfields, 2004-2017

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.

The focus of the terrestrial sampling was for the analyses 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 2017 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. The concentrations of uranium isotopes in beetroot were higher in 2017, in comparison to those in recent years, but the concentrations were low. Concentrations of thorium were also low in vegetable and grass samples, with the carbon-14 concentration was just above the default value used to represent the background levels. 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 – 2017) of uranium discharges and total uranium radionuclide concentrations in food (cabbage; 2004 – 2013: beetroot; 2014 – 2017). 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 and higher value in beetroot in 2017 were 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 technetium-99, neptunium-237 and "other transuranic radionuclides" increased (due to the processing of particular residues) in 2017, in comparison to releases in 2016. 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 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 2017 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.

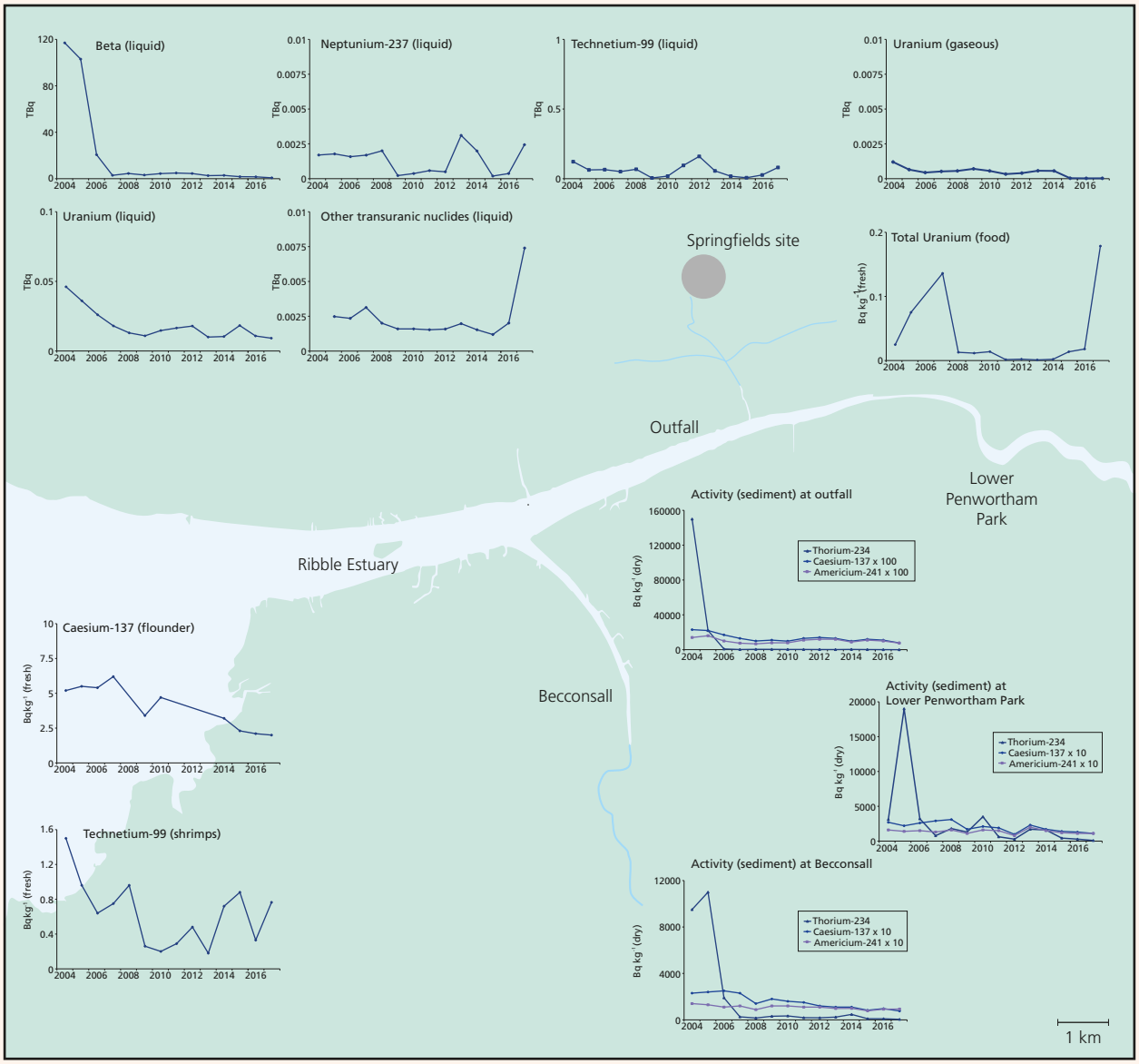



**Figure 2.5.** Discharges of gaseous and liquid radioactive wastes and monitoring of the environment, Springfields 2004–2017 (Note different scales used for discharges and activity concentrations)

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 2017, thorium-234 concentrations in sediments (over the range of sampling sites) were lower compared to those in 2016 and the values reported for the outfall, Becconsall and Lower Penwortham Park were the lowest values in recent years. Over a much longer timescale (2004 – 2017), these concentrations have also 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.

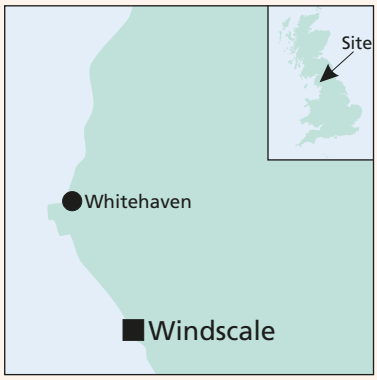
Caesium-137, americium-241 and plutonium radionuclides were found in biota and sediments from the Ribble Estuary in 2017. The presence of these radionuclides was due to past liquid discharges from Sellafield, carried from west Cumbria into the Ribble Estuary by sea currents and adsorbed on fine-grained muds. The concentrations observed were generally similar to those in recent years.

Figure 2.5 also provides trend information over time (2004 – 2017) 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 evidence of decreasing concentrations overall. Concentrations of technetium-99 in shrimps generally declined over the whole period, consistent with

the reduction in technetium-99 discharges from Sellafield (Figure 2.17); the apparent increases in recent years was due to the inclusion of reported less than values.

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 2017, gamma dose rates in the estuary, excluding rates taken for houseboat assessments, were generally lower to those in 2016, but with some small variations at some sites. In 2017, gamma dose rates measured in the vicinity of one of the houseboat locations (at Becconsall) were lower than those in 2016. Beta dose rates over salt marsh (where comparisons can be made) were similar to those in recent years.

## 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 2019 (NDA, 2018). The Windscale site is located at Sellafield and this site is discussed in Section 2.4.

In March 2017, Sellafield Limited submitted an application to vary its environmental permit. In June 2017, the Environment Agency consulted on the application. The permit variation application covers several issues relating to changes to the permitted waste types and activity limits. The application was to facilitate the disposal of decommissioning waste from the site. The opportunity was taken to make a number of other improvements to the permit. The changes requested were:

- Increase in disposal limits for the Calder Landfill Extension Segregated Area (CLESA) site landfill (from 37 Bq $g^{-1}$ to an average of 200 Bq $g^{-1}$)
- 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
- Removal of THORP plant limits based on adoption of standardised reporting of radioactive discharges

The varied permit was issued by the Environment Agency and was effective from 1 December 2017. There were some improvement and pre-operational conditions associated with the new disposal limits for CLESA.

In July 2017, Sellafield Limited published their first Corporate Strategy, as a wholly-owned subsidiary of the NDA, as well as a Transformation Plan (**https://www.gov.uk/government/collections/priorities-and-progress**).

Sellafield Limited continued retrievals of sludge from legacy pond facilities in 2017 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 2017, a number of decommissioning projects continued including that of the Calder Hall reactors.

During the financial year 2017/18, 305 tonnes of uranium were processed through THORP (compared with 450 tonnes in 2016/2017). In respect of Magnox fuel, 384 tonnes of uranium were processed for 2017/18 (compared with 465 tonnes in 2016/2017). The reprocessing of the remaining fuel is scheduled to end in late 2018 and 2020 for THORP and Magnox reprocessing, respectively (NDA, 2018).

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 2017, some changes were found in the amounts (and mixes) of species consumed and in handling and intertidal occupancy rates (Moore *et al.*, 2018a) from the full habits survey conducted in 2013. Further afield, the most recent habits surveys were conducted to determine the consumption and occupancy rates by members of the public on the Dumfries and Galloway coast in 2017 (SEPA, *in press*/a) and around Barrow and the south-west Cumbrian coast in 2012 (Garrod *et al.*, 2013). On the Dumfries and Galloway coast, a large increase in both the fish and crustacean consumption rates has been observed, together with an increase in the occupancy rate, in comparison with those of the previous survey in 2012. The results of these surveys 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 near Whitehaven in Cumbria. Although the plant closed in 1992, an environmental legacy has occurred from these past operations due to the decay of the long-lived parent radionuclides (historical discharges to sea) and the production of the daughter products. 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 site and chemical plant (near Whitehaven) 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 the 2017 review (Moore *et al*., 2018a). 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 an environmental legacy of naturally occurring radionuclides from non-nuclear industrial activity from the former phosphate works near 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 environmental legacy of historical discharges is difficult to determine above a variable background (see Appendix 1, Annex 4).

In 2017, the highest *total dose* in the vicinity of Sellafield was assessed to have been 0.25 mSv, or 25 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 environmental legacy of naturally occurring radionuclides). As in most recent years, the representative person was adults consuming molluscan shellfish at high rates near Sellafield. The person also consumed significant quantities of other seafood. This represents a decrease in *total dose* in 2017, from 0.41 mSv in 2016. The decrease in *total dose* was mostly attributable to lower concentrations of polonium-210 in locally caught crustaceans (lobsters) in 2017, in comparison to those in 2016. Polonium-210 (and lead-210) are important radionuclides in that small changes in levels above background significantly influence the dose contribution from these radionuclides (due to a relatively high dose coefficient used in converting the activity concentration to a dose value) and therefore the value of the estimated dose. Direct radiation from the Sellafield site (0.004 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 2017 were from crustacean, mollusc and fish consumption and (75, 12 and 7 per cent, respectively) and external exposure over sediments (6 per cent). The important radionuclides were polonium-210, americium-241, iodine-129, and plutonium-239+240 (67, 11, 5 and 4 per cent, respectively).

Artificial radionuclides discharged by Sellafield (including external radiation) and the environmental legacy of naturally occurring radionuclides contributed 0.077 mSv and 0.18 mSv, respectively (values are rounded to two significant figures). In 2016, the contributions were 0.074 mSv and 0.34 mSv, respectively. In 2017, the contribution from the external radiation was 0.016 mSv (0.019 mSv in 2016). Data for naturally occurring radionuclides in fish and shellfish, and their variation in recent years, are discussed in Section 7.4.

The contribution to the *total dose* of 0.077 mSv in 2017 from artificial radionuclides (including external radiation) was higher than in 2016 (0.074 mSv). The small increase in the contribution to the *total dose* from 2016 was mostly attributed to higher americium-241 concentrations in crustaceans (lobsters) in 2017. The contributing radionuclides in 2017 were mostly americium-241, iodine-129, plutonium-239+240 and carbon-14 (35, 15, 13 and 5 per cent, respectively). External exposure was 21 per cent (26 per cent in 2016) of the *total dose* from artificial radionuclides.

The contribution to the *total dose* of 0.18 mSv in 2017 from naturally occurring radionuclides was lower than in 2016 (0.34 mSv). In 2017, the most contributing radionuclide was polonium-210 (~ 95 per cent). The decrease in the *total dose* was mostly attributable to

lower concentrations of polonium-210 in locally caught crustaceans (lobsters) in 2017, in comparison to those in 2016. In 2017, polonium-210 concentrations (above expected background) in locally caught lobsters and other crustaceans (including crabs) contributed 0.11 mSv and 0.059 mSv (values are rounded to two significant figures), respectively to the *total dose*. In 2017, there was no contribution to the *total dose* from polonium-210 concentrations (above the expected background) in mollusc samples (as in 2016).

Contributions to the highest *total dose* each year (2004 – 2017), from all pathways and sources by specific radionuclides, are given in Figure 2.6. Over the period, the trend is of generally declining dose. 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 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 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 in locally caught lobsters and crabs.

The contributions (from all pathways and sources) to the highest *total dose* each year from the non-nuclear and nuclear industries, and from each pathway of exposure (for adults), are also given in Figures 2.7 and 2.8, respectively. The overall trend from the nuclear industries 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 – 2017. The pathways of exposure contributing the highest dose were mollusc, crustacean and sea fish consumers.

Other age groups received less exposure than the adult *total dose* of 0.25 mSv in 2017 (10 year-old children: 0.12; 1 year-old infants: 0.071; prenatal children: 0.052, 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.

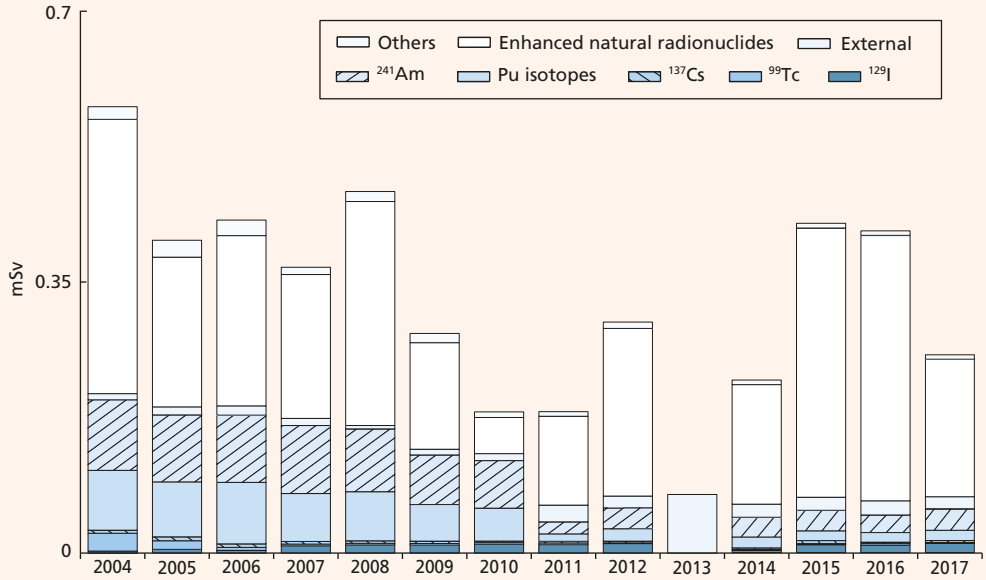



**Figure 2.6.** Contributions to *total dose* from all sources at Sellafield, 2004-2017 (The highest *total dose* in 2013 due to Sellafield discharges was to people living on houseboats near Barrow in Cumbria)

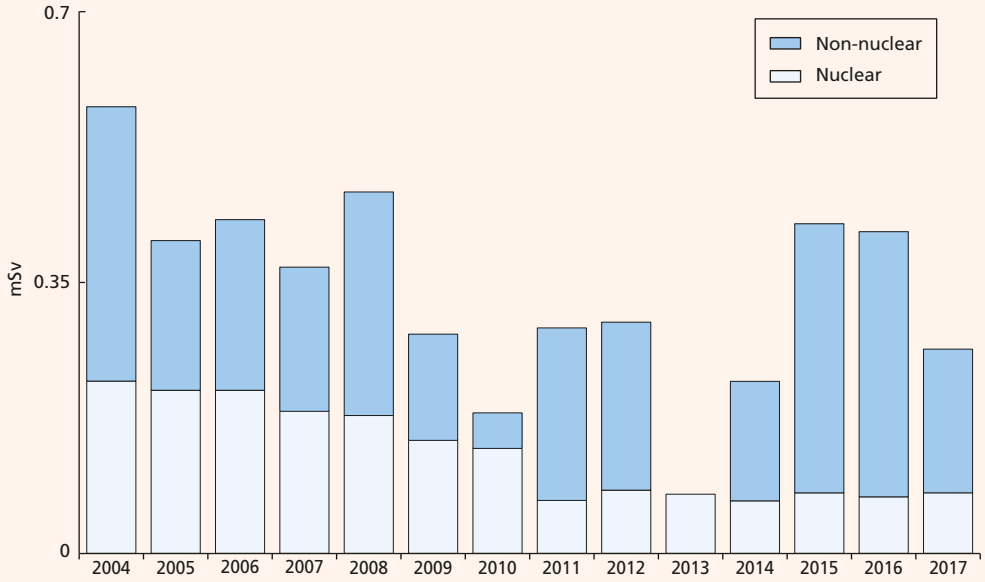



**Figure 2.7.** Contributions from nuclear and non-nuclear industries to *total dose* from all sources at Sellafield, 2004-2017 (The highest *total dose* in 2013 due to Sellafield discharges was to people living on houseboats near Barrow in Cumbria)

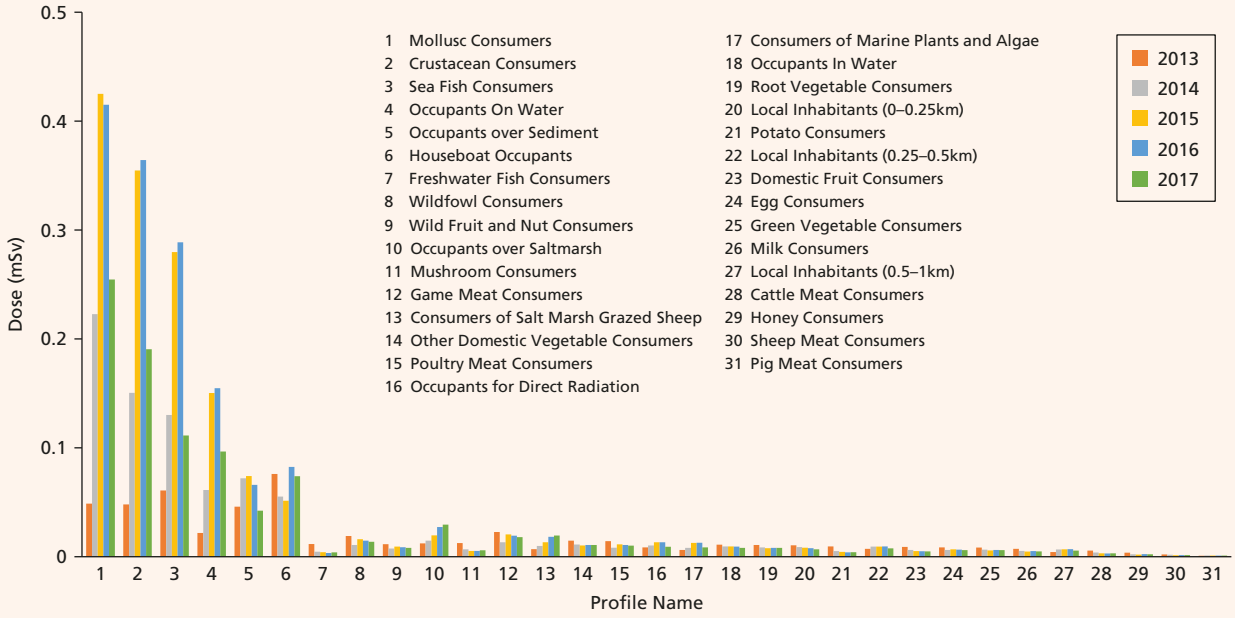



**Figure 2.8.** Contributions from each pathway of exposure to the *total dose* from all sources, 2013-2017

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

In 2017, the dose to a representative person receiving the highest *total dose* from the pathways predominantly relating to gaseous discharges and direct radiation was 0.011 mSv (Table 2.17), and up from 0.008 mSv (in 2016). The most exposed age group in 2017 was adults consuming other domestic vegetables (at high rates) and the dominant contribution to this dose was external exposure over sediments. This represents a change in the representative person from 2016 (local children living near to the site). The small increase in the *total dose*, and the change in the most exposed group, was attributable to a combination of reasons: the inclusion of a result obtained for a root vegetable (not collected in 2016) in the assessment in 2017, and thus including the contribution of americium-241 in swede (reported as a less than value); an increase from the external exposure over sediments in 2017 (from gamma dose rate measurements). The most significant contributors in 2017 to the *total dose* for adults were from external exposure over sediments, consumption of root vegetables and direct radiation from the site (32, 31, and 19 per cent, respectively), the most important radionuclide was americium-241 (27 per cent). Other ages received less exposure than the *total dose* for adults of 0.011 mSv in 2017 (10 year-old children: 0.007; 1 year-old infants: 0.007; prenatal children: 0.006, equivalent values rounded to one significant figure).

Contributions to the highest *total dose* each year, by specific radionuclides, are given in Figure 2.9 over the period 2004 – 2017. 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 – 2017, *total doses* 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 2017, 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 0.011 mSv (Table 2.17) in 2017, or approximately 1 per cent of the dose limit to members of the public, and similar to that in 2016 (0.013 mSv). Other age groups received less exposure than the infants (1 year-old) dose of 0.012 mSv in 2017 (adults: 0.008; 10 year-old children: 0.008; prenatal children: less than 0.005).

## 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 (2017 habits survey). The second is based on a five-year rolling average using habits data gathered from 2013 to 2017. Some changes were found in the amounts (and mixes) of species consumed. For molluscs (winkles and other molluscs), the overall consumption rates were unchanged in 2017 but increased in the 2016 and 2012 – 2016 data sets. For crustaceans (crab, lobster, and other crustaceans), overall consumption rates decreased (by small amounts) in 2017, but increased (by small amounts) for the 2013 – 2017 data sets (cod, other fish and lobster). For fish (cod, other fish), overall consumption rates decreased (by small amounts) in 2017 but increased (by small amounts) for the 2013 – 2017 data sets. The occupancy rate over sediments decreased, by small amounts in both the 2017 and 2013 – 2017 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 2017. The doses from artificial radionuclides to people, who consume a large amount of seafood, were 0.082 mSv (0.084 mSv in 2016) and 0.085 mSv (0.083 mSv in 2016) using the annual and five-year rolling average habits data, respectively, in 2017. These doses each include a contribution due to external radiation exposure over sediments. Doses were similar using both sets of habits data in 2017.

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 0.18 mSv in 2017. Most of this was due to polonium-210 (96 per cent). The reason for the change in dose in 2017 (from 0.35 mSv in 2016) is the same as that contributing to the *total dose* for all sources, i.e. lower concentrations of polonium-210 in locally caught lobsters in 2017, in comparison to those 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 2017, and values rounded to two significant figures) was also 0.18 mSv (Table 2.17).

Taking artificial and enhanced natural radionuclides together, the source specific doses were both 0.27 mSv (values are rounded to two significant figures) for the annual and five-year rolling average habits data,

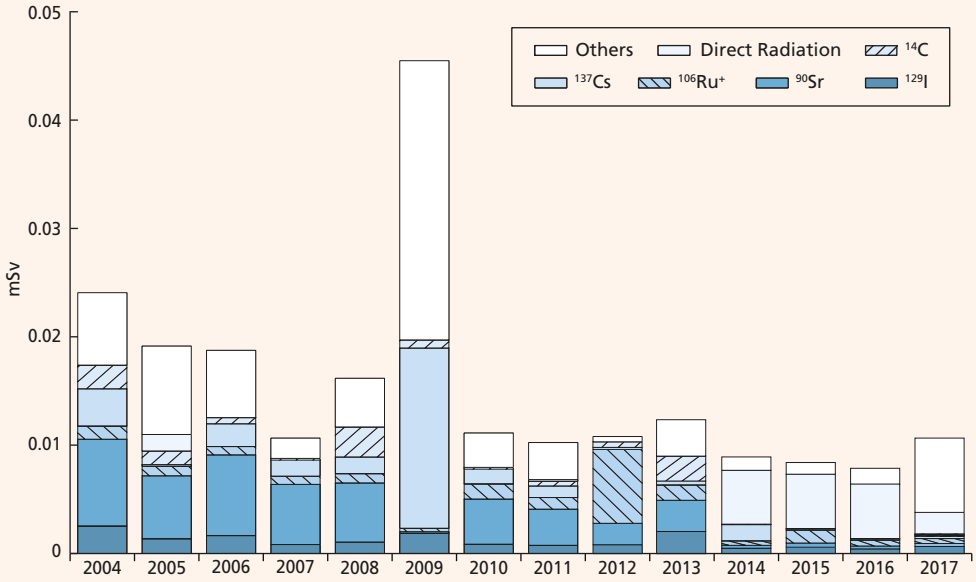



**Figure 2.9.** Contributions to *total dose* from gaseous discharge and direct radiation sources at Sellafield, 2004-2017 (+ based on limits of detection for concentrations in foods)

respectively. These estimates are larger (by a small amount) than the estimate of *total dose* from all sources of 0.25 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 typical 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 2017 (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 2017 (Table 2.16), in comparison to those in 2016. On the Dumfries and Galloway coast, the decrease in dose to 0.035 mSv in 2017 (from 0.044 mSv in 2016) was mostly due to the findings of new habits information, and the requirement to revise the locations used to determine external exposure from gamma dose measurements and occupancy rates. All doses of the wider communities 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 2017.

## 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 2017 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 2017, the dose was 0.071 mSv, or approximately 7 per cent of the dose limit, and down from 0.081 mSv in 2016 (see Section 5.2). Other people received lower external doses in 2017. The estimated dose to a high-occupancy houseboat dweller in the River Ribble was 0.028 mSv (see Section 2.2). The dose to a person who spends a long time over the marsh in the Ravenglass Estuary was 0.007 mSv in 2017, and down from 0.011 mSv in 2016. The reason for the small decrease in dose was a combination of lower occupancy rates (from the revised habits data) and lower dose rates measurements in the Ravenglass Estuary, in 2017, in comparison to those in 2016.

The doses to people in 2017 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 2017, the doses to people from recreational use of beaches varied from 0.006 to 0.011 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 0.012 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 trapped. 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 2017, 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 0.11 mSv and 0.067 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 2017, the dose (including contributions from Chernobyl and weapon test fallout) was estimated to be 0.020 mSv, which was 2 per cent of the dose limit for members of the public, and similar to that in 2016 (0.019 mSv). 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 2017 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 2017. Gaseous discharges were generally similar (in comparison to those in 2016), although antimony-125, krypton-85 and iodine-129

decreased, and plutonium alpha increased (by small amounts), in 2017. The decreases in discharges reflect lower fuel throughput in the THORP and Magnox reprocessing plant.

## 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 2017 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.

The results of monitoring in 2017 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 very limited evidence of the effects of Sellafield's atmospheric discharges detected in data for carbon-14 (in offal). 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 2017 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. Strontium-90 was positively detected in food and grass samples and in one soil sample (Seascale) and strontium-90. In 2017, the maximum iodine-129 concentration in milk was reported as a less than value. Small enhancements (above the expected background) in concentrations of carbon-14 were found in some food samples (including milk and offal), as in recent years. Concentrations of transuranic radionuclides, when detectable in these foods, were very low. As in 2016, antimony-125 concentrations were below the limits of detection in all terrestrial samples in 2017, despite relatively enhanced discharges in previous years. Trends in maximum concentrations of radionuclides in milk (near Sellafield), and corresponding discharge levels, for more than a decade are shown in Figure 2.10. 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 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 2017 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).

All discharges of liquid wastes from Sellafield were much less than the permit limits in 2017. Liquid discharges were generally similar (in comparison to those in 2016), although iodine-129 decreased in 2017. 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 shutdowns that occur from year to year.

The long-term downward trend of technetium-99 discharges from Sellafield is given in Figure 2.11 (1989 – 2017) and Figure 2.12 (2004 – 2017). Technetium-99 discharges have substantially reduced from the peak of 192 TBq in 1995. Technetium-99 discharges 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 2017, 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 2.13 and 2.14.

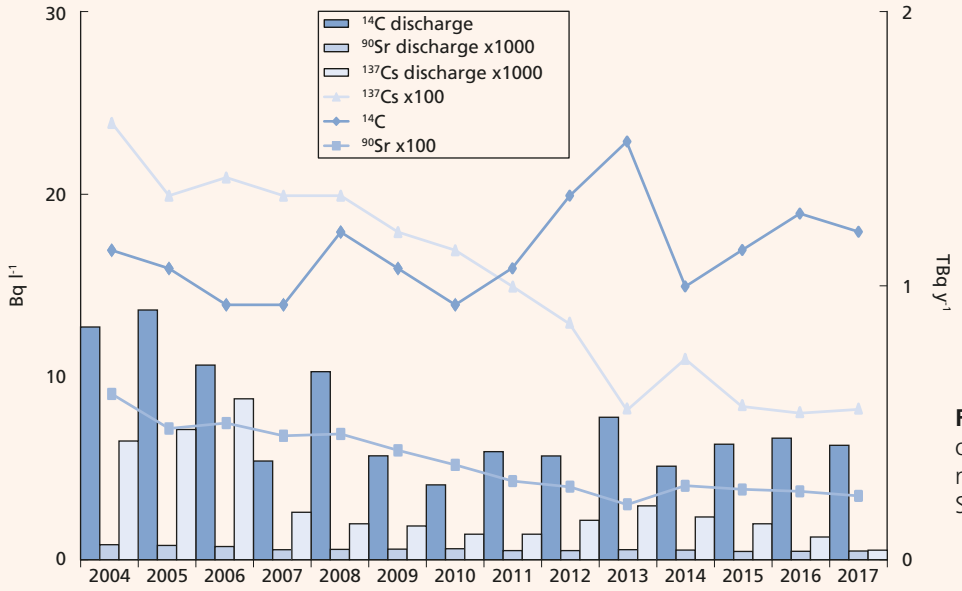



**Figure 2.10.** Discharges of gaseous wastes and monitoring of milk near Sellafield, 2004-2017

## 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 2.15 – 2.20. There was variability from year to year, particularly for the more mobile radionuclides. Liquid discharges of technetium-99 in 2017 were similar to those in recent years. 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 2.17). For the transuranic elements (Figures 2.19 and 2.20), 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 fish and shellfish were generally similar in 2017, in comparison to those in recent years (with minor variations). Overall, concentrations of plutonium radionuclides and americium-241 in lobsters and winkles were higher (by small amounts) in 2017 compared to those in 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 2017, in comparison to those in 2016. Over the longer time period, activity concentrations in fish and shellfish appear to be generally declining (with minor variations) at a slow rate (Figure 2.18). 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 in earlier decades.

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 (Table 2.5). With an expected carbon-14 concentration from natural sources ~ 21 Bq $kg^{-1}$ (see Table X4.1), the data suggest a continued local enhancement of carbon-14 due to discharges from Sellafield. In 2017, tritium is reported as the highest activity concentration in marine fish (plaice, 170 Bq $kg^{-1}$) from Whitehaven, with a similar concentration of Organically Bound Tritium (OBT). In previous years,

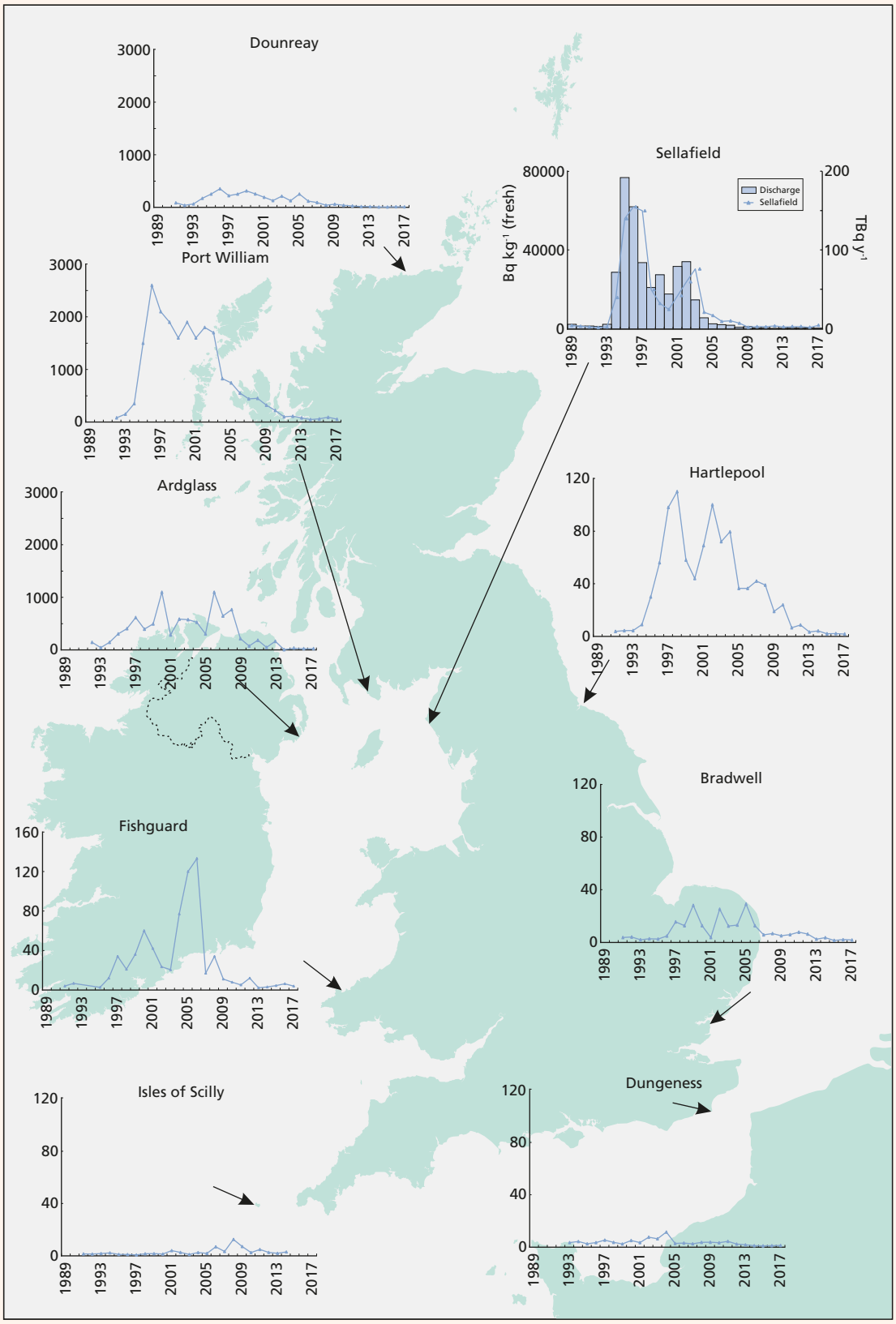



**Figure 2.11.** Technetium-99 in UK seaweed (*Fucus vesiculosus*) from Sellafield liquid discharges between 1989-2017 (Note different scales used for Ardglass, Dounreay, Fishguard, Port William and Sellafield)

virtually all of the total tritium was associated with organic matter. Nevertheless, due to the low radiotoxicity of this isotope of hydrogen and the low concentrations observed, the overall dose implication was very small. Promethium-147 was detected at a very low concentration (reported as just above the less than value) in fish (plaice) in 2017.

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 2017 and 2016 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 2017 were also broadly similar (where comparisons can be made) to those in 2016.

Transuranic radionuclide data for fish and shellfish samples (chosen on the basis of potential radiological significance) in 2017 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 2017 and 2016 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 2017 (in comparison to those in 2016) at most of the north-eastern Irish Sea locations. Americium-241 concentrations in mussels (near Sellafield) were lower in 2017, in comparison to those in 2016. The mean concentration of americium-241 in mussels (Ravenglass and Whitehaven outer harbour) in 2017 is the lowest reported values, in comparison to those reported in previous years. Overall, plutonium-239+240 and americium-241 concentrations in lobsters and winkles (near Sellafield) were similar (with minor variations) in 2017, in comparison to those in recent years (including the lowest reported values in lobsters in 2016). 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 2017 are shown in Table 2.8. Radionuclides detected include cobalt-60, strontium-90, 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 2017, in comparison to those in 2016.

The trends over time (1988 – 2017) for activity concentrations in mud from Ravenglass and liquid discharges from Sellafield are shown in Figures 2.21 – 2.24. 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 2.23). The cobalt-60 concentration in mud from Ravenglass was similar in 2017 to the lowest value reported in 2016, generally continuing the downward trend (as in recent years). Over the last decade, caesium-137 and transuranic concentrations in sediments have remained relatively constant (Figures 2.21, 2.22 and 2.24). Since the mid-1990s, discharges of caesium-137, plutonium isotopes and americium-241 have remained at low levels, but with some variability. There is 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 2.18 – 2.20) 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 2.25. Concentrations of both radionuclides diminish with distance from Sellafield. Overall, concentrations in 2017 at a given location were

generally similar to those in 2016, 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).

## 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 2017 were generally similar to those in recent years (with small variations in comparison to those in 2016). 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. In 2017, gamma dose rates did not show a significant excess above natural background downstream of the site. 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 2.26. 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 is 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.

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 2.22). 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 trap 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 2017 are given in Table 2.10. Overall, where comparisons can be made, measured dose rates in 2017 were generally similar to those in 2016 (with minor variations).

## 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 2017 were generally similar to those in 2016 (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 2017, 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.

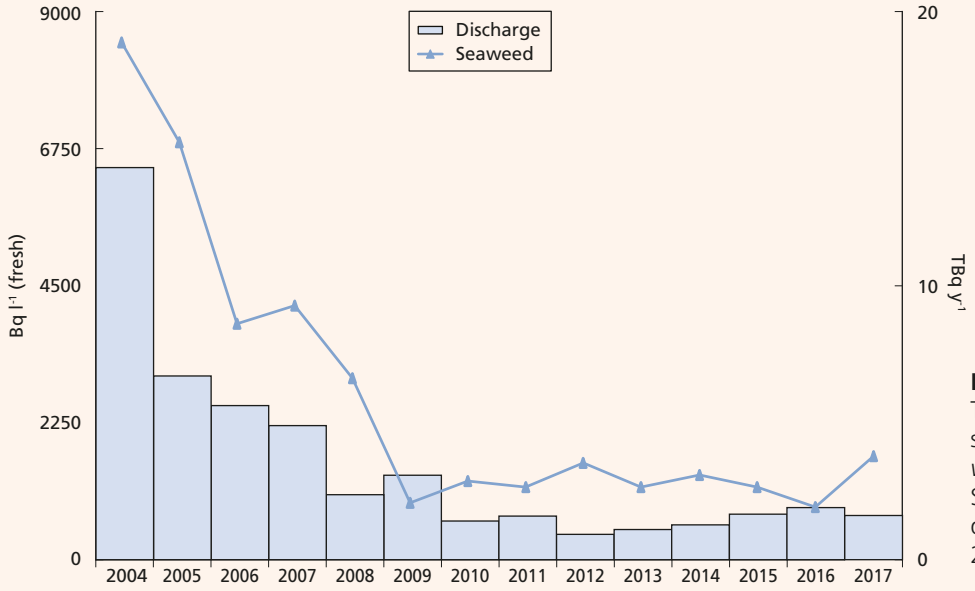



**Figure 2.12.** Technetium-99 in UK seaweed (*Fucus vesiculosus*) from Sellafield liquid discharges between, 2004-2017

Vehicle-mounted beach survey work, by the Sellafield site operator's contractors, began in November 2006. The survey equipment used (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.

Further beach monitoring for the 2017 calendar year was completed in line with the Environment Agency's specification, of approximately 152 hectares (Sellafield Limited, 2018), against a programme target of 150 hectares. In 2017, there was a change implemented to the beach finds categories in that the 'stone' category is replaced by 'object'. This means that all items larger than 2 mm in size (e.g. granules, gravel, wire, pebble and stones) are now classified as objects. The number of radioactive finds identified in 2017 was 226, of which approximately 85 per cent were classified as particles (less than 2 mm in size) and the remainder as objects (all of which were stones). The number of finds were typical of those in recent years. Most of the finds were concentrated on a 5 km stretch of beach running NW from the Sellafield site. All have been removed from the beaches.

In October 2017, one of the finds detected (particle) exceeded the characterisation triggers set within the Environment Agency's intervention trigger levels: **https://www.gov.uk/government/publications/sellafield-radioactive-objects-intervention-plan**.

The particle was within the range of previous measurements; and therefore, does not require immediate further consideration nor challenges the PHE risk assessment (Brown and Etherington, 2011).

Monitoring along the Cumbrian coast will continue for 2018, with the current proposal being a further 150 hectares to be surveyed. As in 2017, the 2018 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 meet the primary aim of providing reassurance that overall risks to beach users remain at or below those estimated in the PHE risk assessment.

In 2012, PHE reported their review of the results and position on risk following the introduction of the improved monitoring (Groundhog™ Synergy 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.

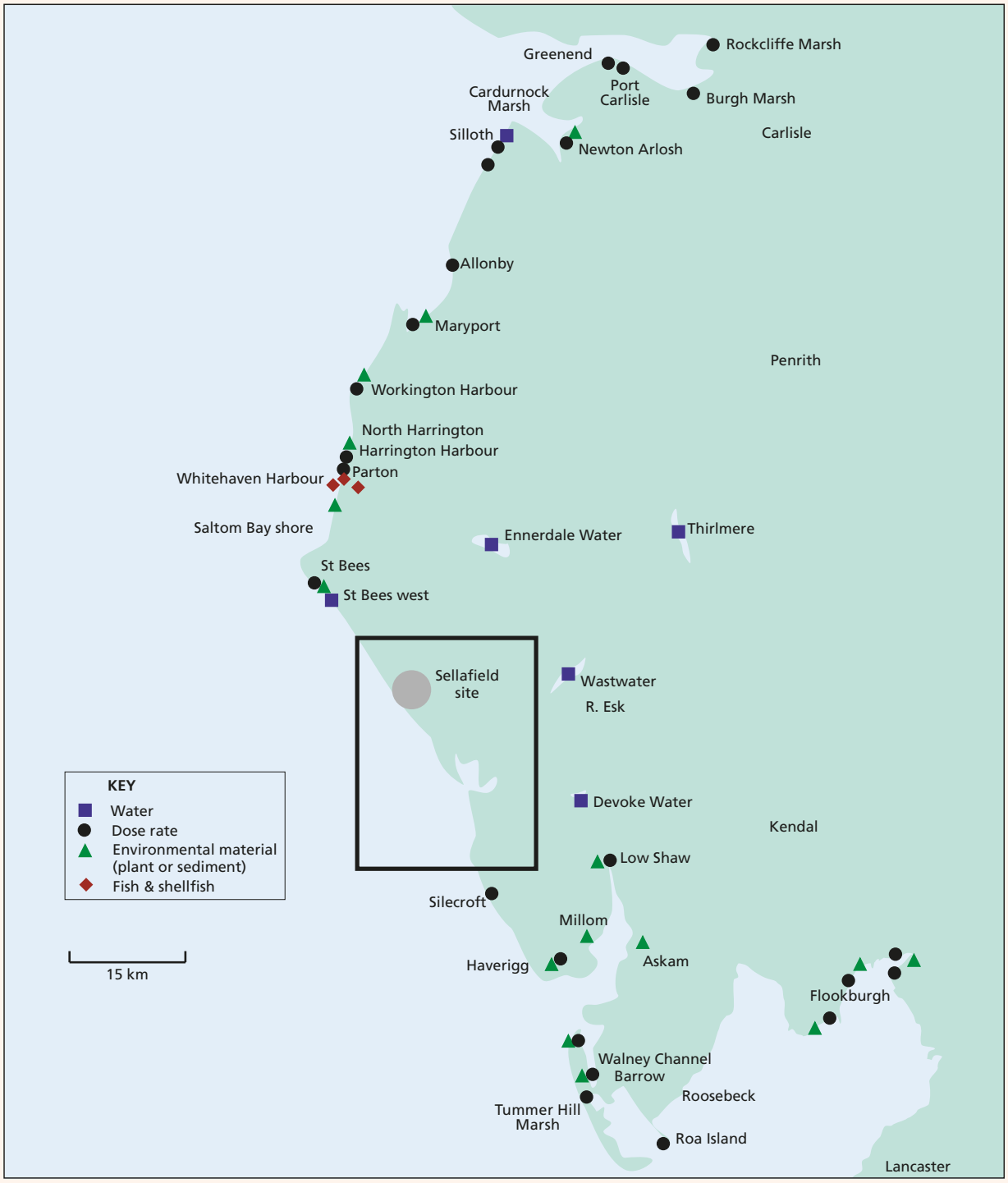



**Figure 2.13.** Monitoring locations in Cumbria, 2017 (not including farms)

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.

The Environment Agency have provided updates on progress of the enhanced beach monitoring between 2010 – 2013, and these are reported in earlier RIFE reports. Work prior to 2010 is also described elsewhere (Environment Agency, FSA, NIEA and SEPA, 2010).

Further detail on enhanced beach monitoring data compiled so far can be obtained on the UK Government website: **https://www.gov.uk/government/publications/sellafield-radioactive-objects-intervention-plan/sellafield-radioactive-objects-intervention-plan#monitoring-beaches-near-sellafield**.


**Figure 2.14.** Monitoring locations at Sellafield, 2017 (not including farms)

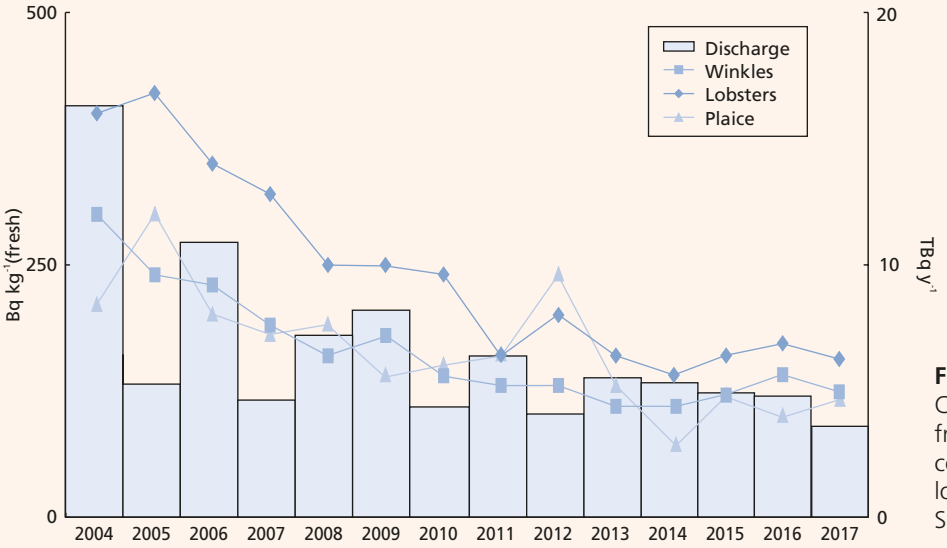



**Figure 2.15.**
Carbon-14 liquid discharge from Sellafield and concentrations in plaice, lobsters and winkles near Sellafield, 2004-2017

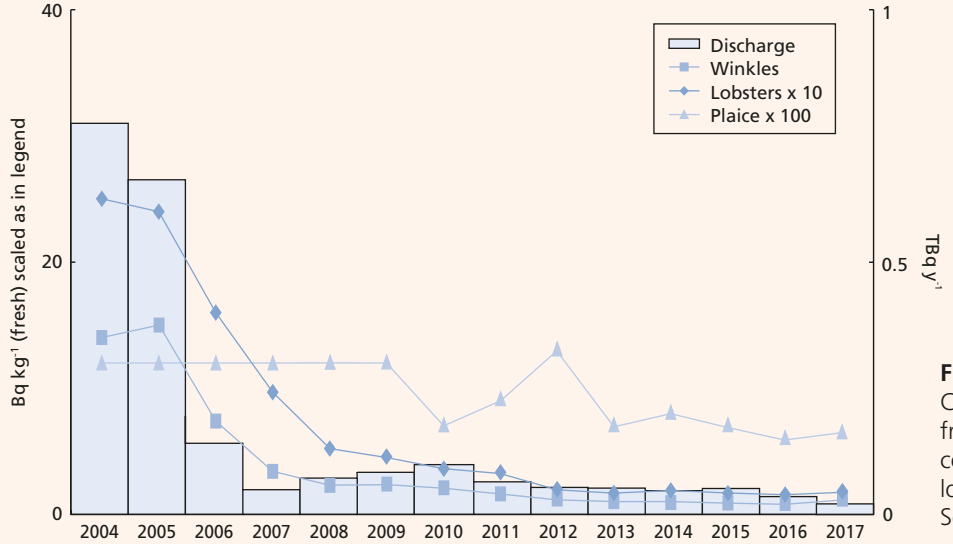



**Figure 2.16.**
Cobalt-60 liquid discharge from Sellafield and concentrations in plaice, lobsters and winkles near Sellafield, 2004-2017

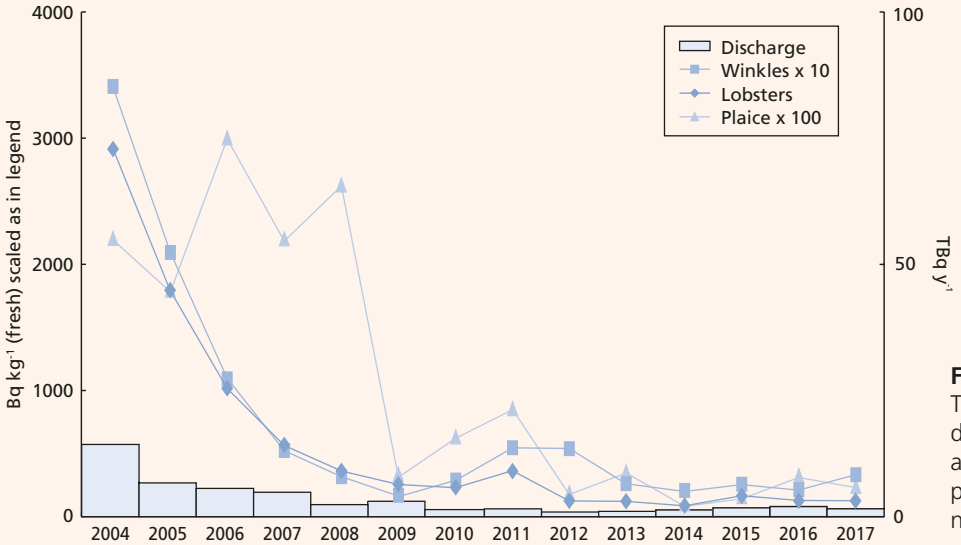



**Figure 2.17.**
Technetium-99 liquid discharge from Sellafield and concentrations in plaice, lobsters and winkles near Sellafield, 2004-2017

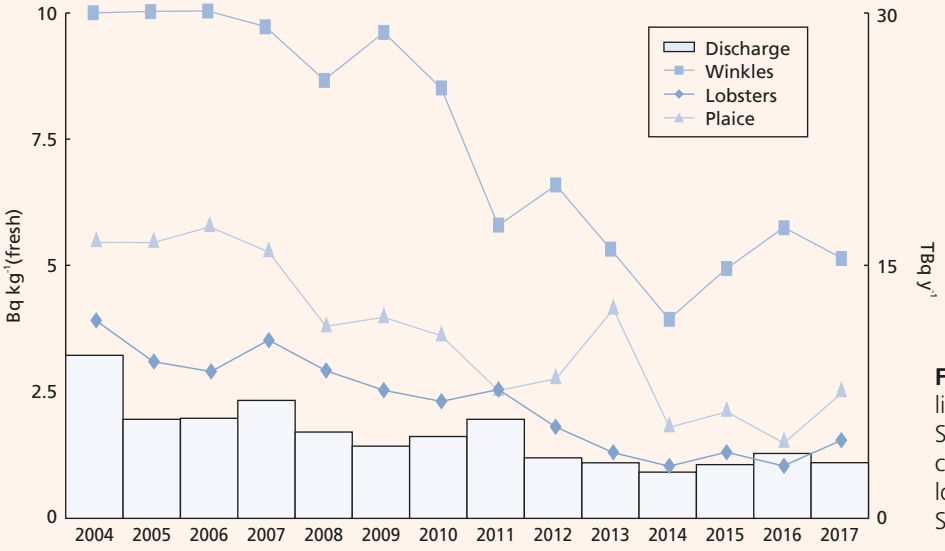



**Figure 2.18.** Caesium-137 liquid discharge from Sellafield and concentrations in plaice, lobsters and winkles near Sellafield, 2004-2017

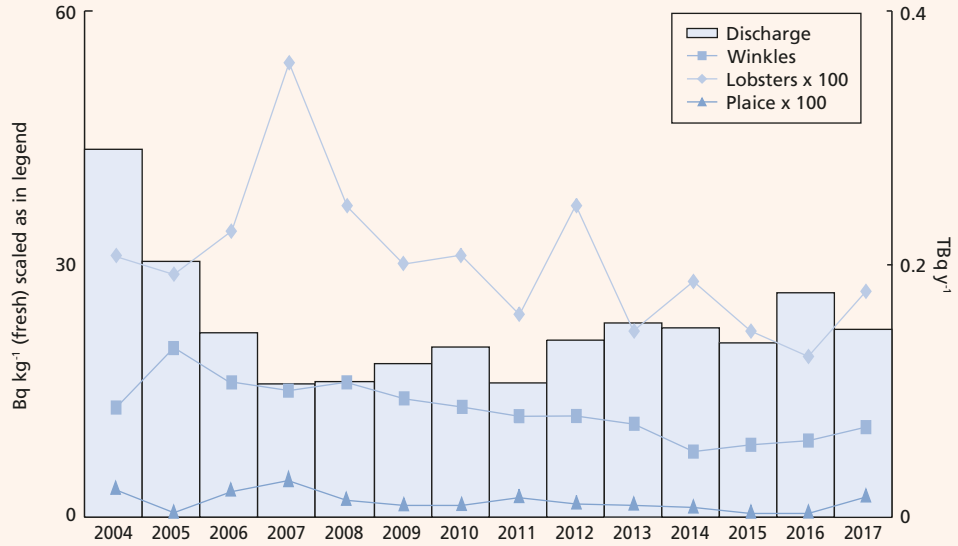



**Figure 2.19.** Plutonium-239+240 liquid discharge from Sellafield and concentrations in plaice, lobsters and winkles near Sellafield, 2004-2017

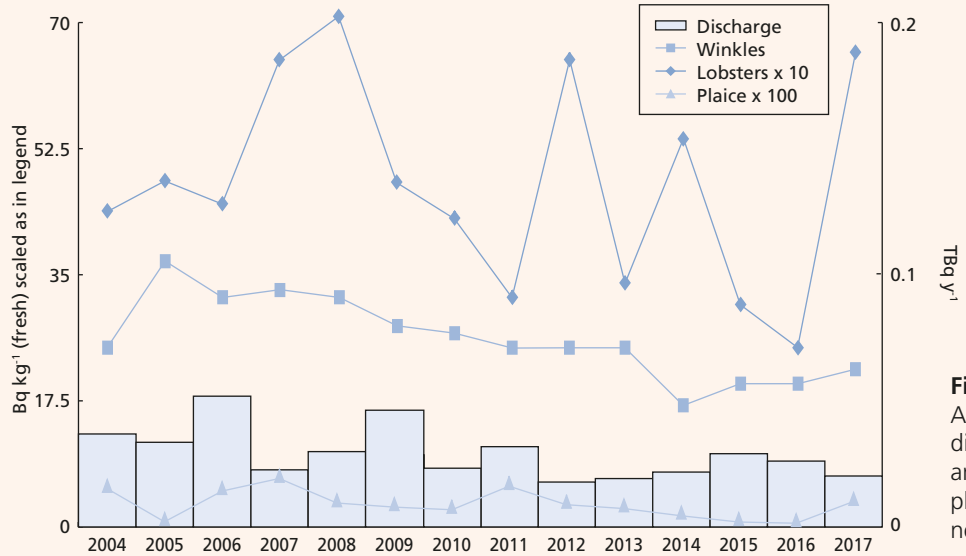



**Figure 2.20.** Americium-241 liquid discharge from Sellafield and concentrations in plaice, lobsters and winkles near Sellafield, 2004-2017

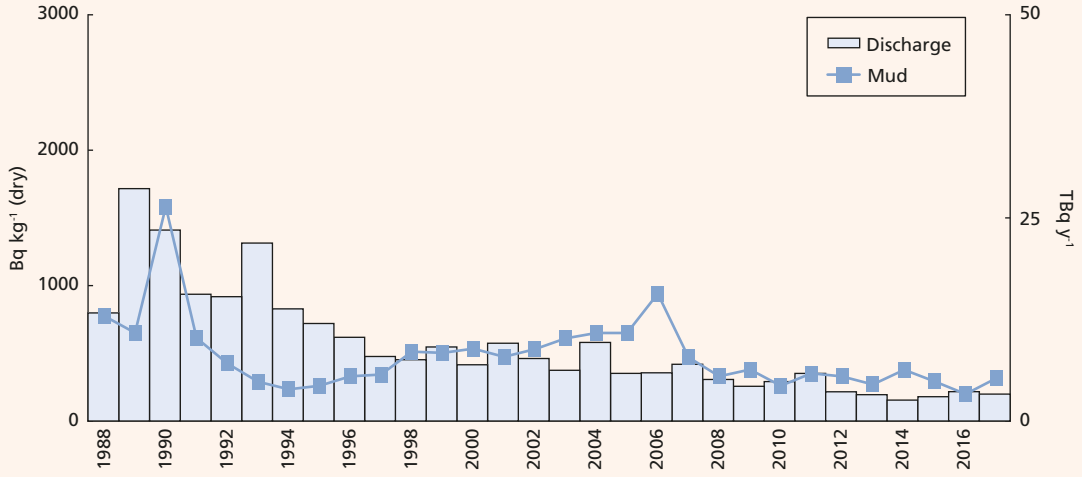



**Figure 2.21.** Caesium-137 liquid discharge from Sellafield and concentration in mud at Ravenglass, 1988-2017

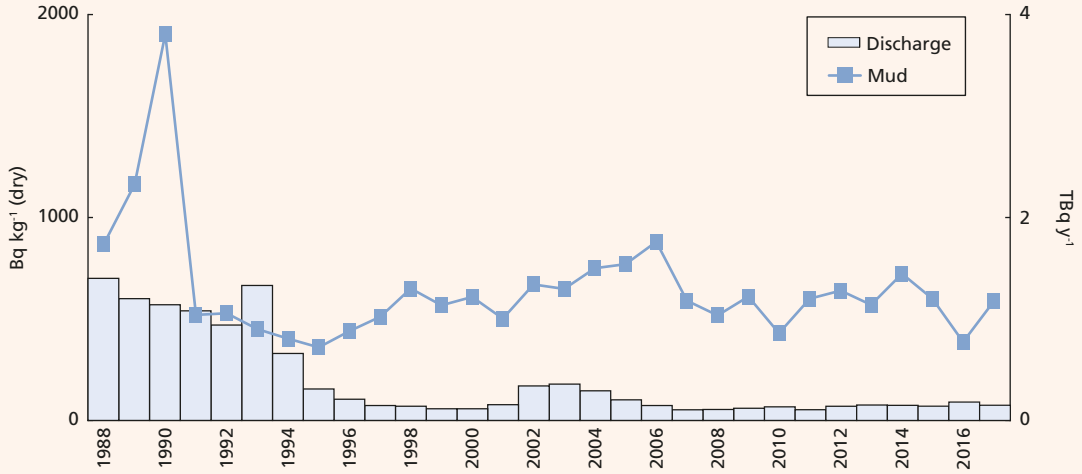



**Figure 2.22.** Plutonium-alpha liquid discharge from Sellafield and plutonium-239+240 concentration in mud at Ravenglass, 1988-2017

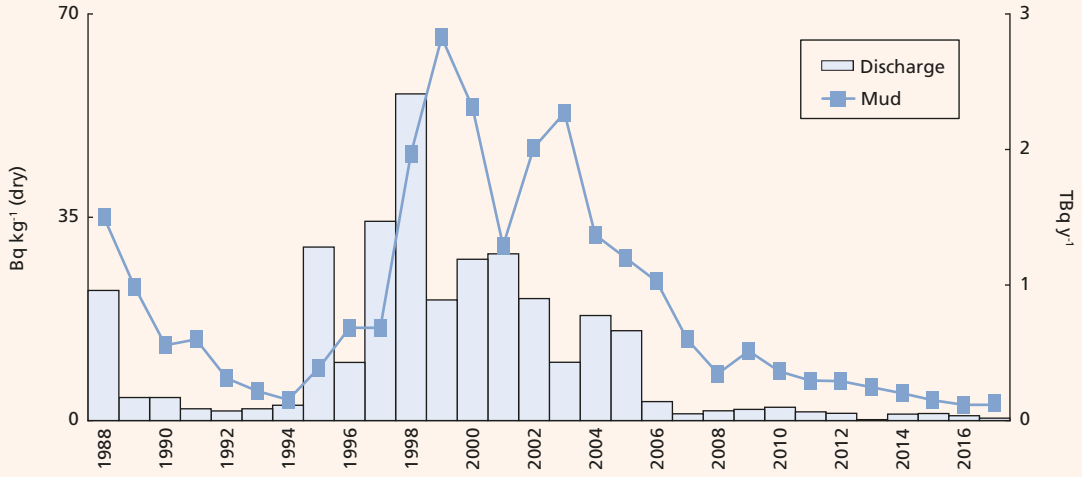



**Figure 2.23.** Cobalt-60 liquid discharge from Sellafield and concentration in mud at Ravenglass, 1988-2017

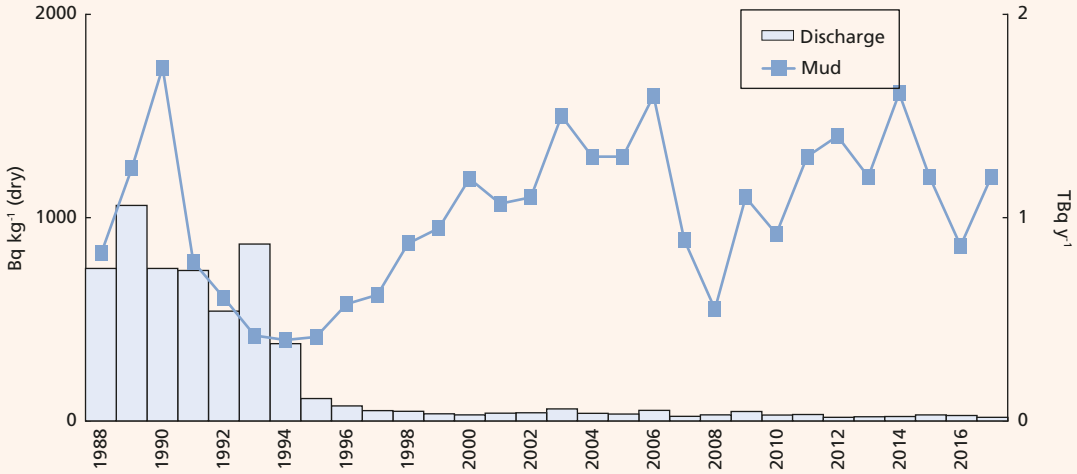



**Figure 2.24.** Americium-241 liquid discharge from Sellafield and concentration in mud at Ravenglass, 1988-2017

## 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 2017 of seaweeds from shorelines of the Cumbrian coast and further afield. Comparing 2017 and 2016 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 2017 and 2004 to 2017), are shown in Figures 2.11 and 2.12, 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 (except at St Bees) in 2017, in comparison to those in 2016. Over the last 5 years, small enhancements have been found, year on year, but technetium-99 concentrations in seaweed in 2017 were still below values reported prior to 2009 (Figure 2.12). At one specific location (Auchencairn, Scotland), known to have had fluctuating concentrations in previous years, activity concentrations in seaweed (*Fucus*) were higher in 2017 compared with those in 2016. 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 2017, 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).

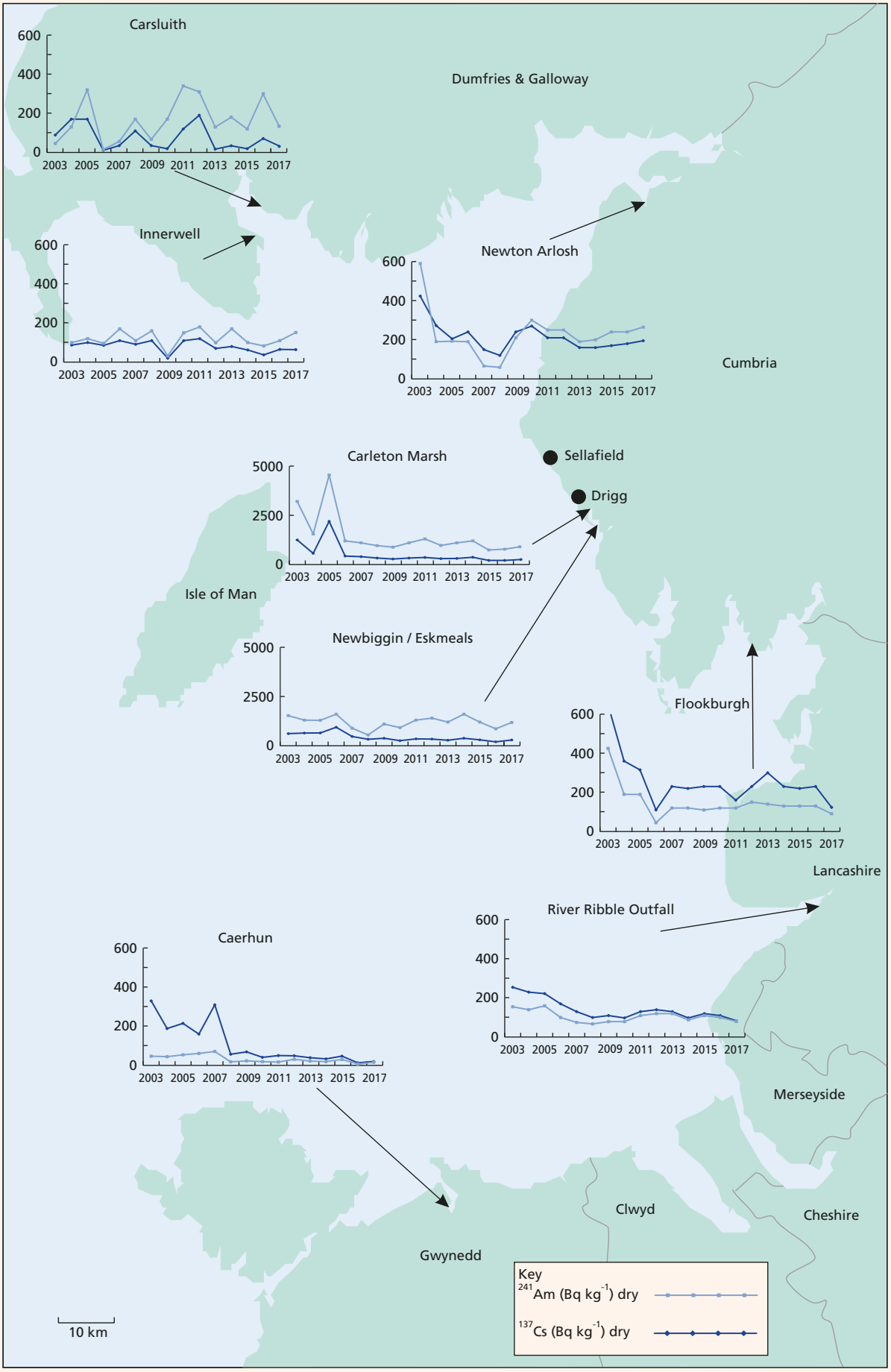



**Figure 2.25:** Concentrations of americium-241 and caesium-137 in coastal sediments in North West England and South West Scotland between 2003-2017 (Note different scales used for Newbiggin and Carleton Marsh)

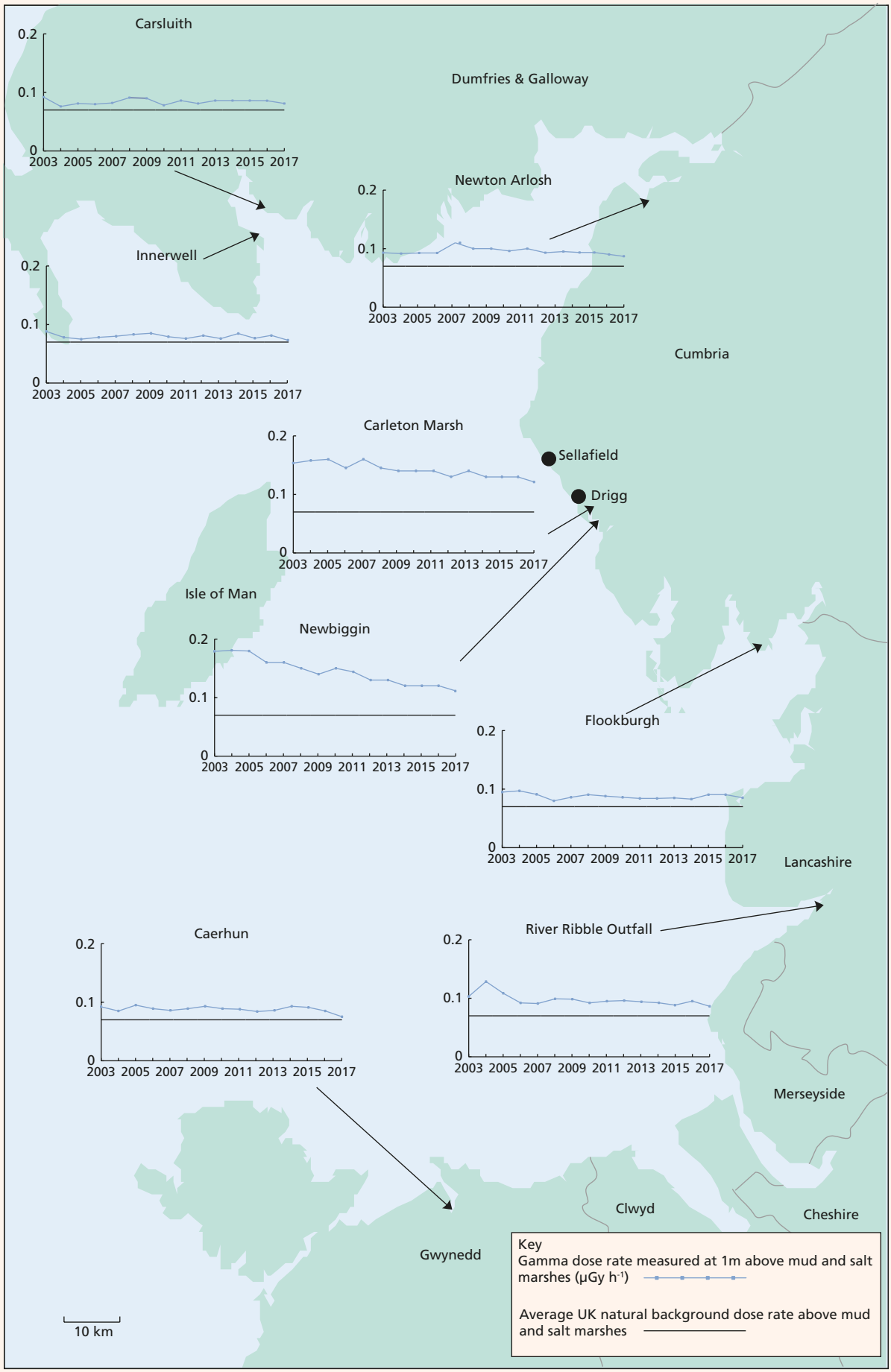



**Figure 2.26.** Gamma dose rates above fine coastal sediments (mud and salt marshes) in North West England and South West Scotland between 2003-2017

The results of measurements in 2017 are given in Table 2.13. Generally, the activity concentrations, where positively detected, show lower concentrations than were found in the immediate vicinity of Sellafield (Table 2.4). In 2017, a very low concentration of tritium was positively detected in a sheep sample (offal) and iodine-129 was positively detected in milk (just above the less than value). As in previous years, the evidence for sea to land transfer was very limited in 2017. 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 plutonium-238 to plutonium-239+240 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 freshwater 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 2017 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 radioactivity 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 2017, there was no evidence of tritium downstream, nor upstream of the outfall (Table 2.14). These are not potable waters 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 2.13) 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 2017 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).

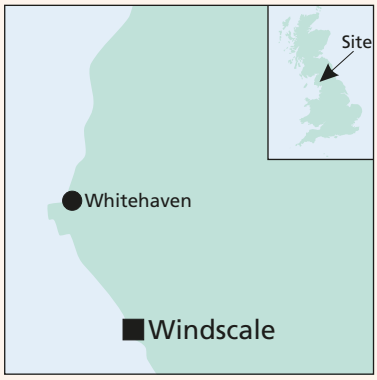
### 2.3.4 Monitoring of unusual pathways

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, describing the consequences of this monitoring, and remedial measures taken by the site operator, is available in earlier RIFE reports (e.g. Environment Agency, FSA, FSS, NIEA, NRW and SEPA, 2015). Results of the analysis of a wood pigeon sample collected in 2017 are included in Table 2.4. The maximum caesium-137 concentration in the muscle of wood pigeon was detected just above the less than value (0.24 Bq $kg^{-1}$) in 2017 and generally similar to the those in recent years. 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 2017 are shown in Table 2.15, and activity concentrations are 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. The 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. Following an application from Sellafield Limited, and acceptance by ONR, the site operators were granted a new site license effective from 1 April 2017, that covers Sellafield only (amalgamating the Sellafield and Windscale nuclear sites).

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 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, 2017

| 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 | 0.010[c] | - | - | 0.010 | <0.005 | - | - |
| Springfields | | | | | | | | |
| ***Total dose* - all sources** | **Adult occupants on houseboats** | **0.028** | **-** | **-** | **0.028** | **-** | **-** | **-** |
| Source specific doses | Seafood consumers | 0.013[c] | <0.005 | - | 0.012 | - | - | - |
| | Fishermen handling nets or pots[b] | 0.033 | - | - | 0.033 | - | - | - |
| | Houseboat occupants | 0.028 | - | - | 0.028 | - | - | - |
| | Children playing at Lower Penwortham[c] | <0.005 | - | - | <0.005 | <0.005 | - | - |
| | External in intertidal areas (farmers) | 0.023 | - | - | 0.023 | - | - | - |
| | 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 subtracting background and cosmic sources from measured gamma dose rates)*

## Table 2.2(a) Concentrations of radionuclides in food and the environment near Capenhurst, 2017

| Material | Location | No. of sampling observations | Mean radioactivity concentration (fresh)[a], Bq kg$^{-1}$ | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | $^{3}$H | $^{99}$Tc | $^{137}$Cs | $^{234}$Th | $^{234}$U | $^{235}$U | $^{238}$U |
| **Marine/freshwater samples** | | | | | | | | | |
| Dab | Liverpool Bay | 1 | <25 | | 0.94 | | | | |
| Shrimps | Wirral | 1 | <25 | 0.53 | 0.78 | | | | |
| Mussels | Liverpool Bay | 1 | <25 | | 1.30 | 2.6 | | | |
| Cockles | Dee Estuary | 1 | <25 | 0.50 | 0.72 | 3.0 | | | |
| Sediment | Rivacre Brook | 2[E] | | 530 | <5.6 | 130 | 300 | 11 | 130 |
| Sediment | Rivacre Brook (1.5km downstream) | 2[E] | | 36 | 1.3 | 19 | 18 | <0.84 | 13 |
| Sediment | Rossmore (3.1km downstream) | 2[E] | | 22 | 0.87 | 17 | 17 | <1.1 | 14 |
| Sediment | Rivacre Brook (4.3km downstream) | 2[E] | | 15 | <0.42 | <7.3 | 13 | <1.1 | 11 |
| Freshwater | Rivacre Brook | 2[E] | <3.0 | <0.32 | | | 0.071 | <0.0032 | 0.028 |
| Freshwater | Rivacre Brook (1.5km downstream) | 2[E] | <3.0 | <0.34 | | | 0.037 | <0.0021 | 0.017 |
| Freshwater | Rossmore (3.1km downstream) | 2[E] | <3.0 | <0.37 | | | 0.029 | <0.0023 | 0.017 |
| Freshwater | Rivacre Brook (4.3km downstream) | 2[E] | <3.1 | <0.34 | | | 0.027 | <0.0020 | 0.017 |

| Material | Location | No. of sampling observations | Mean radioactivity concentration (fresh)[a], Bq kg$^{-1}$ | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | $^{237}$Np | $^{238}$Pu | $^{239}$Pu+ $^{240}$Pu | $^{241}$Am | $^{242}$Cm | $^{243}$Cm+ $^{244}$Cm | Gross alpha | Gross beta |
| **Marine/freshwater samples** | | | | | | | | | | |
| Dab | Liverpool Bay | 1 | | | | <0.20 | | | | |
| Shrimps | Wirral | 1 | | 0.00098 | 0.0058 | 0.012 | * | * | | |
| Mussels | Liverpool Bay | 1 | | | | 1.8 | | | | |
| Cockles | Dee Estuary | 1 | | 0.057 | 0.38 | 1.3 | * | * | | |
| Sediment | Rivacre Brook | 2[E] | <3.4 | | | | | | 480 | 1000 |
| Sediment | Rivacre Brook (1.5km downstream) | 2[E] | <0.70 | | | | | | <240 | 440 |
| Sediment | Rossmore (3.1km downstream) | 2[E] | <0.50 | | | | | | <120 | 580 |
| Sediment | Rivacre Brook (4.3km downstream) | 2[E] | <0.50 | | | | | | <130 | 390 |
| Freshwater | Rivacre Brook | 2[E] | <0.040 | | | | | | <0.079 | 0.51 |
| Freshwater | Rivacre Brook (1.5km downstream) | 2[E] | <0.020 | | | | | | <0.059 | 0.27 |
| Freshwater | Rossmore (3.1km downstream) | 2[E] | <0.040 | | | | | | <0.069 | 0.24 |
| Freshwater | Rivacre Brook (4.3km downstream) | 2[E] | <0.040 | | | | | | <0.055 | 0.21 |

| Material | Location or selection[b] | No. of sampling observations[d] | Mean radioactivity concentration (fresh)[a], Bq kg$^{-1}$ | | | | |
|---|---|---|---|---|---|---|---|
| | | | $^{3}$H[c] | $^{99}$Tc | $^{234}$U | $^{235}$U | $^{238}$U |
| **Terrestrial samples** | | | | | | | |
| Milk | | 2 | <4.2 | <0.026 | <0.00050 | <0.00036 | <0.00056 |
| Milk | max | | <5.0 | <0.032 | <0.00068 | <0.00039 | |
| Beetroot | | 1 | | <0.081 | 0.011 | 0.00059 | 0.011 |
| Grass | | 1 | | <0.070 | 0.015 | 0.00089 | 0.014 |
| Grass/herbage | North of Ledsham | 1[E] | | <1.4 | 0.43 | <0.34 | <0.81 |
| Grass/herbage | South of Capenhurst | 1[E] | | <1.2 | <0.088 | <0.065 | <0.097 |
| Grass/herbage | East of Capenhurst | 1[E] | | <0.81 | 0.22 | <0.058 | 0.23 |
| Grass/herbage | Dunkirk Lane (0.9km South of Site) | 1[E] | | <0.76 | <0.081 | <0.046 | 0.12 |
| Soil | North of Ledsham | 1[E] | | <5.5 | 19 | <1.1 | 19 |
| Soil | South of Capenhurst | 1[E] | | <5.8 | 19 | <0.88 | 19 |
| Soil | East of Capenhurst | 1[E] | | <5.3 | 23 | 1.6 | 20 |
| Soil | Dunkirk Lane (0.9km South of Site) | 1[E] | | <5.4 | 20 | 0.93 | 19 |

* *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, 2017 | | | |
|---|---|---|---|
| Location | Ground type | No. of sampling observations | μGy $h^{-1}$ |
| **Mean gamma dose rates at 1m over substrate** | | | |
| East of railway station | Grass | 1 | 0.075 |
| Dunkirk Lane | Grass and herbage | 1 | 0.087 |
| Near Lower Brook Farm | Grass | 1 | 0.078 |
| Rivacre Brook Plant outlet | Grass | 2 | 0.086 |
| Rivacre Brook 1.5 km downstream | Grass | 2 | 0.083 |
| Rossmore Road West 3.1 km downstream | Grass | 2 | 0.079 |
| Rivacre Brook 4.3 km downstream | Grass | 1 | 0.077 |
| Rivacre Brook 4.3 km downstream | Mud and stones | 1 | 0.083 |
| North of Ledsham | Grass | 1 | 0.081 |

## Table 2.3(a) Concentrations of radionuclides in food and the environment near Springfields, 2017

| 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 | $^{233}$Pa |
| **Marine samples** | | | | | | | | | | | | |
| Flounder | Ribble Estuary | 1 | | | | | | 2.0 | | | | |
| Sea Bass | Ribble Estuary | 1 | | | | | | 3.4 | | | | |
| Shrimps[d] | Ribble Estuary | 1 | | 44 | | 0.77 | | 1.0 | 0.018 | 0.0021 | 0.0012 | |
| Mussels[d] | Ribble Estuary | 1 | | | | | | 0.93 | 0.20 | 0.19 | 0.12 | |
| Wildfowl | Ribble Estuary | 1 | <2.5 | 43 | <0.055 | | <0.95 | 1.0 | | 0.0066 | 0.0054 | |
| Samphire | Marshside Sands | 1 | | | | <0.12 | | 0.20 | | | | |
| Sediment | River Ribble outfall | 4[E] | | | | | | 78 | 25 | 37 | 25 | 1.8 |
| Sediment | Lea Gate | 2[E] | | | | | | 130 | 35 | 60 | 36 | 9.1 |
| Sediment | Lower Penwortham Park | 4[E] | | | | | | 110 | 34 | 79 | 33 | 1.2 |
| Sediment | Penwortham road bridge - West bank | 2[E] | | | | | | 100 | 31 | 52 | 29 | 4.1 |
| Sediment | Lytham Yacht Club | 1[E] | | | | | | 180 | 41 | 62 | 35 | |
| Sediment | Becconsall | 4[E] | | | | | | 76 | 29 | 41 | 27 | |
| Sediment | Freckleton | 1[E] | | | | | | 230 | 46 | 88 | 43 | 3.0 |
| Sediment | Hutton Marsh | 1[E] | | | | | | 240 | 40 | 120 | 39 | |
| Sediment | Longton Marsh | 1[E] | | | | | | 490 | 54 | 340 | 52 | |
| Grass (washed) | Hutton Marsh | 1[E] | | | | <0.87 | | | | | | |
| Grass (unwashed) | Hutton Marsh | 1[E] | | | | <2.2 | | | | | | |
| Soil | Hutton Marsh | 1[E] | | | | 55 | | | | | | |

| 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 | | | | | | | | <0.07 | | |
| Sea Bass | Ribble Estuary | 1 | | | | | | | | <0.20 | | |
| Shrimps[d] | Ribble Estuary | 1 | | | | | 0.0012 | 0.00098 | 0.0058 | 0.012 | | |
| Mussels[d] | Ribble Estuary | 1 | | | | | | 0.092 | 0.55 | 1.1 | | |
| Wildfowl | Ribble Estuary | 1 | | | | | | 0.0018 | 0.012 | 0.021 | | |
| Samphire | Marshside Sands | 1 | | | | | | | | <0.08 | | |
| Sediment | River Ribble outfall | 4[E] | 49 | 18 | <1.1 | 20 | | | | 76 | 360 | 850 |
| Sediment | Lea Gate | 2[E] | 250 | 34 | 1.6 | 35 | | | | 130 | 520 | 1400 |
| Sediment | Lower Penwortham Park | 4[E] | 90 | 24 | <1.2 | 27 | | | | 110 | 390 | 910 |
| Sediment | Penwortham road bridge - West bank | 2[E] | 210 | 24 | <0.75 | 25 | | | | 90 | 390 | 1200 |
| Sediment | Lytham Yacht Club | 1[E] | 71 | 27 | 1.3 | 27 | | | | 170 | 560 | 1200 |
| Sediment | Becconsall | 4[E] | <46 | 20 | <1.1 | 22 | | | | 93 | 400 | 960 |
| Sediment | Freckleton | 1[E] | 140 | 28 | 1.1 | 32 | | | | 210 | 600 | 1500 |
| Sediment | Hutton Marsh | 1[E] | 56 | 28 | <1.7 | 31 | | | | 190 | 590 | 1400 |
| Sediment | Longton Marsh | 1[E] | 44 | 33 | <2.4 | 35 | | | | 310 | 1000 | 1600 |

## 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 | <2.2 | 9.9 | 0.047 | <0.019 | <0.06 | <0.063 | 0.012 | 0.015 | |
| Sediment | Deepdale Brook | 2[E] | | | | | <0.69 | | | | 50 |
| Grass | | 1 | <2.7 | 13 | 0.18 | <0.030 | <0.07 | <0.069 | <0.00031 | 0.0035 | |
| Freshwater[e] | Ulnes Walton | 1[E] | <2.3 | | | | <0.26 | | <0.0011 | <0.00054 | |

| 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 | 0.0036 | <0.00046 | 0.0022 | | | | | | |
| Milk | max | | 0.0041 | <0.00052 | 0.0025 | | | | | | |
| Beetroot | | 1 | 0.12 | 0.0032 | 0.10 | 0.000046 | 0.00016 | <0.29 | 0.00012 | | |
| Sediment | Deepdale Brook | 2[E] | 44 | 1.6 | 42 | | | | | 210 | 910 |
| Grass | | 1 | 0.015 | 0.00057 | 0.011 | 0.00030 | 0.0017 | <0.24 | 0.0039 | | |
| Grass | Opposite site entrance | 1[E] | <0.11 | <0.11 | <0.14 | | | | | | |
| Grass | Opposite windmill | 1[E] | 0.52 | <0.12 | 0.35 | | | | | | |
| Grass | Deepdale Brook | 1[E] | 0.76 | <0.12 | 0.67 | | | | | | |
| Grass | N of Lea Town | 1[E] | <0.35 | <0.11 | <0.17 | | | | | | |
| Soil | Opposite site entrance | 1[E] | 83 | 3.3 | 80 | | | | | | |
| Soil | Opposite windmill | 1[E] | 85 | 3.1 | 79 | | | | | | |
| Soil | Deepdale Brook | 1[E] | 91 | 3.6 | 91 | | | | | | |
| Soil | N of Lea Town | 1[E] | 66 | 2.7 | 70 | | | | | | |
| Freshwater | Deepdale Brook | 4[E] | 0.22 | 0.0097 | 0.21 | | | | | 0.35 | 0.54 |
| Freshwater[e] | Ulnes Walton | 1[E] | 0.013 | <0.0035 | 0.013 | | | | | <0.066 | 0.30 |

[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 not detected by the method used*

[e] *The concentration of $^{228}$Th was <0.0061 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, 2017**

| Location | Material or ground type | No. of sampling observations | µGy $h^{-1}$ |
|---|---|---|---|
| **Mean gamma dose rates at 1m over substrate** | | | |
| Lytham Yacht Club | Salt marsh | 1 | 0.095 |
| Warton Salt Marsh | Salt marsh | 2 | 0.093 |
| Warton Salt Marsh | Salt marsh[a] | 2 | 0.094 |
| Freckleton | Salt marsh | 1 | 0.085 |
| Naze Point | Salt marsh | 2 | 0.096 |
| Banks Marsh (alternative)[b] | Salt marsh | 2 | 0.10 |
| Banks Marsh (alternative)[b] | Salt marsh[a] | 2 | 0.10 |
| Becconsall Boatyard | Grass | 1 | 0.078 |
| Becconsall Boatyard | Grass and mud | 2 | 0.085 |
| Becconsall Boatyard | Salt marsh | 1 | 0.079 |
| Longton Marsh | Salt marsh | 1 | 0.10 |
| Hutton Marsh | Salt marsh | 1 | 0.11 |
| River Ribble outfall | Mud | 4 | 0.085 |
| Savick Brook, confluence with Ribble | Salt marsh | 2 | 0.087 |
| Savick Brook, Lea Gate | Grass | 2 | 0.091 |
| South bank opposite outfall | Salt marsh | 1 | 0.091 |
| Penwortham road bridge | Mud | 2 | 0.082 |
| Lower Penwortham Park | Grass | 4 | 0.075 |
| River Darwen | Grass | 4 | 0.078 |
| Riverbank Angler Location 1 | Grass | 4 | 0.076 |
| Ulnes Walton, BNFL area survey | Grass | 3 | 0.073 |
| **Mean beta dose rates** | | | µSv $h^{-1}$ |
| Banks Marsh (alternative)[b] | Salt marsh | 1 | 0.057 |
| Warton Salt Marsh | Salt marsh | 1 | 0.037 |
| Springfields | Fishing net | 1 | <0.096 |

[a] *15cm above substrate*

[b] *No monitoring was undertaken at Banks Marsh in 2017 (as reported in earlier RIFE reports)*

## Table 2.4 Concentrations of radionuclides in terrestrial food and the environment near Sellafield, 2017

| 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 | $^{125}$Sb | $^{129}$I | $^{131}$I | $^{134}$Cs |
| Milk | | 9 | <2.8 | <3.4 | 18 | <0.05 | <0.035 | <0.026 | <0.42 | <0.13 | <0.0051 | <0.0028 | <0.06 |
| Milk | max | | <3.1 | <5.6 | 22 | <0.06 | <0.054 | <0.030 | <0.46 | <0.14 | <0.0060 | <0.0054 | <0.07 |
| Beef kidney | | 1 | <3.9 | <3.9 | 21 | <0.04 | <0.10 | <0.12 | <0.36 | <0.05 | | | <0.04 |
| Beef liver | | 1 | <4.0 | <4.0 | 30 | <0.07 | <0.050 | 0.10 | <0.47 | <0.22 | <0.016 | | <0.07 |
| Beef muscle | | 1 | <17 | <17 | 25 | <0.04 | 0.045 | <0.087 | <0.32 | <0.09 | <0.016 | | <0.04 |
| Apple | | 1 | <6.9 | <6.9 | 12 | <0.09 | 0.052 | <0.089 | <0.65 | <0.19 | <0.021 | | <0.10 |
| Swede | | 1 | <2.7 | <2.7 | 5.4 | <0.06 | 0.050 | | <0.47 | <0.13 | <0.022 | | <0.06 |
| Cabbage | | 1 | <4.9 | <4.9 | 4.4 | <0.05 | <0.070 | | <0.41 | <0.11 | <0.020 | | <0.06 |
| Carrots | | 1 | <2.6 | <2.6 | 6.1 | <0.05 | 0.040 | <0.088 | <0.36 | <0.11 | <0.063 | | <0.05 |
| Eggs | | 1 | <7.5 | <7.5 | 27 | <0.04 | <0.042 | | <0.19 | <0.06 | <0.032 | | <0.06 |
| Mushrooms | | 1 | <3.0 | <3.0 | 21 | <0.04 | <0.050 | | <0.48 | <0.14 | <0.014 | | <0.06 |
| Pheasant | | 1 | <4.9 | <4.9 | 27 | <0.04 | 0.024 | <0.064 | <0.15 | <0.09 | <0.014 | | <0.05 |
| Potatoes | | 1 | <4.5 | <4.5 | 17 | <0.06 | 0.028 | | <0.46 | <0.13 | <0.015 | | <0.06 |
| Rabbit | | 1 | <3.0 | <3.0 | 29 | <0.04 | 0.024 | <0.089 | <0.32 | <0.11 | <0.011 | | <0.04 |
| Sheep muscle | | 2 | <3.0 | <3.0 | 32 | <0.06 | <0.048 | <0.097 | <0.38 | <0.17 | <0.022 | | <0.07 |
| Sheep muscle | max | | | | 36 | <0.07 | <0.051 | <0.11 | <0.48 | <0.20 | <0.024 | | <0.09 |
| Sheep offal | | 2 | <6.7 | <6.7 | 32 | <0.05 | <0.039 | <0.087 | <0.36 | <0.11 | <0.023 | | <0.05 |
| Sheep offal | max | | <7.3 | <7.3 | 40 | <0.06 | <0.040 | <0.089 | <0.50 | <0.14 | | | <0.06 |
| Wood pigeon muscle | | 2 | <3.1 | <3.1 | 23 | <0.05 | <0.048 | | <0.38 | <0.11 | <0.021 | | <0.05 |
| Wood pigeon muscle | max | | <3.2 | <3.2 | 27 | <0.06 | <0.049 | | <0.46 | <0.13 | <0.022 | | <0.06 |
| Grass | | 1 | <8.2 | <8.2 | 27 | <0.06 | 0.43 | | <0.76 | <0.26 | <0.020 | | <0.11 |
| Grass | Braystones | 1[E] | | <12 | 13 | | 0.85 | | <8.1 | <4.9 | | <1.3 | |
| Grass | River Calder (upstream) | 1[E] | | <12 | 6.3 | | 2.7 | | <2.6 | <1.6 | | <0.48 | |
| Grass | River Calder (downstream) | 1[E] | | <12 | 15 | | 0.81 | | <6.7 | <4.0 | | <1.1 | |
| Soil[d] | | 1 | <3.5 | <3.5 | 5.1 | <0.20 | 4.2 | <1.0 | <2.0 | <0.69 | <0.014 | | <0.30 |
| Soil | Braystones | 1[E] | | <4.8 | 46 | | <2.0 | | <4.0 | <2.2 | | <0.67 | |
| Soil | River Calder (upstream) | 1[E] | | <9.5 | <1.8 | | <2.0 | | <3.3 | <1.9 | | <0.66 | |

**Table 2.4 continued**

| Material | Location or selection[a] | No. of sampling observ-ations[c] | Mean radioactivity concentration (fresh)[b], Bq kg$^{-1}$ | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $^{137}$Cs | Total Cs | $^{234}$U | $^{235}$U | $^{238}$U | $^{238}$Pu | $^{239}$Pu + $^{240}$Pu | $^{241}$Pu | $^{241}$Am |
| Milk | | 9 | <0.10 | <0.086 | | | | <0.000043 | <0.000044 | <0.14 | <0.000042 |
| Milk | max | | <0.16 | <0.12 | | | | <0.000060 | <0.000059 | <0.16 | <0.000059 |
| Beef kidney | | 1 | 0.96 | 0.96 | 0.025 | 0.00028 | 0.023 | <0.00020 | 0.00035 | <0.60 | 0.00059 |
| Beef liver | | 1 | 1.0 | 1.0 | | | | 0.00025 | 0.0023 | <0.27 | 0.0014 |
| Beef muscle | | 1 | 1.1 | 1.1 | | | | 0.000040 | 0.000028 | <0.22 | 0.00017 |
| Apple | | 1 | <0.09 | <0.085 | | | | 0.00087 | 0.00063 | <0.26 | 0.0013 |
| Swede | | 1 | <0.06 | <0.055 | 0.003 | <0.00034 | 0.0015 | | | | <0.33 |
| Cabbage | | 1 | 0.08 | 0.083 | | | | <0.000090 | 0.00028 | <0.37 | 0.00016 |
| Carrots | | 1 | <0.05 | <0.046 | | | | | | | <0.14 |
| Eggs | | 1 | <0.05 | <0.049 | | | | 0.000029 | 0.00022 | <0.28 | 0.00025 |
| Mushrooms | | 1 | 0.56 | 0.56 | | | | 0.012 | 0.076 | <0.33 | 0.16 |
| Pheasant | | 1 | 0.16 | 0.16 | | | | <0.000065 | 0.000021 | <0.28 | 0.000032 |
| Potatoes | | 1 | <0.06 | <0.057 | 0.015 | 0.00065 | 0.015 | 0.000056 | 0.0013 | <0.38 | 0.0012 |
| Rabbit | | 1 | 6.4 | 6.5 | | | | 0.0000057 | 0.000099 | <0.23 | 0.00010 |
| Sheep muscle | | 2 | 0.58 | 0.58 | | | | 0.00010 | 0.00048 | <0.29 | 0.0011 |
| Sheep muscle | max | | 0.62 | 0.62 | | | | 0.00013 | 0.00090 | <0.33 | 0.0020 |
| Sheep offal | | 2 | 0.21 | 0.21 | 0.0032 | <0.00035 | 0.0035 | 0.00024 | 0.0019 | <0.36 | 0.0013 |
| Sheep offal | max | | 0.23 | 0.23 | 0.0045 | <0.00052 | 0.0048 | 0.00034 | 0.0029 | <0.45 | 0.0016 |
| Wood pigeon muscle | | 2 | 0.20 | 0.20 | | | | <0.000049 | 0.00053 | <0.37 | 0.00019 |
| Wood pigeon muscle | max | | 0.24 | 0.24 | | | | <0.000056 | 0.0010 | <0.42 | 0.00028 |
| Grass | | 1 | 0.25 | 0.25 | | | | 0.00097 | 0.0078 | <0.24 | 0.010 |
| Grass | Braystones | 1[E] | <1.1 | | | | | <0.10 | 0.37 | <10 | <1.2 |
| Grass | River Calder (upstream) | 1[E] | 0.74 | | | | | <0.087 | 0.11 | <12 | <0.45 |
| Grass | River Calder (downstream) | 1[E] | <0.87 | | | | | <0.17 | 0.30 | <21 | <0.79 |
| Soil[d] | | 1 | 24 | 24 | | | | 0.27 | 6.5 | <24 | 2.4 |
| Soil | Braystones | 1[E] | 50 | | | | | <0.45 | 5.8 | <35 | 5.4 |
| Soil | River Calder (upstream) | 1[E] | 45 | | | | | <0.43 | 12 | <48 | 3.3 |

[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$^{-1}$*

*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, 2017

| Location | Material | No. of sampling observations | 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 | | | 57 | <0.10 | 0.015 | <0.15 | <0.20 | <0.26 |
| Whitehaven | Cod[c] | 2 | | | 59 | <0.07 | 0.013 | <0.13 | <0.16 | <0.27 |
| Whitehaven | Plaice[a,c] | 2 | 130 | 170 | 110 | <0.06 | 0.045 | <0.28 | <0.21 | 2.7 |
| Ravenglass | Plaice[b,c] | 2 | 120 | 140 | 100 | <0.07 | 0.040 | <0.41 | <0.28 | 3.4 |
| **Lancashire and Merseyside** | | | | | | | | | | |
| Morecambe Bay (Morecambe) | Flounder | 2 | <27 | <31 | 44 | <0.05 | <0.052 | <0.08 | <0.11 | 0.17 |
| Ribble Estuary | Flounder | 1 | | | | <0.07 | | <0.09 | <0.13 | |
| Ribble Estuary | Sea Bass | 1 | | | | <0.07 | | <0.09 | <0.13 | |
| Liverpool Bay | Dab | 1 | | <25 | | <0.07 | | <0.08 | <0.13 | |
| **Scotland** | | | | | | | | | | |
| The Minch | Herring | 1[S] | | | | <0.10 | | <0.28 | <0.27 | |
| The Minch | Mackerel | 1[S] | | | | <0.10 | | <0.27 | <0.26 | |
| Shetland | Fish meal (salmon) | 1[S] | | | | <0.10 | | <0.12 | <0.19 | |
| Shetland | Fish meal (herring) | 1[S] | | | | <0.10 | | <0.10 | <0.17 | |
| Shetland | Fish oil (salmon) | 1[S] | | | | <0.10 | | <0.11 | <0.12 | |
| Shetland | Fish oil (herring) | 1[S] | | | | <0.10 | | <0.12 | <0.19 | |
| Ardrossan South Bay | Mackerel | 1[S] | | | | <0.10 | | <0.21 | <0.14 | |
| Ardrossan South Bay | Salmon | 1[S] | | | | <0.10 | | <0.30 | <0.22 | |
| Kircudbright | Plaice | 2[S] | | | 21 | <0.10 | | <0.28 | <0.23 | <0.20 |
| Inner Solway | Salmon | 1[S] | | <5.0 | | <0.10 | | <0.17 | <0.15 | |
| Inner Solway | Sea trout | 1[S] | | <5.0 | | <0.10 | | <0.47 | <0.30 | |
| **Wales** | | | | | | | | | | |
| North Anglesey | Plaice | 1 | <25 | <25 | 32 | <0.05 | | <0.14 | <0.15 | |
| **Northern Ireland** | | | | | | | | | | |
| North coast | Lesser spotted dogfish | 4[N] | | | | <0.16 | | <1.1 | <0.68 | |
| Ardglass | Herring | 2[N] | | | | <0.09 | | <0.23 | <0.26 | |
| Kilkeel | Cod | 4[N] | | | 25 | <0.07 | | <0.47 | <0.28 | |
| Kilkeel | Plaice | 4[N] | | | | <0.05 | | <0.21 | <0.21 | |
| Kilkeel | Skates / rays | 4[N] | | | | <0.17 | | <0.59 | <0.54 | |
| Kilkeel | Haddock | 4[N] | | | | <0.08 | | <0.52 | <0.25 | |
| **Further afield** | | | | | | | | | | |
| Norwegian Sea | Haddock | 2 | | | | <0.10 | | <0.14 | <0.19 | |

## Table 2.5 continued

| Location | Material | No. of sampling observations | 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 | <0.73 | <0.21 | <0.10 | 2.9 | <0.38 | <0.19 | 160 |
| Whitehaven | Cod[c] | 2 | <0.58 | <0.18 | <0.07 | 2.6 | <0.40 | <0.18 | 160 |
| Whitehaven | Plaice[a,c] | 2 | <0.52 | <0.15 | <0.06 | 2.4 | <0.36 | <0.15 | 130 |
| Ravenglass | Plaice[b,c] | 2 | <0.66 | <0.19 | <0.08 | 2.0 | <0.44 | <0.18 | 120 |
| **Lancashire and Merseyside** | | | | | | | | | |
| Morecambe Bay (Morecambe) | Flounder | 2 | <0.41 | <0.12 | <0.05 | 3.6 | <0.24 | <0.11 | |
| Ribble Estuary | Flounder | 1 | <0.50 | <0.14 | <0.07 | 2.0 | <0.26 | <0.12 | |
| Ribble Estuary | Sea Bass | 1 | <0.60 | <0.19 | <0.08 | 3.4 | <0.40 | <0.20 | |
| Liverpool Bay | Dab | 1 | <0.58 | <0.18 | <0.07 | 0.94 | <0.31 | <0.16 | |
| **Scotland** | | | | | | | | | |
| The Minch | Herring | 1[S] | <0.79 | <0.22 | <0.10 | 0.14 | <0.48 | <0.21 | |
| The Minch | Mackerel | 1[S] | <0.78 | <0.24 | <0.10 | 0.19 | <0.48 | <0.21 | |
| Shetland | Fish meal (salmon) | 1[S] | <0.86 | <0.26 | <0.11 | 0.17 | <0.49 | <0.23 | |
| Shetland | Fish meal (herring) | 1[S] | <0.79 | <0.25 | <0.10 | 0.43 | <0.53 | <0.23 | |
| Shetland | Fish oil (salmon) | 1[S] | <0.82 | <0.26 | <0.10 | <0.10 | <0.46 | <0.20 | |
| Shetland | Fish oil (herring) | 1[S] | <0.82 | <0.25 | <0.10 | <0.10 | <0.48 | <0.22 | |
| Ardrossan South Bay | Mackerel | 1[S] | <0.29 | <0.10 | <0.10 | 0.92 | <0.21 | <0.10 | |
| Ardrossan South Bay | Salmon | 1[S] | <0.49 | <0.14 | <0.10 | 0.16 | <0.32 | <0.13 | |
| Kircudbright | Plaice | 2[S] | <0.54 | <0.15 | <0.10 | <0.12 | <0.33 | <0.15 | |
| Inner Solway | Salmon | 1[S] | <0.36 | <0.10 | <0.10 | 0.15 | <0.21 | <0.10 | |
| Inner Solway | Sea trout | 1[S] | <0.57 | <0.15 | <0.10 | 0.28 | <0.32 | <0.12 | |
| **Wales** | | | | | | | | | |
| North Anglesey | Plaice | 1 | <0.43 | <0.12 | <0.05 | 0.58 | <0.28 | <0.12 | |
| **Northern Ireland** | | | | | | | | | |
| North coast | Lesser spotted dogfish | 4[N] | <1.7 | <0.39 | <0.16 | 0.79 | <0.67 | <0.27 | |
| Ardglass | Herring | 2[N] | <0.83 | <0.25 | <0.10 | 0.62 | <0.55 | <0.25 | |
| Kilkeel | Cod | 4[N] | <0.62 | <0.14 | <0.07 | 0.98 | <0.32 | <0.14 | |
| Kilkeel | Plaice | 4[N] | <0.38 | <0.13 | <0.06 | 0.40 | <0.28 | <0.11 | |
| Kilkeel | Skates / rays | 4[N] | <1.3 | <0.36 | <0.18 | 0.67 | <0.65 | <0.29 | |
| Kilkeel | Haddock | 4[N] | <0.71 | <0.16 | <0.08 | 0.35 | <0.35 | <0.14 | |
| **Further afield** | | | | | | | | | |
| Norwegian Sea | Haddock | 2 | <0.77 | <0.20 | <0.10 | <0.14 | <0.37 | <0.18 | |

[a] *The concentrations of $^{129}$I and $^{147}$Pm were <1.1 Bq kg$^{-1}$ and 0.071 Bq kg$^{-1}$ respectively*
[b] *The concentrations of $^{129}$I and $^{147}$Pm were <1.2 Bq kg$^{-1}$ and <0.028 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, 2017

| 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 | | | 97 | <0.13 | 0.16 | <0.27 | <0.30 | 3.4 | <1.0 |
| Parton | Lobsters[d] | 2 | | | 75 | <0.12 | 0.058 | <0.18 | <0.23 | 52 | <0.85 |
| Parton | Winkles[d] | 2 | | | 84 | 0.35 | 0.24 | <0.23 | <0.22 | 37 | 2.6 |
| Whitehaven | *Nephrops*[a,d] | 2 | 26 | <25 | 66 | <0.04 | 0.086 | <0.07 | <0.08 | 26 | <0.32 |
| Whitehaven outer harbour | Mussels[d] | 2 | | | 90 | 0.17 | 0.25 | <0.08 | <0.11 | 8.3 | 2.8 |
| Nethertown | Winkles[b,d] | 4 | <25 | <25 | 110 | 0.67 | 1.5 | <0.25 | <0.23 | 37 | 5.6 |
| Sellafield coastal area | Crabs[c,d] | 2 | 57 | 47 | 120 | 0.25 | 0.30 | <0.10 | <0.13 | 5.9 | 0.75 |
| Sellafield coastal area | Lobsters[d] | 2 | 130 | 120 | 150 | 0.13 | 0.15 | <0.08 | <0.11 | 150 | <0.47 |
| Ravenglass | Mussels[d] | 2 | | | 91 | <0.10 | 0.16 | <0.11 | <0.13 | 12 | <1.2 |
| Seascale Area | Common prawns[d] | 2 | <25 | 27 | 91 | <0.08 | 0.037 | <0.60 | <0.30 | 0.29 | <0.64 |
| | | | | | | | | | | | |
| **Lancashire and Merseyside** | | | | | | | | | | | |
| Morecambe Bay (Morecambe) | Shrimps | 2 | <35 | 48 | 65 | <0.05 | <0.044 | <0.20 | <0.18 | 0.26 | <0.46 |
| Morecambe Bay (Morecambe) | Mussels | 2 | 140 | 140 | 60 | <0.07 | 0.26 | <0.08 | <0.12 | 27 | <0.60 |
| Morecambe Bay (Middleton Sands) | Winkles | 2 | 250 | 290 | 36 | <0.07 | 0.26 | <0.12 | <0.15 | 10 | <0.60 |
| Ribble Estuary | Shrimps | 1 | | | 44 | <0.06 | | <0.18 | <0.20 | 0.77 | <0.54 |
| Ribble Estuary | Mussels | 1 | | | | <0.06 | | <0.35 | <0.22 | | <0.52 |
| Liverpool Bay | Mussels | 1 | | <25 | | <0.12 | | <0.14 | <0.21 | | <0.99 |
| Dee Estuary | Cockles | 1 | | <25 | | <0.04 | | <0.05 | <0.08 | 0.50 | <0.33 |
| Wirral | Shrimps | 1 | | <25 | | <0.05 | | <1.0 | <0.35 | 0.53 | <0.53 |
| | | | | | | | | | | | |
| **Scotland** | | | | | | | | | | | |
| Kinlochbervie | Crabs | 1[S] | | | | <0.10 | | <0.13 | <0.10 | <0.32 | <0.64 |
| Lewis | Mussels | 1[S] | | | | <0.10 | | <0.24 | <0.19 | | <0.46 |
| Skye | Lobsters | 1[S] | | | | <0.10 | | <0.39 | <0.28 | 2.1 | <0.58 |
| Skye | Mussels | 1[S] | | | | <0.10 | | <0.32 | <0.23 | | <0.51 |
| Islay | Crabs | 1[S] | | | | <0.10 | | <0.29 | <0.22 | | <0.51 |
| Islay | Scallops | 1[S] | | | | <0.10 | | <0.33 | <0.23 | | <0.49 |
| Kirkcudbright | Crabs[d] | 2[S] | | | 52 | <0.10 | | <0.42 | <0.34 | <0.36 | <0.84 |
| Kirkcudbright | Lobsters[d] | 2[S] | | | 53 | <0.10 | <0.10 | <0.35 | <0.29 | 37 | <0.73 |
| Kirkcudbright | Limpets[d] | 1[S] | | | | <0.10 | | <0.41 | <0.42 | | <1.3 |
| Kirkcudbright | Winkles[d] | 2[S] | | | | <0.15 | <0.10 | <0.57 | <0.49 | 5.0 | <1.3 |
| Kirkcudbright | Scallops | 2[S] | | | | <0.10 | | <0.21 | <0.18 | <0.23 | <0.45 |
| Kirkcudbright | Queens | 2[S] | | | | <0.10 | | <0.17 | <0.20 | <0.30 | <0.46 |
| Cutters Pool | Winkles | 1[S] | | | | <0.10 | | <0.32 | <0.25 | | <0.58 |
| Southerness | Winkles | 2[S] | | <5.0 | | <0.15 | <0.10 | <0.95 | <0.65 | 5.1 | <1.4 |
| North Solway coast | Cockles | 1[S] | | | | 0.17 | | <0.14 | <0.14 | | <0.41 |
| North Solway coast | Mussels | 2[S] | | <5.0 | 60 | <0.10 | 0.33 | <0.16 | <0.15 | 19 | <0.40 |
| Inner Solway | Shrimps | 2[S] | | <5.0 | | <0.10 | <0.10 | <0.42 | <0.35 | <0.31 | <0.89 |
| | | | | | | | | | | | |
| **Wales** | | | | | | | | | | | |
| North Anglesey | Crabs | 1 | <25 | <25 | 46 | <0.08 | | <0.08 | <0.13 | | <0.60 |
| North Anglesey | Lobsters | 1 | <25 | <25 | 53 | <0.05 | | <0.05 | <0.09 | 14 | <0.42 |
| | | | | | | | | | | | |
| **Northern Ireland** | | | | | | | | | | | |
| Ballycastle | Lobsters | 2[N] | | | | <0.13 | | <0.26 | <0.32 | 6.7 | <1.1 |
| County Down | Scallops | 2[N] | | | | <0.07 | | <0.73 | <0.19 | | <0.45 |
| Kilkeel | Crabs | 4[N] | | | | <0.07 | | <0.46 | <0.25 | | <0.55 |
| Kilkeel | Lobsters | 4[N] | | | | <0.13 | | <0.93 | <0.45 | 9.6 | <0.96 |
| Kilkeel | *Nephrops* | 4[N] | | | | <0.08 | | <0.51 | <0.36 | 3.4 | <0.77 |
| Minerstown | Winkles | 4[N] | | | | <0.07 | | <0.37 | <0.16 | | <0.58 |
| Carlingford Lough | Mussels | 2[N] | | | | <0.11 | | <0.20 | <0.25 | 1.4 | <0.94 |
| | | | | | | | | | | | |
| **Further afield** | | | | | | | | | | | |
| Cromer | Crabs | 2 | | | | <0.05 | | <0.07 | <0.10 | | <0.42 |
| Southern North Sea | Cockles | 2 | | | | <0.05 | | <0.09 | <0.11 | | <0.42 |

## 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 | <0.17 | <0.29 | <0.13 | 0.77 | <0.58 | | <0.25 | 110 |
| Parton | Lobsters[d] | 2 | <0.13 | <0.24 | <0.10 | 1.0 | <0.39 | | <0.16 | 160 |
| Parton | Winkles[d] | 2 | <0.12 | <0.22 | <0.09 | 2.8 | <0.39 | | <0.18 | 200 |
| Whitehaven | *Nephrops*[a,d] | 2 | <0.05 | <0.09 | <0.04 | 1.9 | <0.17 | 0.065 | <0.08 | 83 |
| Whitehaven outer harbour | Mussels[d] | 2 | <0.07 | <0.17 | <0.06 | 1.4 | <0.31 | | <0.15 | 140 |
| Nethertown | Winkles[b,d] | 4 | <0.13 | <0.42 | <0.09 | 5.0 | <0.48 | 0.84 | <0.21 | 230 |
| Sellafield coastal area | Crabs[c,d] | 2 | <0.09 | <0.16 | <0.07 | 1.1 | <0.28 | 0.025 | <0.13 | 99 |
| Sellafield coastal area | Lobsters[d] | 2 | <0.09 | <0.13 | <0.06 | 1.4 | <0.23 | | <0.10 | 230 |
| Ravenglass | Mussels[d] | 2 | <0.08 | <0.17 | <0.07 | 0.92 | <0.33 | | <0.15 | 91 |
| Seascale Area | Common prawns[d] | 2 | <0.11 | <0.19 | <0.08 | 1.4 | <0.47 | | <0.16 | 100 |
| **Lancashire and Merseyside** | | | | | | | | | | |
| Morecambe Bay (Morecambe) | Shrimps | 2 | <0.08 | <0.14 | <0.05 | 2.3 | <0.31 | | <0.14 | |
| Morecambe Bay (Morecambe) | Mussels | 2 | <0.07 | <0.15 | <0.06 | 1.7 | <0.27 | | <0.12 | 120 |
| Morecambe Bay (Middleton Sands) | Winkles | 2 | <0.09 | <0.19 | <0.07 | 2.0 | <0.41 | | <0.19 | 150 |
| Ribble Estuary | Shrimps | 1 | <0.09 | <0.17 | <0.06 | 1.0 | <0.38 | | <0.16 | |
| Ribble Estuary | Mussels | 1 | <0.06 | <0.17 | <0.03 | 0.93 | <0.34 | | <0.09 | |
| Liverpool Bay | Mussels | 1 | <0.14 | <0.28 | <0.12 | 1.3 | <0.44 | | <0.18 | |
| Dee Estuary | Cockles | 1 | <0.05 | <0.11 | <0.04 | 0.72 | <0.23 | | <0.11 | |
| Wirral | Shrimps | 1 | <0.10 | <0.14 | <0.08 | 0.78 | <0.20 | | <0.14 | |
| **Scotland** | | | | | | | | | | |
| Kinlochbervie | Crabs | 1[S] | <0.10 | <0.20 | <0.10 | <0.10 | <0.38 | | <0.15 | |
| Lewis | Mussels | 1[S] | <0.10 | <0.14 | <0.10 | <0.10 | <0.27 | | <0.11 | |
| Skye | Lobsters | 1[S] | <0.10 | <0.16 | <0.10 | 0.13 | <0.34 | | <0.13 | |
| Skye | Mussels | 1[S] | <0.10 | <0.14 | <0.10 | <0.10 | <0.29 | | <0.11 | |
| Islay | Crabs | 1[S] | <0.10 | <0.15 | <0.10 | <0.10 | <0.33 | | <0.13 | |
| Islay | Scallops | 1[S] | <0.10 | <0.13 | <0.10 | <0.10 | <0.36 | | <0.16 | |
| Kirkcudbright | Crabs[d] | 2[S] | <0.14 | <0.25 | <0.11 | 0.47 | <0.52 | | <0.19 | |
| Kirkcudbright | Lobsters[d] | 2[S] | <0.12 | <0.20 | <0.10 | 0.63 | <0.43 | | <0.17 | |
| Kirkcudbright | Limpets[d] | 1[S] | <0.21 | <0.39 | <0.15 | 1.0 | <0.78 | | <0.33 | |
| Kirkcudbright | Winkles[d] | 2[S] | <0.19 | <0.36 | <0.15 | <0.20 | <0.81 | | <0.34 | |
| Kirkcudbright | Scallops | 2[S] | <0.10 | <0.13 | <0.10 | <0.10 | <0.28 | | <0.11 | |
| Kirkcudbright | Queens | 2[S] | <0.10 | <0.13 | <0.10 | <0.24 | <0.28 | | <0.12 | |
| Cutters Pool | Winkles | 1[S] | <0.12 | <0.17 | <0.10 | 1.7 | <0.29 | | <0.11 | |
| Southerness | Winkles | 2[S] | <0.19 | <0.37 | <0.16 | <0.22 | <0.79 | | <0.30 | |
| North Solway coast | Cockles | 1[S] | <0.10 | <0.13 | <0.10 | 4.3 | <0.27 | | <0.12 | |
| North Solway coast | Mussels | 2[S] | <0.10 | <0.12 | <0.10 | 1.7 | <0.27 | | <0.13 | |
| Inner Solway | Shrimps | 2[S] | <0.12 | <0.24 | <0.11 | <0.10 | <0.54 | | <0.22 | |
| **Wales** | | | | | | | | | | |
| North Anglesey | Crabs | 1 | <0.09 | <0.17 | <0.07 | 0.32 | <0.31 | | <0.14 | |
| North Anglesey | Lobsters | 1 | <0.07 | <0.13 | <0.05 | 0.36 | <0.29 | | <0.14 | 100 |
| **Northern Ireland** | | | | | | | | | | |
| Ballycastle | Lobsters | 2[N] | <0.17 | <0.30 | <0.13 | 0.18 | <0.56 | | <0.25 | |
| County Down | Scallops | 2[N] | <0.08 | <0.11 | <0.06 | 0.18 | <0.25 | | <0.11 | |
| Kilkeel | Crabs | 4[N] | <0.11 | <0.16 | <0.07 | 0.15 | <0.32 | | <0.12 | |
| Kilkeel | Lobsters | 4[N] | <0.13 | <0.22 | <0.12 | 4.9 | <0.39 | | <0.18 | |
| Kilkeel | *Nephrops* | 4[N] | <0.14 | <0.19 | <0.09 | 0.39 | <0.43 | | <0.18 | |
| Minerstown | Winkles | 4[N] | <0.09 | <0.17 | <0.08 | 0.16 | <0.37 | | <0.16 | |
| Carlingford Lough | Mussels | 2[N] | <0.13 | <0.25 | <0.10 | 0.28 | <0.40 | | <0.16 | |
| **Further afield** | | | | | | | | | | |
| Cromer | Crabs | 2 | <0.06 | <0.12 | <0.05 | <0.05 | <0.25 | | <0.11 | |
| Southern North Sea | Cockles | 2 | <0.07 | <0.12 | <0.05 | <0.07 | <0.23 | | <0.11 | |

[a] *The concentration of $^{129}$I was <1.0 Bq kg$^{-1}$*
[b] *The concentration of $^{129}$I was <1.5 Bq kg$^{-1}$*
[c] *The concentration of $^{129}$I was <1.2 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, 2017**

| 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 | | 0.0012 | 0.0074 | <0.087 | 0.013 | * | * |
| Parton | Crabs | 2 | | 0.063 | 0.38 | 2.4 | 1.1 | * | * |
| Parton | Lobsters | 2 | | 0.030 | 0.17 | 1.1 | 1.5 | * | * |
| Parton | Winkles | 2 | | 0.80 | 4.7 | 25 | 9.2 | * | 0.018 |
| Whitehaven | Cod | 2 | | 0.00073 | 0.0049 | <0.22 | 0.0090 | * | * |
| Whitehaven | Plaice | 2 | 0.00021 | 0.0033 | 0.018 | <0.17 | 0.030 | * | 0.000029 |
| Whitehaven | *Nephrops* | 2 | 0.00069 | 0.068 | 0.41 | 2.1 | 1.6 | * | * |
| Whitehaven outer harbour | Mussels | 2 | | 0.45 | 2.7 | 16 | 5.9 | * | 0.012 |
| Nethertown | Winkles | 4 | 0.020 | 1.9 | 9.9 | 60 | 21 | * | 0.041 |
| Sellafield coastal area | Crabs | 2 | 0.0016 | 0.11 | 0.56 | 4.0 | 2.0 | * | 0.0047 |
| Sellafield coastal area | Lobsters | 2 | | 0.056 | 0.26 | 2.2 | 6.5 | * | 0.010 |
| Ravenglass | Plaice | 2 | 0.00022 | 0.0054 | 0.028 | <0.29 | 0.050 | * | 0.00012 |
| Ravenglass | Mussels | 2 | | 0.26 | 1.5 | 9.0 | 3.4 | * | * |
| Seascale | Prawns | 2 | | 0.0064 | 0.037 | <0.61 | 0.077 | * | 0.00025 |
| **Lancashire and Merseyside** | | | | | | | | | |
| Morecambe Bay (Morecambe) | Flounder | 2 | | 0.00042 | 0.0024 | | 0.0045 | * | * |
| Morecambe Bay (Morecambe) | Shrimps | 2 | | 0.0034 | 0.022 | | 0.035 | * | * |
| Morecambe Bay (Morecambe) | Mussels | 2 | | 0.34 | 2.0 | 10 | 3.9 | * | 0.0052 |
| Morecambe Bay (Middleton Sands) | Winkles | 2 | | 0.23 | 1.4 | 7.1 | 2.9 | * | * |
| Ribble Estuary | Flounder | 1 | | | | | <0.07 | | |
| Ribble Estuary | Sea Bass | 1 | | | | | <0.20 | | |
| Ribble Estuary | Shrimps | 1 | 0.0012 | 0.00098 | 0.0058 | | 0.012 | * | * |
| Ribble Estuary | Mussels | 1 | | 0.092 | 0.55 | | 1.1 | * | * |
| Liverpool Bay | Dab | 1 | | | | | <0.20 | | |
| Liverpool Bay | Mussels | 1 | | | | | 1.8 | | |
| Dee Estuary | Cockles | 1 | | 0.057 | 0.38 | | 1.3 | * | * |
| Wirral | Shrimps | 1 | | 0.00095 | 0.0060 | | 0.0091 | * | * |
| | | | | | | | | | |
| **Scotland** | | | | | | | | | |
| The Minch | Herring | 1[S] | | 0.0025 | 0.0030 | | 0.0068 | | |
| The Minch | Mackerel | 1[S] | | 0.0025 | 0.0033 | | 0.0063 | | |
| Shetland | Fish meal (salmon) | 1[S] | | 0.011 | 0.0052 | | 0.0099 | | |
| Shetland | Fish meal (herring) | 1[S] | | 0.0038 | 0.0045 | | 0.0055 | | |
| Shetland | Fish oil (salmon) | 1[S] | | 0.0013 | 0.0038 | | 0.0078 | | |
| Shetland | Fish oil (herring) | 1[S] | | 0.00082 | 0.0032 | | 0.0019 | | |
| Kinlochbervie | Crabs | 1[S] | | 0.045 | 0.17 | | 0.27 | | |
| 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] | | | | | <0.14 | | |
| Ardrossan South Bay | Mackerel | 1[S] | | <0.0019 | 0.0019 | | 0.013 | | |
| Ardrossan South Bay | Salmon | 1[S] | | 0.00027 | 0.00039 | | 0.0019 | | |
| Kirkcudbright | Plaice | 2[S] | | 0.00025 | 0.00079 | | 0.0021 | | |
| Kirkcudbright | Scallops | 2[S] | | 0.0094 | 0.055 | | 0.016 | | |
| Kirkcudbright | Queens | 2[S] | | 0.0019 | 0.0095 | | 0.0049 | | |
| Kirkcudbright | Crabs | 2[S] | | 0.022 | 0.13 | | 0.53 | | |

**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 |
| Kirkcudbright | Lobsters | 2$^{S}$ | | 0.0085 | 0.039 | | 0.24 | | |
| Kirkcudbright | Winkles | 2$^{S}$ | | 0.035 | 0.17 | | 0.20 | | |
| Kirkcudbright | Limpets | 1$^{S}$ | | | | | 5.2 | | |
| Cutters Pool | Winkles | 1$^{S}$ | | | | | 5.8 | | |
| Southerness | Winkles | 2$^{S}$ | | 0.53 | 2.9 | | 0.46 | | |
| North Solway coast | Cockles | 1$^{S}$ | | 1.1 | 6.0 | | 17 | | |
| North Solway coast | Mussels | 2$^{S}$ | | 0.52 | 3.2 | | 6.5 | | |
| Inner Solway | Salmon | 1$^{S}$ | | | | | <0.10 | | |
| Inner Solway | Sea trout | 1$^{S}$ | | | | | <0.10 | | |
| Inner Solway | Shrimps | 2$^{S}$ | | <0.00079 | 0.0022 | | 0.0058 | | |
| **Wales** | | | | | | | | | |
| North Anglesey | Plaice | 1 | | | | | <0.11 | | |
| North Anglesey | Crabs | 1 | | | | | <0.09 | | |
| North Anglesey | Lobsters | 1 | | 0.0034 | 0.019 | 0.21 | 0.26 | * | 0.00019 |
| **Northern Ireland** | | | | | | | | | |
| North coast | Lesser spotted dogfish | 4$^{N}$ | | | | | <0.13 | | |
| Ballycastle | Lobsters | 2$^{N}$ | | | | | <0.29 | | |
| County Down | Scallops | 2$^{N}$ | | | | | <0.10 | | |
| Ardglass | Herring | 2$^{N}$ | | | | | <0.27 | | |
| Kilkeel | Cod | 4$^{N}$ | | | | | <0.15 | | |
| Kilkeel | Plaice | 4$^{N}$ | | | | | <0.08 | | |
| Kilkeel | Skates / rays | 4$^{N}$ | | | | | <0.26 | | |
| Kilkeel | Haddock | 4$^{N}$ | | | | | <0.09 | | |
| Kilkeel | Crabs | 4$^{N}$ | | | | | <0.13 | | |
| Kilkeel | Lobsters | 4$^{N}$ | | | | | <0.17 | | |
| Kilkeel | *Nephrops* | 1$^{N}$ | | 0.0017 | 0.012 | | 0.028 | * | * |
| Minerstown | Winkles | 1$^{N}$ | | 0.026 | 0.17 | | 0.12 | * | * |
| Carlingford Lough | Mussels | 2$^{N}$ | | | | | <0.11 | | |
| **Further afield** | | | | | | | | | |
| Norwegian Sea | Haddock | 2 | | | | | <0.11 | | |
| Cromer | Crabs | 2 | | | | | <0.10 | | |
| Southern North Sea | Cockles/Mussels | 1 | | 0.0012 | 0.011 | | 0.0075 | * | * |

* *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, 2017

| 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 | <0.70 | | <2.7 | <0.54 | <5.7 | <2.8 | <0.68 | 190 | <3.0 |
| Maryport Outer Harbour | Sediment | 2 | <0.59 | | <1.4 | <0.38 | <3.4 | <1.6 | <0.41 | 100 | <2.1 |
| Workington Harbour | Sediment | 2 | <0.33 | | <1.2 | <0.34 | <2.5 | <1.3 | <0.35 | 39 | <2.0 |
| Harrington Harbour | Sediment | 2 | <0.39 | | <1.2 | <0.36 | <2.8 | <1.5 | <0.37 | 74 | <2.0 |
| Whitehaven Outer Harbour | Sediment | 4 | <0.39 | <2.1 | <1.3 | <0.31 | <2.7 | <1.4 | <0.35 | 55 | <1.9 |
| St Bees beach | Sediment | 4 | <0.53 | | <1.2 | <0.23 | <2.5 | <1.3 | <0.33 | 49 | <1.7 |
| Ehen spit | Sediment | 4 | <0.40 | | <1.4 | <0.30 | <2.9 | <1.5 | <0.35 | 96 | <2.1 |
| Sellafield beach, S of former pipeline | Sediment | 4 | <0.41 | | <1.3 | <0.24 | <2.7 | <1.3 | <0.34 | 29 | <1.6 |
| River Calder - downstream | Sediment | 4 | <0.43 | | <1.6 | <0.28 | <2.9 | <1.5 | <0.38 | 45 | <1.9 |
| River Calder - upstream | Sediment | 4 | <0.69 | | <2.3 | <0.54 | <4.2 | <2.1 | <0.61 | 34 | <2.5 |
| Seascale beach | Sediment | 4 | <0.45 | | <1.5 | <0.31 | <2.9 | <1.5 | <0.39 | 23 | <1.7 |
| Ravenglass - Carleton Marsh | Sediment | 4 | <2.1 | 69 | <5.0 | <0.93 | 50 | <4.9 | <1.1 | 220 | <7.0 |
| River Mite Estuary (erosional) | Sediment | 4 | <1.6 | 46 | <3.2 | <0.82 | 27 | <4.0 | <0.93 | 240 | <4.3 |
| Ravenglass - Raven Villa | Sediment | 4 | <1.5 | | <2.5 | <0.50 | <28 | <2.6 | <0.63 | 150 | <4.7 |
| Newbiggin (Eskmeals) | Sediment | 4 | 2.9 | 68 | <2.3 | <0.50 | <18 | <2.5 | <0.58 | 260 | <3.6 |
| Haverigg | Sediment | 2 | <0.59 | | <1.6 | <0.45 | <5.9 | <2.1 | <0.51 | 70 | <2.2 |
| Millom | Sediment | 2 | <0.63 | | <1.8 | <0.47 | <6.6 | <2.2 | <0.66 | 83 | <2.3 |
| Askam Pier | Sediment | 2 | <0.42 | | <1.2 | <0.27 | <2.8 | <1.5 | <0.37 | 44 | <1.8 |
| Low Shaw | Sediment | 2 | <0.34 | | <1.0 | <0.25 | <2.4 | <1.2 | <0.32 | 57 | <1.7 |
| Walney Channel - N of discharge point | Sediment | 2 | <0.44 | | <1.3 | <0.36 | <3.0 | <1.5 | <0.46 | 62 | <2.0 |
| Sand Gate Marsh | Sediment | 1 | <0.46 | | <0.92 | <0.30 | <2.8 | <1.5 | <0.42 | 42 | <1.5 |
| Kents Bank | Sediment | 1 | <0.47 | | <1.1 | <0.41 | <3.5 | <1.8 | <0.44 | 120 | <1.9 |
| Arnside | Sediment | 1 | <0.45 | | <2.6 | <0.38 | <4.1 | <1.9 | <0.45 | 200 | <3.0 |

| Location | Material | No. of sampling observ-ations | Mean radioactivity concentration (dry), Bq kg$^{-1}$ | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | $^{154}$Eu | $^{155}$Eu | $^{238}$Pu | $^{239}$Pu + $^{240}$Pu | $^{241}$Pu | $^{241}$Am | Gross alpha | Gross beta |
| **Cumbria** | | | | | | | | | | |
| Newton Arlosh | Sediment | 2 | <1.8 | <1.2 | | | | 260 | 650 | 940 |
| Maryport Outer Harbour | Sediment | 2 | <1.0 | <0.85 | | | | 290 | 640 | 840 |
| Workington Harbour | Sediment | 2 | <0.82 | <0.79 | | | | 28 | 410 | 860 |
| Harrington Harbour | Sediment | 2 | <0.95 | <0.78 | | | | 42 | 310 | 830 |
| Whitehaven Outer Harbour | Sediment | 4 | <0.93 | <0.73 | 11 | 69 | 220 | 100 | 220 | 500 |
| St Bees beach | Sediment | 4 | <0.86 | <0.66 | | | | 150 | <190 | 430 |
| Ehen spit | Sediment | 4 | <0.97 | <0.81 | | | | 100 | 280 | 780 |
| Sellafield beach, S of former pipeline | Sediment | 4 | <0.96 | <0.62 | | | | 120 | <160 | 450 |
| River Calder - downstream | Sediment | 4 | <1.1 | <0.75 | | | | 62 | <150 | 650 |
| River Calder - upstream | Sediment | 4 | <1.7 | <1.0 | | | | | 270 | 1400 |
| Seascale beach | Sediment | 4 | <1.1 | <0.66 | | | | 110 | 210 | 470 |
| Ravenglass - Carleton Marsh | Sediment | 4 | 2.7 | <2.1 | 70 | 390 | 1900 | 870 | 1200 | 1300 |
| River Mite Estuary (erosional) | Sediment | 4 | 2.4 | <2.3 | 69 | 400 | 1700 | 950 | 1300 | 1200 |
| Ravenglass - Raven Villa | Sediment | 4 | 1.6 | <1.9 | | | | 580 | 1100 | 990 |
| Newbiggin (Eskmeals) | Sediment | 4 | 3.0 | <2.0 | 93 | 550 | 2300 | 1200 | 1700 | 1200 |
| Haverigg | Sediment | 2 | <1.5 | <0.88 | | | | 250 | 440 | 730 |
| Millom | Sediment | 2 | <1.6 | <0.93 | | | | 230 | 520 | 790 |
| Askam Pier | Sediment | 2 | <1.0 | <0.70 | | | | 130 | 240 | 860 |
| Low Shaw | Sediment | 2 | <0.84 | <0.68 | | | | 130 | 260 | 640 |
| Walney Channel - N of discharge point | Sediment | 2 | <1.1 | <0.79 | | | | 160 | 370 | 750 |
| Sand Gate Marsh | Sediment | 1 | <1.2 | <0.68 | | | | 54 | 210 | 580 |
| Kents Bank | Sediment | 1 | <1.2 | <0.81 | | | | 87 | 360 | 670 |
| Arnside | Sediment | 1 | <1.1 | <1.1 | | | | 160 | 500 | 1200 |

**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 | <0.33 | | | | | | 9.1 | |
| Half Moon Bay | Sediment | 2 | <0.46 | | | | | | 59 | |
| Red Nab Point | Sediment | 2 | <0.48 | | | | | | 15 | |
| Potts Corner | Sediment | 2 | <0.43 | | | | | | 13 | |
| Sunderland Point | Sediment | 1 | <0.40 | <0.70 | <0.40 | <2.6 | <1.5 | <0.38 | 53 | <2.0 |
| Conder Green | Sediment | 1 | <0.49 | <1.5 | <0.48 | <3.8 | <1.9 | <0.51 | 74 | <2.9 |
| Hambleton | Sediment | 1 | <0.56 | <1.7 | <0.51 | <4.7 | <2.4 | <0.64 | 180 | <3.5 |
| Skippool Creek | Sediment | 1 | <0.66 | <1.8 | <0.56 | <4.9 | <2.4 | <0.59 | 180 | <2.9 |
| Fleetwood | Sediment | 1 | <0.41 | <1.1 | <0.26 | <2.4 | <1.3 | <0.34 | 9.5 | <1.5 |
| Blackpool | Sediment | 1 | <0.30 | <0.88 | <0.20 | <1.9 | <1.0 | <0.27 | 1.9 | <1.2 |
| Crossens Marsh | Sediment | 1 | <1.6 | <5.1 | <1.2 | <13 | <6.6 | <1.6 | 190 | <7.5 |
| Ainsdale | Sediment | 1 | <0.31 | <0.73 | <0.21 | <2.0 | <1.1 | <0.29 | 2.7 | <1.1 |
| Rock Ferry | Sediment | 1 | <0.45 | <1.4 | <0.40 | <3.3 | <1.7 | <0.44 | 85 | <2.3 |

| 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 | | | | | 12 | | |
| Half Moon Bay | Sediment | 2 | | | 7.4 | 44 | 95 | | |
| Red Nab Point | Sediment | 2 | | | | | 14 | | |
| Potts Corner | Sediment | 2 | | | | | 14 | | |
| Sunderland Point | Sediment | 1 | <0.98 | <0.86 | | | 79 | 200 | 730 |
| Conder Green | Sediment | 1 | <1.3 | <1.2 | | | 97 | 360 | 750 |
| Hambleton | Sediment | 1 | <1.5 | <1.4 | | | 210 | 430 | 1200 |
| Skippool Creek | Sediment | 1 | <1.6 | <1.2 | | | 230 | 370 | 1100 |
| Fleetwood | Sediment | 1 | <0.95 | <0.59 | | | 21 | <110 | 460 |
| Blackpool | Sediment | 1 | <0.76 | <0.47 | | | 3.3 | <120 | 260 |
| Crossens Marsh | Sediment | 1 | <3.8 | <3.2 | | | 210 | 360 | 1200 |
| Ainsdale | Sediment | 1 | <0.81 | <0.47 | | | 2.8 | <110 | 210 |
| Rock Ferry | Sediment | 1 | <1.1 | <0.92 | | | 74 | 300 | 930 |

**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 | <0.10 | <0.10 | <0.29 | <0.10 | <0.10 | 5.8 |
| Garlieston | Sediment | 1[S] | <0.10 | 0.11 | <0.12 | 0.13 | <0.35 | <0.10 | <0.10 | 27 |
| Innerwell | Sediment | 2[S] | <0.10 | 0.26 | <0.33 | <0.45 | <0.81 | <0.19 | <0.11 | 62 |
| Carsluith | Sediment | 1[S] | <0.10 | 0.19 | <0.10 | <0.10 | <0.36 | 0.32 | <0.10 | 27 |
| Skyreburn | Sediment | 2[S] | <0.10 | <0.10 | <0.17 | <0.20 | <0.66 | <0.22 | <0.10 | 20 |
| Kirkcudbright | Sediment[a] | 2[S] | <0.10 | 0.37 | <0.25 | <0.26 | <1.3 | <0.42 | <0.12 | 81 |
| Rascarrel Bay | Sediment[a] | 1[S] | <0.10 | 0.14 | <0.13 | <0.11 | <0.53 | 0.38 | <0.10 | 28 |
| Palnackie Harbour | Sediment | 2[S] | <0.14 | 0.45 | <0.54 | <0.65 | <1.7 | <0.60 | <0.23 | 110 |
| Gardenburn | Sediment | 2[S] | <0.10 | 0.38 | <0.24 | <0.24 | 1.3 | <0.33 | <0.12 | 120 |
| Kippford Slipway | Sediment | 2[S] | <0.10 | 0.44 | <0.31 | <0.53 | <7.4 | <0.41 | <0.13 | 120 |
| Kippford Merse | Sediment | 1[S] | <0.10 | 0.26 | <0.39 | <0.59 | 1.3 | <0.19 | <0.12 | 88 |
| Kirkconnell Merse | Sediment | 1[S] | <0.10 | <0.10 | <0.42 | <0.33 | <1.1 | <0.46 | <0.14 | 170 |
| Southerness | Sediment | 1[S] | <0.10 | <0.10 | <0.17 | <0.37 | <0.57 | <0.18 | <0.10 | 8.2 |

| 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] | <0.32 | <0.10 | <0.12 | | | 0.93 | | |
| Garlieston | Sediment | 1[S] | <0.34 | <0.10 | 0.77 | 4.5 | 31 | 60 | | |
| Innerwell | Sediment | 2[S] | <0.83 | <0.23 | 1.2 | 13 | 77 | 150 | | |
| Carsluith | Sediment | 1[S] | <0.36 | 0.21 | 0.60 | 12 | 83 | 130 | 280 | 1700 |
| Skyreburn | Sediment | 2[S] | <0.75 | <0.20 | <0.43 | 2.7 | 17 | 22 | | |
| Kirkcudbright | Sediment[a] | 2[S] | <0.75 | <0.33 | 1.7 | | | <84 | | |
| Rascarrel Bay | Sediment[a] | 1[S] | <0.61 | <0.11 | <0.34 | | | 59 | | |
| Palnackie Harbour | Sediment | 2[S] | <1.4 | <0.35 | <1.3 | 19 | 120 | 210 | | |
| Gardenburn | Sediment | 2[S] | <0.79 | 0.50 | 1.4 | 18 | 120 | 200 | | |
| Kippford Slipway | Sediment | 2[S] | <1.1 | <0.35 | 0.78 | 22 | 140 | 260 | | |
| Kippford Merse | Sediment | 1[S] | <1.1 | 0.33 | 1.1 | 14 | 110 | 180 | | |
| Kirkconnell Merse | Sediment | 1[S] | <1.0 | <0.19 | 1.4 | 7.6 | 47 | 83 | 250 | 1800 |
| Southerness | Sediment | 1[S] | <0.65 | <0.16 | <0.19 | 2.1 | 13 | 27 | | |

## 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 | 1 | | <0.77 | <2.3 | <0.51 | <5.2 | <2.6 | <0.70 | 46 | <2.8 |
| Llandudno | Sediment | 1 | | <0.52 | <1.7 | <0.36 | <3.4 | <1.7 | <0.49 | 2.3 | <2.0 |
| Caerhun | Sediment | 1 | | <0.61 | <2.0 | <0.41 | <4.1 | <2.0 | <0.58 | 13 | <2.3 |
| Llanfairfechan | Sediment | 1 | | <0.61 | <2.1 | <0.43 | <4.2 | <2.1 | <0.58 | 14 | <2.3 |
| **Northern Ireland** | | | | | | | | | | | |
| Carrichue | Sandy mud | 1$^{N}$ | <0.30 | <0.24 | <0.74 | <0.71 | <2.4 | <0.74 | <0.34 | 1.6 | <2.0 |
| Carrichue | Mud | 1$^{N}$ | <0.46 | <0.38 | <3.9 | <8.3 | <3.1 | <0.88 | <0.35 | 1.4 | <2.0 |
| Portrush | Sand | 2$^{N}$ | <0.35 | <0.25 | <2.6 | <6.0 | <2.4 | <0.71 | <0.34 | 0.56 | <1.7 |
| Oldmill Bay | Mud | 2$^{N}$ | <0.53 | <0.54 | <1.9 | <2.7 | <4.9 | <1.3 | <0.68 | 39 | <2.4 |
| Ballymacormick | Sandy mud | 1$^{N}$ | <0.34 | <0.35 | <0.75 | <0.56 | <3.0 | <0.87 | <0.44 | 11 | <1.7 |
| Ballymacormick | Mud | 1$^{N}$ | <0.29 | <0.12 | <1.3 | <1.5 | <3.2 | <0.89 | <0.40 | 10 | <2.1 |
| Strangford Lough - Nicky's Point | Mud | 2$^{N}$ | <0.33 | <0.24 | <1.9 | <2.9 | <2.8 | <0.72 | <0.41 | 15 | <1.7 |
| Dundrum Bay | Mud | 2$^{N}$ | <0.48 | <0.34 | <1.3 | <1.9 | <4.1 | <1.1 | <0.54 | 28 | <2.2 |
| Carlingford Lough | Mud | 2$^{N}$ | <0.40 | <0.32 | <1.4 | <1.5 | <3.4 | <1.1 | <0.46 | 36 | <2.2 |

| 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 | 1 | <1.9 | <1.1 | | | 35 | | | 280 | 910 |
| Llandudno | Sediment | 1 | <1.3 | <0.79 | | | | | | <120 | 590 |
| Caerhun | Sediment | 1 | <1.5 | <0.91 | | | 9.7 | | | 190 | 620 |
| Llanfairfechan | Sediment | 1 | <1.5 | <0.90 | | | 12 | | | 150 | 510 |
| **Northern Ireland** | | | | | | | | | | | |
| Carrichue | Sandy mud | 1$^{N}$ | <0.77 | <0.95 | | | 2.7 | | | | |
| Carrichue | Mud | 1$^{N}$ | <0.92 | <0.95 | 0.18 | 0.89 | 1.5 | * | * | | |
| Portrush | Sand | 2$^{N}$ | <0.86 | <0.73 | | | <1.1 | | | | |
| Oldmill Bay | Mud | 2$^{N}$ | <1.2 | <1.1 | | | 8.9 | | | | |
| Ballymacormick | Sandy mud | 1$^{N}$ | <1.1 | <0.83 | | | 11 | | | | |
| Ballymacormick | Mud | 1$^{N}$ | <0.95 | <1.0 | | | 11 | | | | |
| Strangford Lough - Nicky's Point | Mud | 2$^{N}$ | <0.88 | <0.96 | | | 5.7 | | | | |
| Dundrum Bay | Mud | 2$^{N}$ | <1.4 | <1.1 | | | 9.1 | | | | |
| Carlingford Lough | Mud | 2$^{N}$ | <1.2 | <1.2 | 1.8 | 12 | 9.0 | * | * | | |

* *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, 2017**

| 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 | 1 | 0.075 |
| Burgh Marsh | Salt marsh | 1 | 0.074 |
| Port Carlisle 1 | Mud | 1 | 0.083 |
| Port Carlisle 1 | Mud and sand | 1 | 0.074 |
| Port Carlisle 2 | Grass | 2 | 0.080 |
| Newton Arlosh | Salt marsh | 2 | 0.086 |
| Silloth harbour | Sand | 1 | 0.10 |
| Silloth harbour | Sand and shingle | 1 | 0.089 |
| Allonby | Sand | 2 | 0.076 |
| Maryport harbour | Mud and sand | 1 | 0.076 |
| Maryport harbour | Sand | 1 | 0.090 |
| Workington harbour | Shingle | 2 | 0.10 |
| Harrington harbour | Sand | 1 | 0.11 |
| Harrington harbour | Sand and pebbles | 1 | 0.099 |
| | | | |
| **Cumbria, Whitehaven-Drigg** | | | |
| Whitehaven - outer harbour | Sand | 3 | 0.089 |
| Whitehaven - outer harbour | Sand and pebbles | 1 | 0.086 |
| St Bees | Sand | 4 | 0.071 |
| Nethertown beach | Pebbles | 1 | 0.11 |
| Nethertown beach | Shingle | 3 | 0.12 |
| Ehen spit | Sand and pebbles | 1 | 0.10 |
| Ehen spit | Sand and shingle | 1 | 0.11 |
| Ehen spit | Shingle | 2 | 0.11 |
| Braystones | Grass | 1 | 0.083 |
| Braystones beach | Pebbles | 1 | 0.10 |
| Braystones beach | Shingle | 3 | 0.11 |
| Sellafield dunes | Grass | 4 | 0.098 |
| North of former pipeline on foreshore | Sand | 4 | 0.074 |
| South of former pipeline on foreshore | Sand | 4 | 0.075 |
| River Calder downstream of site | Grass | 4 | 0.081 |
| River Calder upstream of site | Grass | 1 | 0.095 |
| Seascale beach | Sand | 3 | 0.071 |
| Seascale beach | Sand and shingle | 1 | 0.082 |
| | | | |
| **Cumbria, Ravenglass-Askam** | | | |
| Ravenglass - Carleton Marsh | Grass | 1 | 0.12 |
| Ravenglass - Carleton Marsh | Grass and mud | 1 | 0.13 |
| Ravenglass - Carleton Marsh | Salt marsh | 2 | 0.12 |
| Ravenglass - River Mite estuary (erosional) | Grass | 1 | 0.13 |
| Ravenglass - River Mite estuary (erosional) | Salt marsh | 3 | 0.12 |
| Ravenglass - Raven Villa | Salt marsh | 4 | 0.12 |
| Ravenglass - boat area | Sand and pebbles | 3 | 0.10 |
| Ravenglass - boat area | Stones | 1 | 0.10 |
| Ravenglass - ford | Sand | 4 | 0.087 |
| Muncaster Bridge | Grass | 4 | 0.11 |
| Ravenglass - salmon garth | Mud and sand | 1 | 0.093 |
| Ravenglass - salmon garth | Sand | 2 | 0.095 |
| Ravenglass - salmon garth | Sand and shingle | 1 | 0.11 |
| Ravenglass - Eskmeals Nature Reserve | Salt marsh | 3 | 0.098 |
| Newbiggin/Eskmeals Bridge | Salt marsh | 4 | 0.11 |
| Newbiggin/Eskmeals viaduct | Salt marsh | 4 | 0.11 |
| Tarn Bay | Sand | 4 | 0.072 |

**Table 2.9 continued**

| Location | Ground type | No. of sampling observations | Mean gamma dose rate in air at 1m, μGy $h^{-1}$ |
|---|---|---|---|
| Silecroft | Shingle | 2 | 0.11 |
| Haverigg | Mud and sand | 1 | 0.094 |
| Haverigg | Sand | 1 | 0.090 |
| Millom | Sand | 1 | 0.098 |
| Millom | Sand and slag | 1 | 0.11 |
| Low Shaw | Grass | 2 | 0.079 |
| Askam | Sand | 4 | 0.068 |
| Askam Pier | Sand | 4 | 0.078 |
| | | | |
| **Cumbria, Walney-Arnside** | | | |
| Walney Channel, N of discharge point | Sand | 4 | 0.085 |
| Tummer Hill Marsh | Salt marsh | 2 | 0.10 |
| Roa Island | Mud | 1 | 0.089 |
| Roa Island | Sand | 1 | 0.093 |
| Sand Gate Marsh | Grass | 1 | 0.079 |
| Sand Gate Marsh | Salt marsh | 1 | 0.070 |
| Kents Bank 2 | Salt marsh | 2 | 0.078 |
| Arnside 2 | Grass | 2 | 0.084 |
| | | | |
| **Lancashire and Merseyside** | | | |
| Morecambe Central beach | Sand | 1 | 0.076 |
| Morecambe Central beach | Sand and pebbles | 1 | 0.074 |
| Half Moon Bay | Sand | 1 | 0.081 |
| Half Moon Bay | Sand and stones | 1 | 0.081 |
| Red Nab Point | Sand and shingle | 1 | 0.074 |
| Red Nab Point | Sand and pebbles | 1 | 0.072 |
| Middleton Sands | Sand | 2 | 0.074 |
| Sunderland Point | Sand | 2 | 0.092 |
| Colloway Marsh | Salt marsh | 2 | 0.11 |
| Lancaster | Grass | 1 | 0.078 |
| Aldcliffe Marsh | Salt marsh | 2 | 0.085 |
| Conder Green | Grass and salt marsh | 1 | 0.088 |
| Conder Green | Mud | 1 | 0.089 |
| Pilling Marsh | Salt marsh | 2 | 0.092 |
| Knott End | Sand | 2 | 0.076 |
| Height o' th' hill - River Wyre | Salt marsh | 2 | 0.093 |
| Hambleton | Grass | 1 | 0.087 |
| Hambleton | Grass and mud | 1 | 0.098 |
| Skippool Creek 1 | Salt marsh | 2 | 0.097 |
| Skippool Creek 2 | Salt marsh | 2 | 0.096 |
| Fleetwood shore 1 | Sand | 2 | 0.071 |
| Fleetwood shore 2 | Salt marsh | 2 | 0.11 |
| Blackpool | Sand | 2 | 0.065 |
| Crossens Marsh | Salt marsh | 2 | 0.088 |
| Ainsdale | Sand | 2 | 0.066 |
| Rock Ferry | Mud and sand | 2 | 0.087 |
| West Kirby | Sand | 2 | 0.072 |
| Flint 1 | Mud | 2 | 0.087 |
| Flint 2 | Salt marsh | 2 | 0.091 |
| | | | |
| **Scotland** | | | |
| Piltanton Burn | Sand | $2^{S}$ | 0.069 |
| Garlieston | Rocks | $2^{S}$ | 0.070 |
| Innerwell | Shingle | $1^{S}$ | 0.066 |

**Table 2.9 continued**

| Location | Ground type | No. of sampling observations | Mean gamma dose rate in air at 1m, μGy $h^{-1}$ |
|---|---|---|---|
| Innerwell | Rocks | 1[S] | 0.078 |
| Bladnoch | Salt marsh | 2[S] | 0.071 |
| Carsluith | Sand | 2[S] | 0.080 |
| Skyreburn Bay (Water of Fleet) | Sediment | 2[S] | 0.078 |
| Kirkcudbright | Salt marsh | 2[S] | 0.072 |
| Cutters Pool | Winkle bed | 3[S] | 0.082 |
| Cutters Pool | Rocks and sand | 1[S] | 0.090 |
| Rascarrel Bay | Sand | 2[S] | 0.079 |
| Gardenburn | Grass | 2[S] | 0.077 |
| Palnackie Harbour | Grass | 2[S] | 0.076 |
| Kippford - Slipway | Mud | 2[S] | 0.086 |
| Kippford - Merse | Salt marsh | 1[S] | 0.079 |
| Kippford - Merse | Mud | 1[S] | 0.088 |
| Kirkconnell Marsh | Sediment | 2[S] | 0.068 |
| Southerness | Sand | 2[S] | 0.067 |
| **Wales** | | | |
| Rhyl | Grass and mud | 1 | 0.081 |
| Rhyl | Salt marsh | 1 | 0.082 |
| Llandudno | Pebbles | 1 | 0.090 |
| Llandudno | Shingle | 1 | 0.098 |
| Caerhun | Grass | 1 | 0.084 |
| Caerhun | Salt marsh | 1 | 0.074 |
| Llanfairfechan | Sand | 1 | 0.077 |
| Llanfairfechan | Sand and shells | 1 | 0.072 |
| **Northern Ireland** | | | |
| Lisahally | Mud | 1[N] | 0.062 |
| Donnybrewer | Shingle | 1[N] | 0.053 |
| Carrichue | Mud | 1[N] | 0.056 |
| Bellerena | Mud | 1[N] | 0.058 |
| Benone | Sand | 1[N] | 0.056 |
| Castlerock | Sand | 1[N] | 0.052 |
| Portstewart | Sand | 1[N] | 0.057 |
| Portrush, Blue Pool | Sand | 1[N] | 0.059 |
| Portrush, White Rocks | Sand | 1[N] | 0.057 |
| Portballintrae | Sand | 1[N] | 0.058 |
| Giant's Causeway | Sand | 1[N] | 0.058 |
| Ballycastle | Sand | 1[N] | 0.054 |
| Cushendun | Sand | 1[N] | 0.058 |
| Cushendall | Sand and stones | 1[N] | 0.062 |
| Red Bay | Sand | 1[N] | 0.064 |
| Carnlough | Sand | 1[N] | 0.055 |
| Glenarm | Sand | 1[N] | 0.056 |
| Half Way House | Sand | 1[N] | 0.055 |
| Ballygally | Sand | 1[N] | 0.060 |
| Drains Bay | Sand | 1[N] | 0.057 |
| Larne | Sand | 1[N] | 0.058 |
| Whitehead | Sand | 1[N] | 0.059 |
| Carrickfergus | Sand | 1[N] | 0.060 |
| Jordanstown | Sand | 1[N] | 0.061 |
| Helen's Bay | Sand | 1[N] | 0.064 |
| Groomsport | Sand | 1[N] | 0.067 |
| Millisle | 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 $h^{-1}$ |
|---|---|---|---|
| Ballywalter | Sand | 1[N] | 0.062 |
| Ballyhalbert | Sand | 1[N] | 0.063 |
| Cloghy | Sand | 1[N] | 0.072 |
| Portaferry | Shingle and stones | 1[N] | 0.082 |
| Kircubbin | Sand | 1[N] | 0.077 |
| Greyabbey | Sand | 1[N] | 0.076 |
| Ards Maltings | Mud | 1[N] | 0.072 |
| Island Hill | Mud | 1[N] | 0.072 |
| Nicky's Point | Mud | 1[N] | 0.077 |
| Strangford | Shingle and stones | 1[N] | 0.097 |
| Kilclief | Sand | 1[N] | 0.071 |
| Ardglass | Mud | 1[N] | 0.081 |
| Killough | Mud | 1[N] | 0.084 |
| Ringmore Point | Sand | 1[N] | 0.074 |
| Tyrella | Sand | 1[N] | 0.075 |
| Dundrum | Sand | 1[N] | 0.096 |
| Newcastle | Sand | 1[N] | 0.10 |
| Annalong | Sand | 1[N] | 0.11 |
| Cranfield Bay | Sand | 1[N] | 0.084 |
| Mill Bay | Sand | 1[N] | 0.11 |
| Greencastle | Sand | 1[N] | 0.079 |
| Rostrevor | Sand | 1[N] | 0.11 |
| Narrow Water | Mud | 1[N] | 0.089 |

[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, 2017**

| Vessel or location | Type of gear | No. of sampling observations | Mean beta dose rate in tissue, μSv $h^{-1}$ |
|---|---|---|---|
| 104 | Nets | 2 | <0.084 |
| 106 | Nets | 1 | <0.081 |
| 109 | Nets | 2 | <0.083 |
| 111 | Nets | 1 | <0.085 |
| 113 | Nets | 1 | <0.084 |
| North 1 | Lobster pots | 1 | 0.095 |
| North 2 | Lobster pots | 1 | 0.14 |
| South 1 | Lobster pots | 1 | 0.11 |
| South 2 | Lobster pots | 1 | <0.11 |

**Table 2.11 Beta radiation dose rates over intertidal areas of the Cumbrian coast, 2017**

| Location | Ground type | No. of sampling observations | Mean beta dose rate in tissue, μSv $h^{-1}$ |
|---|---|---|---|
| Whitehaven - outer harbour | Sand | 3 | 0.14 |
| Whitehaven - outer harbour | Sand and stones | 1 | 0.18 |
| St Bees | Sand | 3 | 0.12 |
| Sellafield beach, N of discharge point | Sand | 3 | 0.10 |
| Ravenglass - Raven Villa | Salt marsh | 4 | 0.16 |
| Tarn Bay | Sand | 4 | 0.17 |

**Table 2.12 Concentrations of radionuclides in aquatic plants from the Cumbrian coast and further afield, 2017**

| 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 | <0.64 | | | <0.87 | <0.42 | 150 | <3.9 | <0.63 | <2.2 |
| Harrington Harbour | Seaweed | 2 | <0.34 | | | <0.46 | <0.24 | 170 | <2.1 | <0.34 | <1.3 |
| St Bees[b] | Seaweed | 2 | <0.48 | | <0.52 | <0.61 | <0.33 | 370 | <2.9 | <0.48 | <1.6 |
| Sellafield[c] | Seaweed | 2 | <0.53 | | <2.1 | <0.66 | <0.34 | 1700 | <3.0 | <0.49 | <1.8 |
| Ravenglass | Samphire | 1[F] | <0.08 | <0.18 | | <0.17 | <0.13 | 0.67 | <0.63 | <0.10 | <0.19 |
| Ravenglass[d] | Seaweed | 2 | <0.41 | | 1.0 | <0.51 | <0.26 | 120 | <2.5 | <0.39 | <1.4 |
| **Lancashire** | | | | | | | | | | | |
| Half Moon Bay | Seaweed | 2 | <0.54 | | | <0.66 | <0.36 | 220 | <3.5 | <0.54 | <2.0 |
| Marshside Sands | Samphire | 1[F] | <0.10 | <0.23 | | <0.20 | <0.15 | <0.12 | <0.75 | <0.12 | <0.20 |
| **Scotland** | | | | | | | | | | | |
| Lerwick | *Fucus vesiculosus* | 1[S] | <0.10 | <0.19 | | <0.26 | <0.34 | 3.0 | <0.53 | <0.10 | <0.14 |
| Kinlochbervie | *Fucus vesiculosus* | 2[S] | <0.10 | <0.21 | | <0.23 | <0.26 | 24 | <0.62 | <0.11 | <0.17 |
| Lewis | *Fucus vesiculosus* | 1[S] | <0.10 | <0.12 | | <0.19 | <0.29 | 9.8 | <0.33 | <0.10 | <0.10 |
| Islay | *Fucus vesiculosus* | 1[S] | <0.10 | <0.18 | | <0.21 | <0.24 | 18 | <0.52 | <0.10 | <0.15 |
| Campbeltown | *Fucus vesiculosus* | 1[S] | <0.10 | <0.19 | | <0.24 | <0.28 | 50 | <0.60 | <0.10 | <0.17 |
| Port William | *Fucus vesiculosus* | 4[S] | <0.10 | <0.19 | | <0.19 | <0.20 | 50 | <0.57 | <0.11 | <0.17 |
| Garlieston | *Fucus vesiculosus* | 4[S] | <0.10 | <0.17 | | <0.20 | <0.23 | 43 | <0.52 | <0.11 | <0.15 |
| Auchencairn | *Fucus vesiculosus* | 4[S] | <0.10 | <0.19 | | <0.21 | <0.22 | 280 | <0.59 | <0.12 | <0.16 |
| **Wales** | | | | | | | | | | | |
| Cemaes Bay | Seaweed | 2 | <0.46 | | | <0.57 | <0.30 | 89 | <2.6 | <0.42 | <1.6 |
| Porthmadog | Seaweed | 2 | <0.45 | | | <0.63 | <0.30 | 1.9 | <2.7 | <0.44 | <1.6 |
| Lavernock Point | Seaweed | 2 | <0.45 | | | <0.67 | <0.30 | <1.1 | <2.9 | <0.48 | <1.6 |
| Fishguard | Seaweed | 2 | <0.42 | | | <1.2 | <0.27 | <3.6 | <3.0 | <0.50 | <1.6 |
| **Northern Ireland** | | | | | | | | | | | |
| Portrush | *Fucus* spp. | 4[N] | <0.07 | <0.16 | | <0.22 | <0.32 | | <0.50 | <0.10 | <0.12 |
| Portaferry[a] | *Rhodymenia* spp. | 1[N] | <0.04 | <0.08 | | <0.32 | <1.3 | 0.25 | <0.73 | <0.08 | <0.15 |
| Ardglass | *Fucus vesiculosus* | 4[N] | <0.07 | <0.16 | | <0.29 | <0.35 | 26 | <0.57 | <0.10 | <0.13 |
| Carlingford Lough | *Ascophyllum nodosum* | 1[N] | <0.05 | <0.15 | | <0.13 | <0.11 | | <0.43 | <0.07 | <0.13 |
| Carlingford Lough | *Fucus* spp. | 3[N] | <0.05 | <0.16 | | <0.18 | <0.28 | 50 | <0.49 | <0.09 | <0.14 |

**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 | 1.3 | <0.56 | 2.8 | <1.5 | | | | 1.8 |
| Harrington Harbour | Seaweed | 2 | 2.3 | <0.3 | 0.69 | <0.92 | | | | 0.90 |
| St Bees[b] | Seaweed | 2 | <3.4 | <0.42 | 1.3 | <1.2 | | 0.60 | 3.0 | 1.9 |
| Sellafield[c] | Seaweed | 2 | 5.5 | <0.43 | 4.0 | <1.2 | | 1.7 | 7.9 | 4.3 |
| Ravenglass | Samphire | 1[F] | | <0.08 | 0.79 | <0.36 | <0.16 | | | 2.0 |
| Ravenglass[d] | Seaweed | 2 | 2.0 | <0.35 | 6.4 | <1.2 | | 1.6 | 8.7 | 20 |
| **Lancashire** | | | | | | | | | | |
| Half Moon Bay | Seaweed | 2 | 1.9 | <0.50 | 2.0 | <1.6 | | | | <0.76 |
| Marshside Sands | Samphire | 1[F] | | <0.10 | 0.20 | <0.29 | <0.13 | | | <0.08 |
| **Scotland** | | | | | | | | | | |
| Lerwick | *Fucus vesiculosus* | 1[S] | | <0.10 | <0.10 | <0.35 | <0.14 | | | <0.10 |
| Kinlochbervie | *Fucus vesiculosus* | 2[S] | | <0.10 | <0.11 | <0.37 | <0.17 | | | <0.13 |
| Lewis | *Fucus vesiculosus* | 1[S] | | <0.10 | 0.14 | <0.31 | <0.14 | | | <0.15 |
| Islay | *Fucus vesiculosus* | 1[S] | | <0.10 | <0.10 | <0.34 | <0.14 | | | <0.10 |
| Campbeltown | *Fucus vesiculosus* | 1[S] | | <0.10 | 0.23 | <0.36 | <0.16 | | | <0.10 |
| Port William | *Fucus vesiculosus* | 4[S] | | <0.10 | 0.41 | <0.34 | <0.15 | | | 0.43 |
| Garlieston | *Fucus vesiculosus* | 4[S] | | <0.10 | 2.0 | <0.34 | <0.14 | | | 4.6 |
| Auchencairn | *Fucus vesiculosus* | 4[S] | | <0.10 | 1.3 | <0.37 | <0.14 | | | 1.4 |
| **Wales** | | | | | | | | | | |
| Cemaes Bay | Seaweed | 2 | | <0.39 | <0.34 | <1.2 | | | | <0.41 |
| Porthmadog | Seaweed | 2 | | <0.42 | <0.66 | <1.1 | | | | <0.37 |
| Lavernock Point | Seaweed | 2 | | <0.38 | <0.32 | <1.3 | <0.59 | | | <0.38 |
| Fishguard | Seaweed | 2 | | <0.36 | <0.31 | <1.2 | | | | <0.28 |
| **Northern Ireland** | | | | | | | | | | |
| Portrush | *Fucus* spp. | 4[N] | | <0.06 | <0.06 | <0.27 | <0.11 | | | <0.10 |
| Portaferry[a] | *Rhodymenia* spp. | 1[N] | | <0.08 | 0.61 | <0.30 | <0.13 | 0.088 | 0.51 | 0.96 |
| Ardglass | *Fucus vesiculosus* | 4[N] | | <0.08 | 0.57 | <0.35 | <0.17 | | | 0.35 |
| Carlingford Lough | *Ascophyllum nodosum* | 1[N] | | <0.06 | 0.20 | <0.31 | <0.14 | | | <0.15 |
| Carlingford Lough | *Fucus* spp. | 3[N] | | <0.07 | 0.19 | <0.30 | <0.17 | | | <0.10 |

[a] *$^{242}$Cm and $^{243+244}$Cm were not detected by the method used*
[b] *The concentrations of $^{14}$C was < 5.7 Bq kg$^{-1}$*
[c] *The concentrations of $^{14}$C was 45 Bq kg$^{-1}$*
[d] *The concentrations of $^{14}$C was < 11 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, 2017

| Material and 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 | $^{95}$Nb | $^{95}$Zr | $^{99}$Tc | $^{106}$Ru | $^{125}$Sb | $^{129}$I | $^{134}$Cs |
| Milk | | 3 | | <3.2 | 18 | <0.06 | <0.027 | <0.11 | <0.13 | <0.020 | <0.44 | <0.13 | <0.011 | <0.06 |
| Milk | max | | | | | | 0.031 | <0.14 | <0.14 | 0.021 | <0.48 | | 0.024 | <0.07 |
| Beef kidney | | 1 | | | | <0.12 | <0.06 | <0.20 | <0.27 | | <1.1 | <0.37 | | <0.14 |
| Beef liver | | 1 | | <8.3 | 41 | <0.05 | <0.051 | <0.09 | <0.05 | <0.083 | <0.52 | <0.11 | <0.019 | <0.05 |
| Beef muscle | | 1 | | <3.9 | 27 | <0.03 | <0.047 | <0.12 | <0.16 | <0.12 | <0.62 | <0.18 | <0.012 | <0.08 |
| Blackberries | | 1 | <5.3 | <5.3 | 20 | <0.02 | 0.11 | <0.04 | <0.11 | | <0.36 | <0.15 | <0.018 | <0.06 |
| Sheep muscle | | 2 | | <5.2 | 26 | <0.06 | <0.034 | <0.13 | <0.13 | <0.087 | <0.38 | <0.15 | <0.019 | <0.05 |
| Sheep muscle | max | | | <6.5 | 28 | | <0.043 | <0.17 | <0.15 | <0.088 | <0.39 | <0.16 | | <0.06 |
| Sheep offal | | 2 | | <9.4 | 36 | <0.08 | <0.042 | <0.10 | <0.13 | <0.096 | <0.52 | <0.20 | <0.02 | <0.08 |
| Sheep offal | max | | | 15 | 43 | <0.11 | <0.047 | <0.13 | <0.16 | <0.097 | <0.54 | <0.25 | | <0.11 |

| Material and selection[a] | | No. of sampling observ-ations[c] | Mean radioactivity concentration (fresh)[b], Bq kg$^{-1}$ | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $^{137}$Cs | Total Cs | $^{144}$Ce | $^{234}$U | $^{235}$U | $^{238}$U | $^{238}$Pu | $^{239}$Pu + $^{240}$Pu | $^{241}$Pu | $^{241}$Am |
| Milk | | 3 | <0.10 | | <0.34 | | | | <0.000029 | <0.000031 | <0.17 | 0.000024 |
| Milk | max | | 0.13 | | | | | | <0.000051 | <0.000051 | <0.22 | 0.000038 |
| Beef kidney | | 1 | 0.54 | 0.54 | <0.84 | 0.0091 | 0.00058 | 0.010 | <0.00011 | 0.00011 | <0.46 | 0.00015 |
| Beef liver | | 1 | 0.26 | 0.26 | <0.25 | | | | 0.000059 | 0.0011 | <0.28 | 0.00087 |
| Beef muscle | | 1 | 1.8 | 1.8 | <0.30 | | | | <0.00013 | 0.000054 | <0.30 | 0.00020 |
| Blackberries | | 1 | <0.07 | <0.074 | <0.35 | | | | 0.00016 | 0.00084 | <0.21 | 0.0015 |
| Sheep muscle | | 2 | 4.2 | 4.2 | <0.25 | | | | 0.000028 | 0.00030 | <0.30 | 0.00060 |
| Sheep muscle | max | | 7.4 | 7.4 | <0.32 | | | | 0.000038 | 0.00038 | 0.31 | 0.0010 |
| Sheep offal | | 2 | 2.0 | 2.0 | <0.43 | | | | 0.000037 | 0.00044 | <0.26 | 0.011 |
| Sheep offal | max | | 3.4 | 3.4 | <0.52 | | | | 0.000039 | 0.00058 | <0.27 | 0.018 |

[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, 2017

| Location | No. of sampling observ-ations | 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 | 250 | <0.30 | <0.021 | <0.31 | <0.25 | <0.0024 | 0.003 | <3.1 | 12 |
| River Ehen (100m downstream of sewer outfall) | 4 | <5.2 | <0.29 | <0.11 | <0.31 | <0.24 | <0.0023 | <0.0013 | <0.027 | 0.54 |
| River Calder (downstream) | 4 | <3.9 | <0.27 | <0.012 | <0.30 | <0.23 | <0.0014 | <0.0012 | <0.022 | 0.15 |
| River Calder (upstream) | 4 | <3.5 | <0.31 | <0.016 | <0.32 | <0.24 | <0.0026 | <0.0017 | <0.025 | 0.050 |
| River Ehen (upstream of site and tidal confluence) | 4 | <3.9 | <0.29 | <0.011 | <0.31 | <0.24 | <0.0034 | <0.0027 | <0.055 | 0.30 |
| Wast Water | 1 | <4.0 | <0.25 | | | <0.22 | | | <0.021 | 0.089 |
| Ennerdale Water | 1 | <4.0 | <0.13 | | <0.13 | <0.10 | | | <0.033 | 0.056 |
| Sellafield Tarn | 1 | <7.9 | | 0.056 | | <0.25 | <0.0031 | <0.0025 | | |
| Devoke Water | 1 | <3.6 | <0.12 | | <0.13 | <0.10 | | | <0.018 | 0.066 |
| Thirlmere | 1 | <4.1 | <0.27 | | | <0.22 | | | <0.033 | 0.10 |

[a] *The concentration of $^{99}Tc$ was <0.65 Bq $l^{-1}$*

## Table 2.15 Concentrations of radionuclides in road drain sediments from Whitehaven and Seascale, 2017

| 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 | <1.8 | <2.0 | <1.8 | 160 | 2.3 | 17 | 32 |
| Seascale SS 233 | 1 | <1.5 | <2.0 | <1.5 | 120 | 1.6 | 13 | 22 |
| Seascale SS 209 | 1 | <0.39 | <2.0 | <0.39 | 16 | 1.8 | 12 | 17 |
| Seascale SS 232 | 1 | <0.32 | <2.0 | <0.32 | 25 | 2.7 | 19 | 24 |
| Seascale SS 231 | 1 | <0.64 | <2.0 | <0.58 | 42 | 5.8 | 37 | 63 |
| Whitehaven SS 201 | 1 | <3.2 | <2.0 | <3.3 | 31 | <0.46 | 1.2 | <2.5 |

## Table 2.16 Doses from artificial radionuclides in the Irish Sea, 2007-2017

| Group | Exposure, mSv per year | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 |
| Northern Ireland | 0.015 | 0.017 | 0.012 | 0.010 | 0.010 | 0.011 | 0.010 | 0.009 | 0.009 | 0.011 | 0.010 |
| Dumfries and Galloway | 0.060 | 0.047 | 0.047 | 0.040 | 0.040 | 0.046 | 0.044 | 0.045 | 0.038 | 0.044 | 0.035 |
| Whitehaven | 0.009 | 0.009 | 0.011 | 0.010 | 0.010 | 0.013 | 0.010 | 0.012 | 0.017 | 0.016 | 0.017 |
| 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 | 0.085 |
| Morecambe Bay | 0.037 | 0.042 | 0.041 | 0.046 | 0.034 | 0.034 | 0.036 | 0.032 | 0.031 | 0.024 | 0.026 |
| North Wales | 0.014 | 0.018 | 0.015 | 0.013 | 0.014 | 0.014 | 0.013 | 0.018 | 0.014 | 0.015 | 0.014 |

## Table 2.17 Individual radiation exposures, Sellafield, 2017

| 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** | **0.25[e]** | **0.061** | **0.18** | **-** | **0.016** | **-** | **-** | **-** |
| ***Total dose* - maximum effect of gaseous release and direct radiation sources** | | | | | | | | |
| **Adult other domestic vegetable consumers** | **0.011[b]** | **<0.005** | **<0.005** | **<0.005** | **<0.005** | **-** | **<0.005** | **<0.005** |
| ***Total dose* - maximum effect of liquid release source** | | | | | | | | |
| **Adult mollusc consumers** | **0.25[e]** | **0.061** | **0.18** | **-** | **0.016** | **-** | **-** | **-** |
| **Source specfic doses** | | | | | | | | |
| **Seafood consumers** | | | | | | | | |
| Local seafood consumers (habits averaged 2013-17) | 0.27[f] | 0.058 | 0.18 | - | 0.028 | - | - | - |
| Local seafood consumers (habits for 2017) | 0.27[g] | 0.058 | 0.18 | - | 0.024 | - | - | - |
| Whitehaven seafood consumers | 0.017 | 0.017 | - | - | - | - | - | - |
| Dumfries and Galloway seafood and wildfowl consumers | 0.035 | 0.027 | - | - | 0.009 | - | - | - |
| Morecambe Bay seafood consumers | 0.026 | 0.009 | - | - | 0.017 | - | - | - |
| Northern Ireland seafood consumers | 0.010 | 0.008 | - | - | <0.005 | - | - | - |
| North Wales seafood consumers | 0.014 | 0.008 | - | - | 0.006 | - | - | - |
| **Other groups** | | | | | | | | |
| Ravenglass Estuary, marsh users | 0.007 | - | - | - | 0.005 | <0.005 | - | - |
| Fishermen handling nets or pots[c] | 0.11 | - | - | - | 0.11 | - | - | - |
| Bait diggers and shellfish collectors[c] | 0.067 | - | - | - | 0.067 | - | - | - |
| Ribble Estuary houseboats | 0.028 | - | - | - | 0.028 | - | - | - |
| Barrow Houseboats | 0.071 | - | - | - | 0.071 | - | - | - |
| Local infant consumers of locally grown food at Ravenglass | 0.020[b] | - | - | 0.020 | - | - | - | - |
| Local infant consumers of locally grown food at LLWR near Drigg | 0.005[b] | - | - | 0.005 | - | - | - | - |
| Infant inhabitants and consumers of locally grown food | 0.011[b] | - | - | 0.010 | - | - | <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 | 0.006 | - | - | - | 0.006 | - | - | - |
| North Cumbria | 0.011 | - | - | - | 0.011 | - | - | - |
| Sellafield | 0.009 | - | - | - | 0.009 | - | - | - |
| Lancashire | 0.007 | - | - | - | 0.007 | - | - | - |
| North Wales | 0.006 | - | - | - | 0.006 | - | - | - |
| **Recreational user of mud/saltmarsh areas** | | | | | | | | |
| Dumfries and Galloway | <0.005 | - | - | - | <0.005 | - | - | - |
| North Cumbria | <0.005 | - | - | - | <0.005 | - | - | - |
| Sellafield | 0.012 | - | - | - | 0.012 | - | - | - |
| 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 0.077 mSv*

[f] *The dose due to nuclear industry discharges was 0.085 mSv*

[g] *The dose due to nuclear industry discharges was 0.082 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 subtracting 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.

The NDA has ownership of the majority of such sites, with licensed nuclear sites at Harwell and Winfrith in England, and Dounreay in Scotland. 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.

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, the 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 2017, 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 2017 from nuclear establishments in Scotland (Dounreay) are also given in Appendix 2 (Table A2.4).

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.

## Key points

- *Total doses* for the representative person were less than 5 per cent of the dose limit, for sites that were assessed

### Dounreay, Highland

- *Total dose* for the representative person was 0.010 mSv and decreased in 2017
- Liquid discharges of alpha and non-alpha increased in 2017

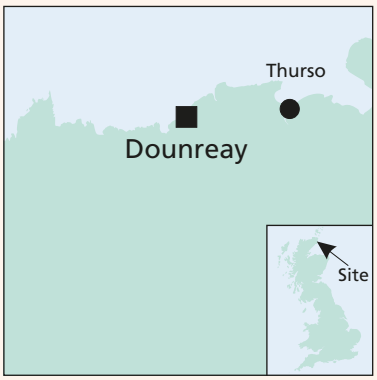
### Harwell, Oxfordshire

- *Total dose* for the representative person was 0.046 mSv and increased in 2017
- Liquid discharges decreased (from Lydebank Brook), and increased (to the sewer), in 2017

### Winfrith, Dorset

- *Total dose* for the representative person was 0.038 mSv and increased in 2017
- Liquid discharges of tritium (inner pipeline) decreased in 2017

## 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, 2018).

From 2005, the NDA became responsible for the UK's civil nuclear liabilities which included those at UKAEA Dounreay, and UKAEA became a contractor to the 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 2015.

During 2017, DSRL undertook changes to its methods of measuring, calculating and reporting of radioactive discharges as a result of the implementation of SEPA's Radiological Monitoring Technical Guidance Note 1 – Standardised Reporting of Radioactive Discharges from Nuclear Sites (SEPA and Environment Agency, 2010). This resulted in changes in some of the reported discharge values (Appendix 2, Table A2.1).

Following the identification of the release of unmonitored gaseous discharges of krypton-85 at the DFR facility in 2016 (as reported in last year's report – RIFE 22), DSRL undertook a site wide review to identify any other unquantified gaseous discharges. This has resulted in revisions being made to previously reported discharges of tritium and non-alpha emitting radionuclides from the site.

In April 2017, DSRL notified SEPA that incorrect duct flowrate information had been used in the calculation of gaseous tritium discharges from the PFR facility. This resulted in revisions being made to previously reported discharges of tritium from the PFR facility. Details of the revised reported discharges from the site are provided in the RIFE errata document: **https://www.sepa.org.uk/environment/radioactive-substances/environmental-monitoring-and-assessment/reports/**.

In May 2017, DSRL notified SEPA of elevated levels of caesium-137 within its non-active drainage system. Investigations by DSRL isolated the source to an area round a single building in the Fuel Cycle Area. Discharges to the marine environment have returned to being below the Limit of Detection and intervention has been taken by DSRL to direct discharges from the source area to the low active drainage network.

In July 2017, DSRL notified SEPA of the identification of a crack in a recently installed section of ventilation ductwork within the PFR Facility. SEPA investigated the circumstances surrounding the occurrence of the crack and installation of this section of ductwork. As a result, SEPA sent a Final Warning Letter to DSRL in relation to the site's arrangements for controlling modifications to equipment.

In September 2017, following several incidents of non-compliance relating to DSRL's reporting of its liquid and gaseous discharges from the site, SEPA issued a Notice of Variation to the site authorisation under RSA 93. The variation requires DSRL to undertake a range of specified improvements; to review and validate its arrangements for the sampling, calculation and reporting of liquid and gaseous discharges and to implement any improvements to its arrangements arising from the review work.

In December 2017, following an application from DSRL, SEPA issued a Notice of Variation to the site authorisation under RSA 93. The variation covered: increases in the gaseous discharge subsidiary-limits associated with the stack height grouping of 2 – 10 m above ground level (to accommodate anticipated increased use of temporary containments during decommissioning activities); addition of stacks associated with the Environmental Analysis Laboratories to the list of authorised gaseous discharge outlets; and a change of the frequency of the results (reported to SEPA) of the monitoring programme undertaken for the on-site Low Level Waste Pits.

In 2017, 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 2017 (Appendix 2, Tables A2.1 and A2.2). Solid waste transfers from Dounreay in 2017 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 0.010 mSv in 2017 (Table 3.1), or 1 per cent of the dose limit, and down from 0.058 mSv in 2016. In 2017, the representative person was adults consuming wild fruit and nuts at high rates, and a change from that in 2016 (adults consuming game meat). The decrease in *total dose* was mostly due to the exclusion of the caesium-137 concentration in game (venison) in 2017 (collected in 2016), the activity most likely from historical releases.

The trend in *total dose* over the period 2004 – 2017 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 previous years (and not sampled in 2017).

Source specific assessments for external pathways (for Geo occupants, who regularly visit Oigin's Geo, and for fishermen), give exposures of less than the *total dose* in 2017 (Table 3.1). In 2017, the dose to a consumer of terrestrial foodstuffs was 0.011 mSv or approximately 1 per cent of the dose limit for members of the public of 1 mSv. As in previous years, adults were identified as the most

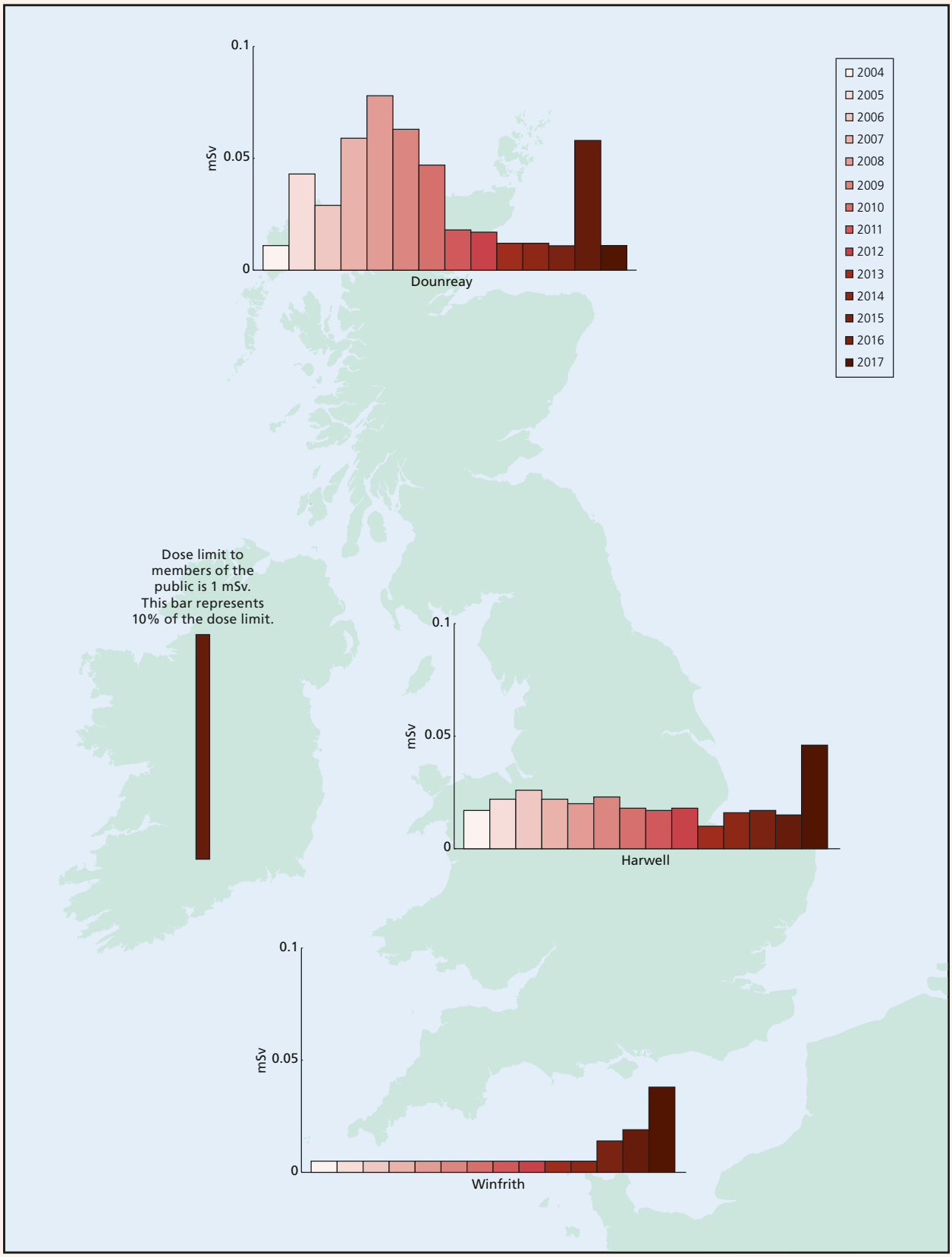



**Figure 3.1.** *Total dose* at research establishments, 2004–2017
(Small doses less than or equal to 0.005 mSv are recorded as being 0.005 mSv)

exposed age group. The reason for the decrease in dose (from 0.043 mSv in 2016) 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 0.008 mSv. The decrease in dose from 0.013 mSv (in 2016) was due to lower gamma dose rates over sand in 2017.

## 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 2017 included the sampling of air, freshwater, grass, soil 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 2017.

The sampling locations for the terrestrial (and marine) monitoring programmes are shown in Figure 3.2 (Dounreay) and Figure 3.3 (north of Scotland). Figure 3.3 also provides time trends of radionuclide discharges (gaseous and liquid). The results for terrestrial samples and radioactivity in air are given in Tables 3.2(a) and (c). The concentrations of radionuclides were generally low and similar to those in previous years. In 2017, low concentrations of caesium-137, strontium-90, antimony-125, iodine-129, niobium-95 and americium-241 are reported in a few food samples (close to the less than values). The caesium-137 concentration in a honey sample (0.30 Bq $kg^{-1}$) was also positively detected again in 2017, but is very low and much lower than the maximum concentrations reported in previous years (e.g. 38 Bq $kg^{-1}$ in 2016). The variability in caesium-137 concentrations between years was likely due to the collection of honey from different pollen sources (i.e. different types of produced honey samples). SEPA will continue to keep this issue under review. Game samples, to determine the typical background concentrations in the vicinity of the site, were not collected in 2017. Earlier RIFE reports have provided results of game monitoring (e.g. Environment Agency, FSA, FSS, NIEA, NRW and SEPA, 2017). Activity concentrations in air samples at locations near to the site are reported as less than values (Table 3.2(c)).

## 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). Discharges of alpha and non-alpha increased by small amounts, in comparison to releases in 2016, but have remained low in 2017.

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 collected (including samples from the outfall area), together with mussels and winkles from areas along the coastline. Additionally, seawater, spume, 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 2017 and 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 recent years. 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. Gamma dose rates were generally similar in 2017 (in comparison to 2016), although lower dose rates were measured over sand (most noticeably at Sandside Bay, Melvich Sands and Castletown Harbour). Beta dose rate measurements are reported as less than values (Table 3.2(b)).

During 2017, DSRL continued vehicle-based monitoring of local public beaches for radioactive fragments in compliance with the requirements of the authorisation granted by SEPA. In 2017, 10 fragments were recovered from Sandside Bay and 5 from the Dounreay foreshore. The caesium-137 activity measured in the fragments recovered from Sandside Bay ranged between 3.8 kBq and 71 kBq (similar to ranges observed in recent years). During beach monitoring on the west foreshore, the presence of caesium-137 contamination was detected on one stone in February 2018. The stone was recovered and brought onto the Dounreay site. It is believed that the contamination on the stone is associated with residual historical contamination from the Castlegate Seep.

In December 2016, one fragment was detected and recovered from the Dounreay foreshore due to the measurement of americium-241. Unlike fragments

* *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.*

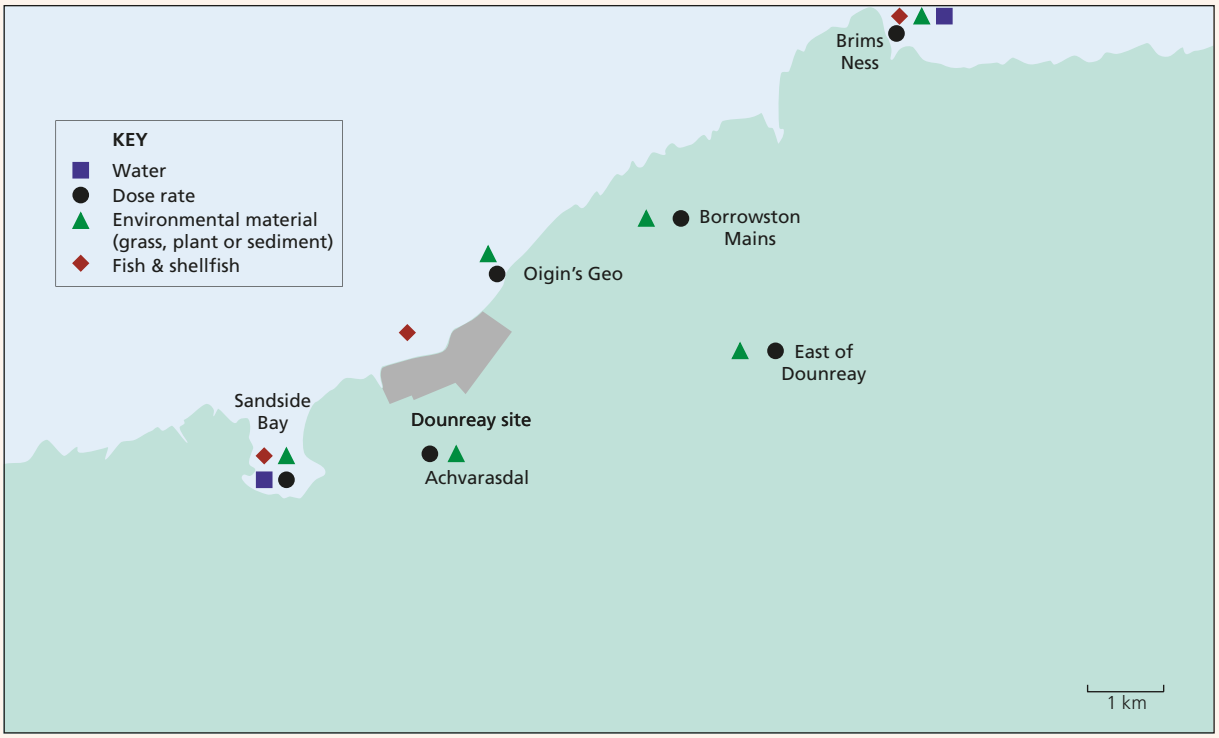



**Figure 3.2.** Monitoring locations at Dounreay, 2017 (not including farms or air sampling locations)

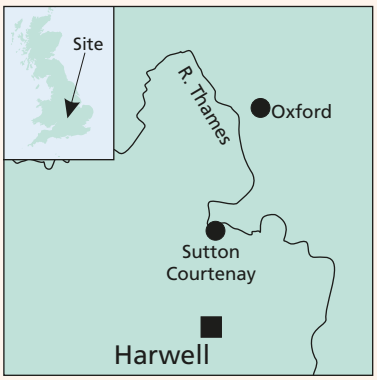
normally detected and removed, the presence of caesium-137 contamination was not detected in this fragment by gamma-ray spectrometry. Further examination and analysis is being carried out to establish the radiological and non-radiological composition to assist in identifying the likely source of the 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 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 2010 and 2011 (PRAG (D), 2010; 2011). In 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 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 upon completion of the seabed remediation work.

* *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.*

## 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

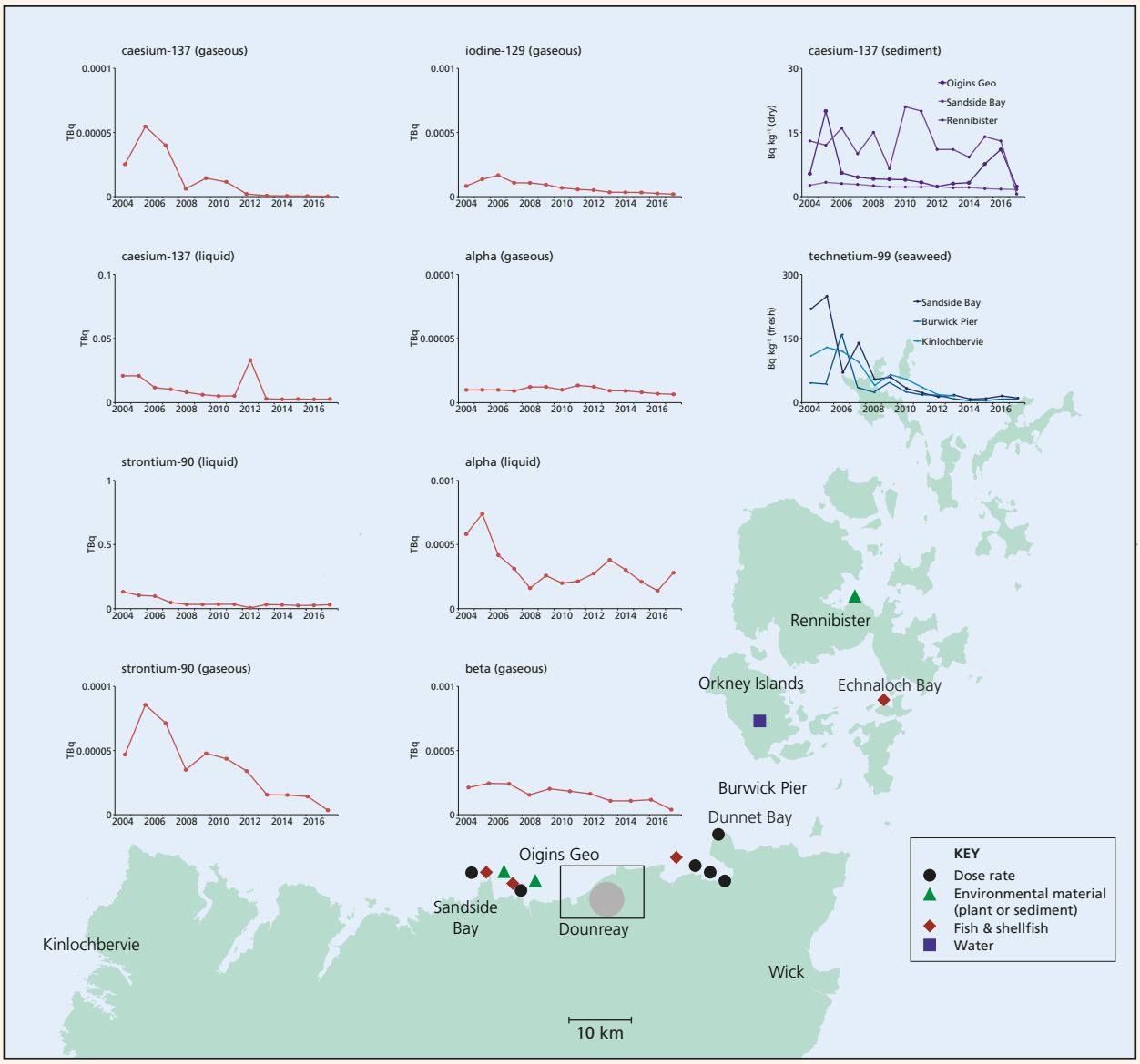



**Figure 3.3.** Monitoring locations, discharges of gaseous and liquid radioactive wastes and monitoring of the environment in the north of Scotland, 2017 (not including farms or air sampling locations). The rectangle around the Dounreay site is the area presented in Figure 3.2.

2064 (NDA, 2018). The most recent habits survey was conducted in 2015 (Clyne *et al.*, 2016b).

## Doses to the public

The *total dose* from all pathways and sources of radiation was 0.046 mSv in 2017 (Table 3.1), which was less than 5 per cent of the dose limit, and up from 0.015 mSv in 2016. The increase in *total dose* (from 2016) was attributed to a higher estimate of direct radiation from the site in 2017. 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 recent years). The trend in *total dose* over the period 2004 – 2017 is given in Figure 3.1. The *total doses* remained broadly similar, from year to year (up to 2016), 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 2017. 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 2017 are shown in Table 3.3(a). The results for tritium and caesium-137 analyses in terrestrial samples are reported as less than values (as in 2016).

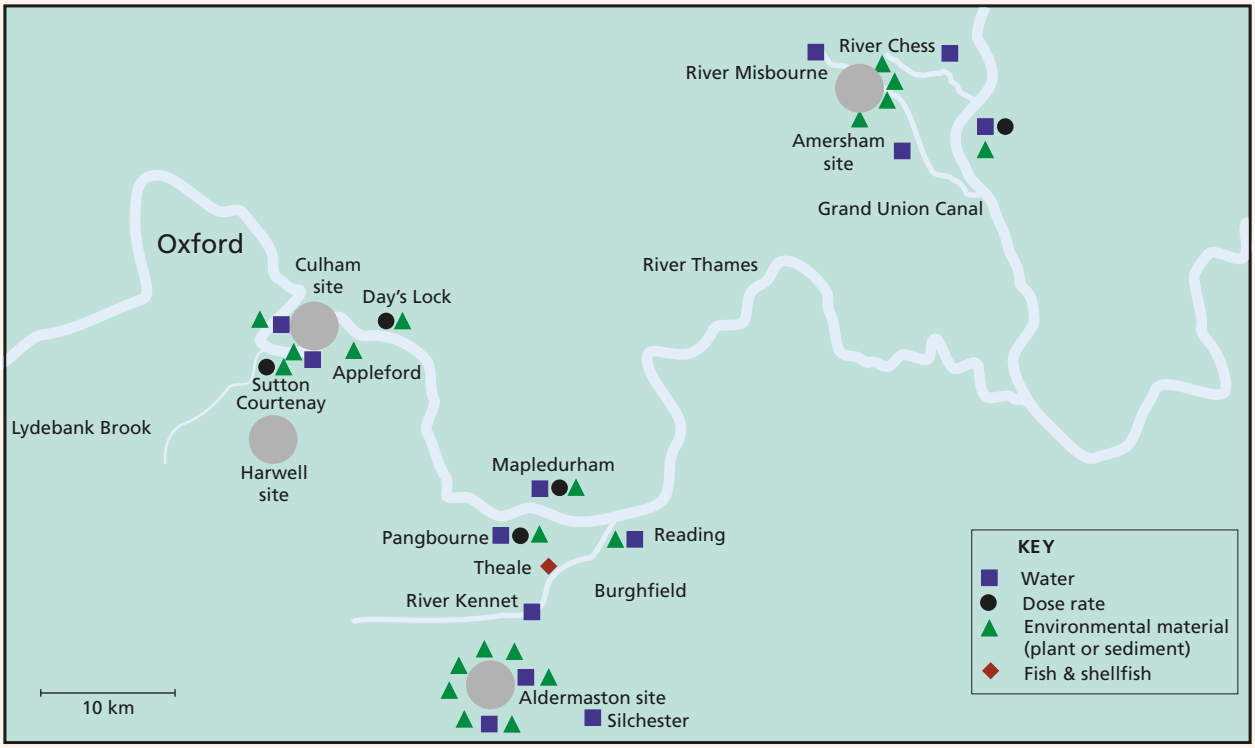



**Figure 3.4.** Monitoring locations at Thames sites, 2017 (not including farms)

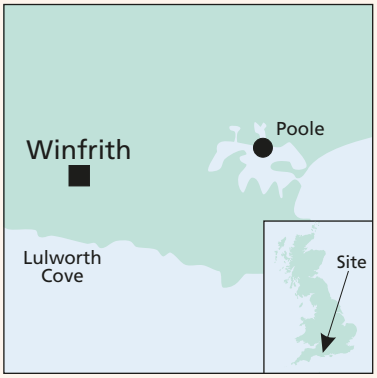
## Liquid waste discharges and aquatic monitoring

Regulated discharges from Harwell are discharged to sewers serving the Didcot Sewage Treatment Works (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. Discharges decreased (from Lydebank Brook) and increased (to the sewer) by small amounts in 2017, in comparison to releases in 2016. However, cobalt-60 and caesium-137 discharged to the sewer in 2016 were the lowest releases for many years. Figure 3.5 shows trends of discharges over time (2000 – 2017) for cobalt-60 and caesium-137. There was an overall reduction in the discharges over the whole period, particularly for cobalt-60, and very low discharges in most recent years.

The aquatic monitoring programme is directed at consumers of freshwater fish and occupancy close to the liquid discharge point. Concentrations of tritium, cobalt-60 and transuranic elements in all aquatic samples, and caesium-137 in 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 than values (except caesium-137, that is close to the less than value). Caesium-137 concentrations in sediments continued to be enhanced above background levels in 2017, but were small in terms of any radiological effect.

In 2017, gamma dose rates (where comparisons can be made) were generally similar to those in 2016.

## 3.3 Winfrith, Dorset




The Winfrith site is located near Winfrith Newburgh. It was established 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, 2018). The most recent habits survey undertaken for Winfrith was in 2003 (McTaggart *et al.*, 2004b).

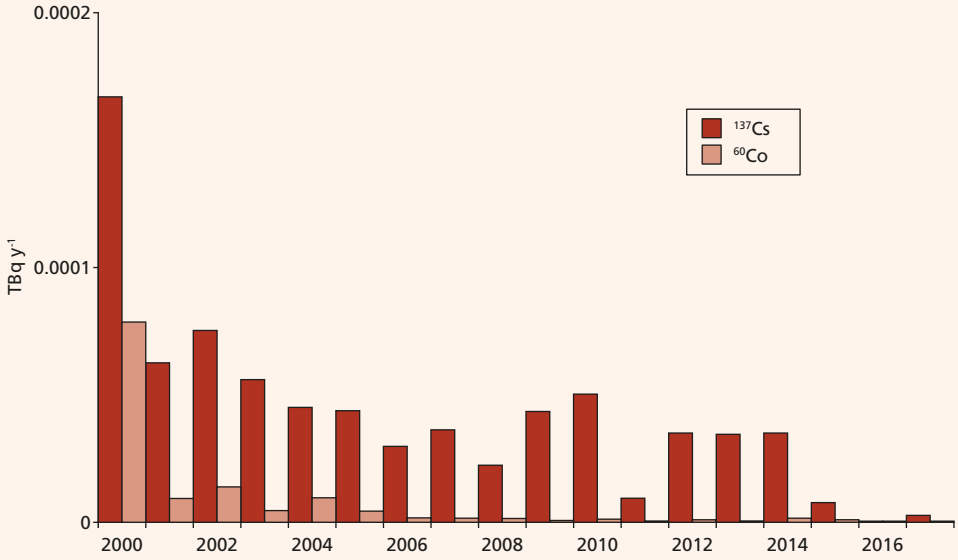



**Figure 3.5.** Trends in liquid discharges of caesium-137 and cobalt-60 from Harwell, Oxfordshire 2000-2017

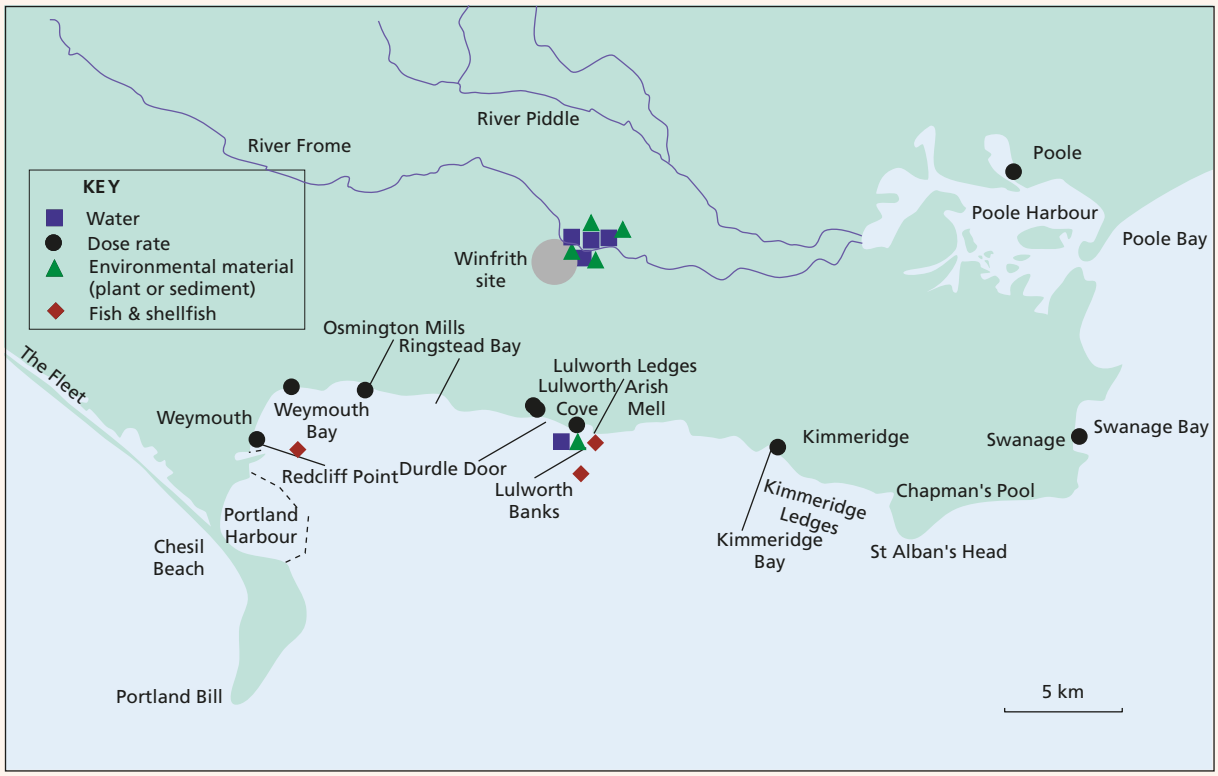



**Figure 3.6.** Monitoring locations at Winfrith, 2017 (not including farms)

## Doses to the public

In 2017, the *total dose* from all pathways and sources of radiation was 0.038 mSv (Table 3.1), or less than 4 per cent of the dose limit, and up from 0.019 mSv in 2016. The representative person was adults living near the site (as in 2016). The increase in *total dose* was due to a higher estimate of direct radiation from the site in 2017. 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 2017 (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 2017. The focus of the terrestrial sampling was for the analyses 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 2017 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

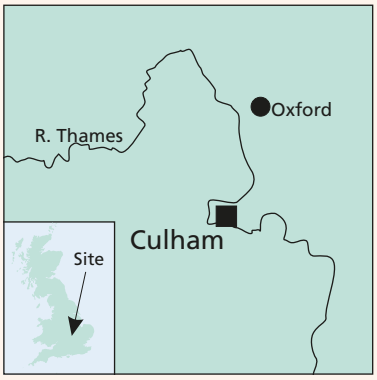
Liquid wastes are disposed via a pipeline to deep water in Weymouth Bay. Discharges of tritium (inner pipeline) decreased in 2017, in comparison to releases in 2016. Figure 3.7 shows trends of liquid discharges over time (2000 – 2017) for tritium and alpha emitting radionuclides. Over the period, alpha-emitting 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 Tradebe Inutec (a provider of independent radioactive waste management services and a tenant on the site). Discharges of alpha-emitting radionuclides from Winfrith (inner pipeline) were less than 1 per cent of the annual limit (as in 2016).

Analyses of seafood and marine indicator materials and measurements of external radiation over muddy intertidal areas were conducted. Data for 2017 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.

## 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 2017 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, the 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. The NDA would then take responsibility for the decommissioning programme that is expected to take 10 years to complete. The current plan is to secure a JET extension to 2020 (UKAEA, 2017).

*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 2017, 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 2017. 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 (60 Bq $kg^{-1}$) in 2017 was similar to that in 2016. 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. The site 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

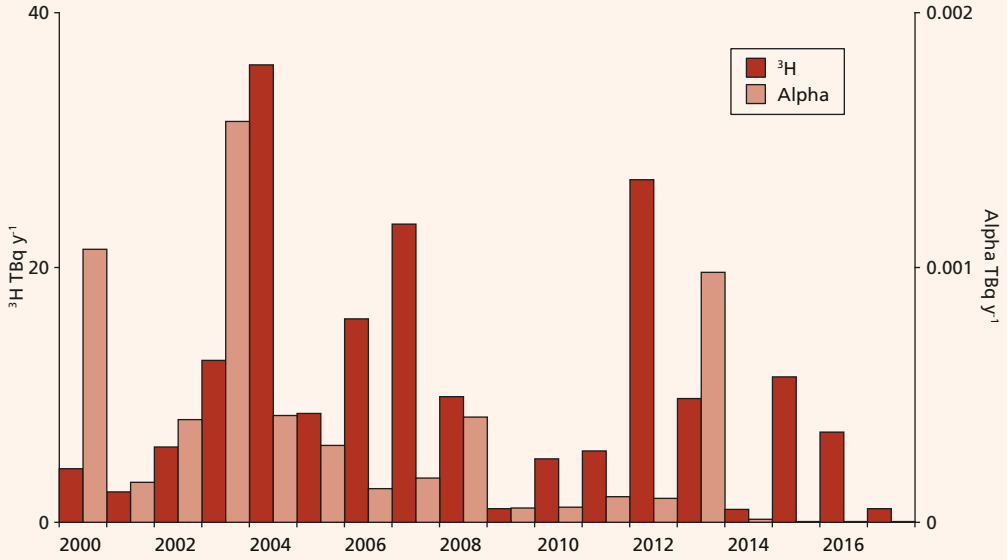



**Figure 3.7.** Trends in liquid discharges of tritium and alpha emitting radionuclides from Winfrith, Dorset 2000-2017

and de-fuelled in 2014. The aim is that the reactor will be dismantled with eventual de-licensing of the site by 2023. In 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, 2015).

Liquid discharges of tritium increased in 2017, in comparison to releases in recent years, due to a discharge from the site's delay tank in September 2017. These discharges have been infrequent since the reactor shut down. The liquid discharge previous to this was in 2014. As in previous years, gaseous and liquid discharges were very low in 2017 (Appendix 2). Monitoring of the environmental effects involved the analysis of grass and crop (potato) samples by gamma-ray spectrometry on behalf of the FSA. Activity concentrations in both samples, from radioactive discharges, are reported as less than values.

## Table 3.1 Individual doses - research sites, 2017

| 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 consumers of wild fruits and nuts** | **0.010** | **-** | **<0.005** | **-** | **-** | **<0.005** | **0.006** |
| Source specific doses | Seafood consumers | 0.008 | <0.005 | - | 0.008 | - | - | - |
| | Geo occupants[b] | <0.005 | - | - | <0.005 | - | - | - |
| | Inhabitants and consumers of locally grown food | 0.011 | - | 0.011 | - | - | <0.005 | - |
| Harwell | | | | | | | | |
| ***Total dose* - all sources** | **Local adult inhabitants (0–0.25km)** | **0.046[c]** | **-** | **-** | **-** | **-** | **<0.005** | **0.046** |
| 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 (0.25–0.5km)** | **0.038** | **<0.005** | **<0.005** | **-** | **-** | **<0.005** | **0.038** |
| 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 subtracting background and cosmic sources from measured gamma dose rates)*

## Table 3.2(a) Concentrations of radionuclides in food and the environment near Dounreay, 2017

| Material | Location | No. of sampling observations | 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 | <0.14 | | <0.27 | | <0.12 | 0.30 |
| Crabs | Pipeline | 2 | | <0.10 | <0.16 | <0.10 | <0.23 | <0.24 | <0.16 | <0.10 |
| Crabs | Strathy | 2 | | <0.10 | <0.19 | | <0.25 | | <0.18 | <0.10 |
| Crabs | Melvich Bay | 2 | | <0.10 | <0.14 | | <0.21 | <0.12 | <0.14 | <0.10 |
| Winkles | Brims Ness | 4 | | <0.10 | <0.25 | <0.10 | <0.55 | | <0.23 | <0.10 |
| Winkles | Sandside Bay | 4 | | <0.10 | <0.19 | <0.10 | <0.40 | <0.35 | <0.19 | <0.10 |
| Mussels | Echnaloch Bay | 4 | | <0.10 | <0.18 | | <0.34 | <0.55 | <0.19 | <0.10 |
| *Fucus vesiculosus* | Brims Ness | 4 | | <0.10 | <0.15 | | <0.18 | | <0.13 | <0.18 |
| *Fucus vesiculosus* | Sandside Bay | 4 | | <0.10 | <0.17 | | <0.19 | 11 | <0.14 | <0.10 |
| *Fucus vesiculosus* | Burwick Pier | 4 | | <0.10 | <0.17 | | <0.18 | 8.1 | <0.16 | <0.10 |
| Sediment | Oigin's Geo | 2 | | <0.10 | <0.35 | | <0.34 | | <0.22 | 2.3 |
| Sediment | Brims Ness | 1 | | <0.10 | <0.21 | | <0.28 | | <0.15 | 1.0 |
| Sediment | Sandside Bay | 1 | | <0.10 | <0.10 | | <0.10 | | <0.10 | 1.6 |
| Sediment | Melvich Bay | 1 | | <0.10 | <0.20 | | <0.16 | | <0.15 | 1.5 |
| Sediment | Strathy | 1 | | <0.10 | <0.10 | | <0.10 | | <0.10 | 0.55 |
| Sediment | Rennibister | 1 | | <0.10 | <0.15 | | <0.10 | | <0.13 | 0.55 |
| Seawater | Brims Ness | 2 | <1.1 | <0.10 | <0.11 | | <0.10 | | <0.11 | <0.10 |
| Seawater | Sandside Bay | 2 | <1.1 | <0.10 | <0.12 | | <0.10 | | <0.12 | <0.10 |
| Spume | Oigin's Geo | 2 | | <0.16 | <0.52 | | <0.47 | | <0.54 | 11 |

| Material | Location | No. of sampling observations | Mean radioactivity concentration (fresh)[a], Bq kg$^{-1}$ | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | $^{154}$Eu | $^{155}$Eu | $^{238}$Pu | $^{239}$Pu + $^{240}$Pu | $^{241}$Am | Gross alpha | Gross beta |
| **Marine samples** | | | | | | | | | |
| Cod | Scrabster | 2 | <0.10 | <0.11 | 0.000 | 0.003 | 0.004 | | |
| Crabs | Pipeline | 2 | <0.11 | <0.14 | 0.013 | 0.073 | 0.14 | 0.82 | 150 |
| Crabs | Strathy | 2 | <0.11 | <0.15 | 0.001 | 0.006 | 0.005 | | |
| Crabs | Melvich Bay | 2 | <0.10 | <0.12 | 0.001 | 0.005 | 0.014 | | |
| Winkles | Brims Ness | 4 | <0.11 | <0.18 | 0.040 | 0.088 | 0.23 | | |
| Winkles | Sandside Bay | 4 | <0.10 | <0.14 | 0.012 | 0.066 | 0.072 | | |
| Mussels | Echnaloch Bay | 4 | <0.10 | <0.14 | 0.015 | 0.087 | 0.051 | | |
| *Fucus vesiculosus* | Brims Ness | 4 | <0.10 | <0.12 | | | <0.10 | 6.6 | 370 |
| *Fucus vesiculosus* | Sandside Bay | 4 | <0.10 | <0.14 | | | <0.13 | 4.3 | 410 |
| *Fucus vesiculosus* | Burwick Pier | 4 | <0.11 | <0.16 | | | <0.12 | | |
| Sediment | Oigin's Geo | 2 | <0.23 | 0.85 | 1.2 | 5.0 | 1.8 | | |
| Sediment | Brims Ness | 1 | <0.12 | <0.22 | 1.6 | 11 | 13 | | |
| Sediment | Sandside Bay | 1 | 0.22 | <0.12 | 2.2 | 14 | 13 | | |
| Sediment | Melvich Bay | 1 | <0.11 | <0.21 | 0.56 | 0.47 | 0.46 | | |
| Sediment | Strathy | 1 | <0.10 | 0.16 | 0.50 | 0.78 | 0.24 | | |
| Sediment | Rennibister | 1 | <0.10 | <0.18 | 0.25 | 1.3 | <0.0091 | | |
| Seawater | Brims Ness | 2 | <0.10 | <0.10 | | | <0.10 | | |
| Seawater | Sandside Bay | 2 | <0.10 | <0.12 | | | <0.10 | | |
| Spume | Oigin's Geo | 2 | <0.22 | <0.51 | 0.62 | 3.1 | 4.3 | | |

## Table 3.2(a) continued

| Material | Location or selection[b] | No. of sampling observations | Mean radioactivity concentration (fresh)[a], Bq kg$^{-1}$ | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | $^{3}$H | $^{90}$Sr | $^{95}$Nb | $^{125}$Sb | $^{129}$I | $^{137}$Cs | $^{155}$Eu | $^{234}$U |
| **Terrestrial samples** | | | | | | | | | | |
| Beef muscle | | 1 | <5.0 | <0.10 | <0.15 | <0.09 | <0.05 | <0.05 | <0.12 | <0.050 |
| Beef offal | | 1 | <5.0 | <0.10 | <0.16 | <0.09 | 0.09 | <0.05 | <0.12 | <0.050 |
| Broccoli | | 2 | <5.0 | <0.14 | <0.34 | <0.12 | <0.10 | <0.05 | <0.11 | |
| Broccoli | max | | | 0.18 | 0.41 | <0.14 | <0.14 | | <0.13 | |
| Cabbage | | 1 | <5.0 | 0.19 | <0.09 | <0.05 | <0.05 | 0.16 | <0.04 | |
| Carrots | | 1 | <5.0 | 0.19 | <0.09 | <0.11 | <0.05 | 0.08 | <0.10 | |
| Eggs | | 1 | <5.0 | <0.10 | <0.10 | <0.13 | <0.06 | <0.05 | <0.10 | |
| Honey | | 1 | <5.0 | <0.10 | <0.15 | <0.13 | <0.09 | 0.30 | <0.12 | |
| Lamb muscle | | 1 | <5.0 | <0.10 | <0.15 | <0.08 | 0.15 | 0.79 | <0.10 | <0.050 |
| Leeks | | 1 | <5.0 | <0.10 | <0.27 | <0.08 | <0.09 | <0.05 | <0.07 | |
| Potatoes | | 1 | <5.0 | <0.10 | <0.09 | <0.06 | <0.05 | <0.05 | <0.07 | |
| Rosehips | | 1 | <5.0 | 0.38 | <0.26 | <0.17 | <0.06 | 0.22 | <0.16 | |
| Turnips | | 1 | <5.0 | 0.20 | <0.19 | <0.06 | <0.07 | <0.05 | <0.07 | |
| Wild mushrooms | | 1 | <5.0 | 0.18 | <0.22 | <0.08 | <0.06 | 2.0 | <0.09 | |
| Grass | | 6 | <5.0 | <0.25 | <0.26 | | <0.06 | <0.09 | <0.12 | <0.077 |
| Grass | max | | | 0.70 | <0.50 | | <0.09 | 0.15 | <0.15 | 0.13 |
| Soil | | 6 | <5.0 | 1.1 | <0.30 | 0.23 | <0.18 | 19 | 2.0 | 34 |
| Soil | max | | | 1.9 | 0.44 | | <0.24 | 32 | | 52 |
| Freshwater | Loch Calder | 1 | <1.0 | | <0.02 | | | <0.01 | <0.01 | |
| Freshwater | Loch Shurrery | 1 | <1.0 | | <0.01 | | | <0.01 | <0.006 | |
| Freshwater | Loch Baligill | 1 | <1.0 | | <0.02 | | | 0.01 | <0.01 | |
| Freshwater | Heldale Water | 1 | <1.0 | | <0.02 | | | <0.01 | <0.01 | |

| Material | Location or selection[b] | No. of sampling observations | Mean radioactivity concentration (fresh)[a], Bq kg$^{-1}$ | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | $^{235}$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 | | |
| Beef offal | | 1 | <0.050 | <0.050 | <0.050 | <0.050 | <0.050 | | |
| Broccoli | | 2 | | | <0.050 | <0.050 | <0.053 | | |
| Broccoli | max | | | | | | 0.056 | | |
| Cabbage | | 1 | | | <0.050 | <0.050 | <0.050 | | |
| Carrots | | 1 | | | <0.050 | <0.050 | <0.050 | | |
| Eggs | | 1 | | | <0.050 | <0.050 | <0.050 | | |
| Honey | | 1 | | | <0.050 | <0.050 | <0.050 | | |
| Lamb muscle | | 1 | <0.050 | <0.050 | <0.050 | <0.050 | <0.050 | | |
| Leeks | | 1 | | | <0.050 | <0.050 | <0.050 | | |
| Potatoes | | 1 | | | <0.050 | <0.050 | <0.050 | | |
| Rosehips | | 1 | | | <0.050 | <0.050 | 0.12 | | |
| Turnips | | 1 | | | <0.050 | <0.050 | <0.050 | | |
| Wild mushrooms | | 1 | | | <0.050 | <0.050 | 0.050 | | |
| Grass | | 6 | <0.050 | <0.081 | <0.050 | <0.050 | <0.050 | | |
| Grass | max | | | 0.14 | | | | | |
| Soil | | 6 | 1.6 | 32 | <0.050 | <0.35 | 0.25 | | |
| Soil | max | | 2.9 | 48 | | 0.59 | 0.36 | | |
| Freshwater | Loch Calder | 1 | | | | | <0.010 | 0.014 | 0.048 |
| Freshwater | Loch Shurrery | 1 | | | | | <0.010 | 0.010 | 0.050 |
| Freshwater | Loch Baligill | 1 | | | | | <0.010 | 0.021 | 0.071 |
| Freshwater | Heldale Water | 1 | | | | | <0.010 | <0.010 | 0.081 |

[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, 2017

| Location | Material or ground type | No. of sampling observations | μGy $h^{-1}$ |
|---|---|---|---|
| **Mean gamma dose rates at 1m over substrate** | | | |
| Sandside Bay | Sand | 2 | <0.052 |
| Sandside Bay | Winkle Bed | 2 | 0.11 |
| Oigin's Geo | Rocks | 1 | 0.14 |
| Oigin's Geo | Stones and Spume | 1 | 0.15 |
| Brims Ness | Rocks and Stones | 2 | 0.092 |
| Melvich | Salt marsh | 2 | 0.068 |
| Melvich Sands | Sand | 2 | 0.052 |
| Strathy Sands | Sand | 2 | 0.059 |
| Thurso riverbank | Sediment | 2 | 0.075 |
| Achvarasdal | Grass | 2 | <0.06 |
| Thurso Park | Grass | 2 | 0.070 |
| Borrowston Mains | Grass | 2 | 0.069 |
| Castletown Harbour | Sand | 2 | 0.066 |
| Dunnet Bay | Sand | 2 | 0.068 |
| Hallam | Grass | 2 | 0.062 |
| **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 | Fishing equipment | 1 | <1.0 |

## Table 3.2(c) Radioactivity in air near Dounreay, 2017

| Location | No. of sampling observations | Mean radioactivity concentration, mBq $m^{-3}$ | | |
|---|---|---|---|---|
| | | $^{137}Cs$ | Gross alpha | Gross beta |
| Shebster | 12 | <0.010 | <0.0072 | <0.20 |
| Reay | 8 | <0.010 | <0.0089 | <0.20 |
| Balmore | 12 | <0.010 | <0.0077 | <0.20 |

## Table 3.3(a) Concentrations of radionuclides in food and the environment near Harwell, 2017

| Material | Location | No. of sampling observ-ations | 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 | <0.08 | * | 0.09 | | | <0.07 | | |
| Sediment | Bank of River Thames (Sutton Courtenay) | 1[E] | | <0.44 | | 2.7 | <0.43 | <0.31 | <0.68 | <76 | 230 |
| Sediment | Bank of River Thames (Day's Lock) | 1[E] | | <0.38 | | 10 | <0.36 | <0.21 | <0.58 | <79 | 290 |
| Freshwater | Day's Lock | 2[E] | <3.3 | <0.27 | | <0.23 | | | | <0.049 | 0.26 |
| Freshwater | River Thames (Long Wittenham) | 4[E] | <3.4 | <0.28 | | <0.24 | | | | <0.049 | 0.33 |

| Material | Location or selection[b] | No. of sampling observations[c] | Mean radioactivity concentration (fresh)[a], Bq kg$^{-1}$ | | |
|---|---|---|---|---|---|
| | | | Organic $^{3}$H | $^{3}$H | $^{137}$Cs |
| **Terrestrial samples** | | | | | |
| Milk | | 2 | <2.9 | <2.9 | <0.05 |
| Milk | max | | <3.3 | <3.3 | <0.06 |
| Strawberries | | 1 | <2.5 | <2.5 | <0.06 |
| Grass | | 1 | <2.7 | <2.7 | <0.08 |

* *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, 2017

| Location | Ground type | No. of sampling observations | µGy h$^{-1}$ |
|---|---|---|---|
| **Mean gamma dose rates at 1m over substrate** | | | |
| Sutton Courtenay | Grass and mud | 2 | 0.072 |
| Day's Lock | Grass and mud | 1 | 0.067 |

## Table 3.4(a) Concentrations of radionuclides in food and the environment near Winfrith, 2017

| 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** | | | | | | | | | | | | | |
| Skates/rays | Weymouth Bay | 1 | | <0.17 | | <0.15 | | | <0.12 | | | | |
| Crabs | Lulworth Banks | 1 | 34 | <0.06 | | <0.06 | | | <0.16 | | | | |
| Scallops | Lulworth Ledges | 1 | | <0.07 | | <0.07 | 0.00034 | 0.0027 | 0.00053 | 0.000099 | 0.000026 | | |
| Seaweed | Lulworth Cove | 1[E] | | <0.52 | <1.5 | <0.36 | | | <0.36 | | | | |
| Seaweed[d] | Bognor Rock | 2[E] | | <0.59 | 1.2 | <0.41 | | | <0.47 | | | | |
| Seawater | Lulworth Cove | 1[E] | | <0.32 | | <0.24 | | | <0.25 | | | <4.3 | 13 |

| Material | Location or selection[b] | No. of sampling observ-ations[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 | <2.8 | <2.8 | 19 | <0.06 | | |
| Milk | max | | | | 21 | | | |
| Beetroot | | 1 | <2.4 | <2.4 | 10 | <0.04 | | |
| Grass | | 1 | <3.4 | <3.4 | 23 | 0.15 | | |
| Grass | Near Newburgh Farm Cottages | 2[E] | | <16 | <6.6 | <0.58 | <1.9 | 170 |
| Grass | Adjacent to railway | 2[E] | | <14 | <6.4 | <1.0 | <2.1 | 180 |
| Sediment | North of site | 1[E] | | | | 1.9 | <130 | <140 |
| Sediment | R Frome (upstream) | 1[E] | | | | <1.3 | 110 | 170 |
| Sediment | R Frome (downstream) | 1[E] | | | | 6.9 | 220 | 320 |
| Sediment | R Win, East of site | 1[E] | | | | 0.91 | 130 | 140 |
| Freshwater | North of site | 2[E] | | 8.4 | | <0.20 | <0.036 | 0.12 |
| Freshwater | R Frome (upstream) | 2[E] | | <3.6 | | <0.20 | <0.031 | 0.12 |
| Freshwater | R Frome (downstream) | 2[E] | | <3.7 | | <0.20 | <0.032 | 0.13 |
| Freshwater | R Win, East of site | 2[E] | | <3.8 | | <0.23 | <0.044 | 0.20 |

[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*
[d] *The concentrations of $^{129}$I was 1.3 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 3.4(b) Monitoring of radiation dose rates near Winfrith, 2017

| Location | Ground type | No. of sampling observations | µGy h$^{-1}$ |
|---|---|---|---|
| **Mean gamma dose rates at 1m over substrate** | | | |
| Weymouth Bay | Sand and pebbles | 1 | 0.058 |
| Osmington Mills | Pebbles | 1 | 0.073 |
| Durdle Door | Pebbles | 1 | 0.070 |
| Lulworth Cove | Pebbles | 1 | 0.068 |
| Kimmeridge Bay | Sand and pebbles | 1 | 0.076 |
| Swanage Bay | Sand | 1 | 0.060 |
| Poole Harbour | Sand | 1 | 0.058 |

**Table 3.5 Concentrations of radionuclides in the environment near Culham, 2017**

| 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 | <2.9 | | <0.24 | <0.046 | 0.28 |
| Freshwater | River Thames (downstream) | 2 | <3.2 | | <0.23 | <0.039 | 0.33 |
| Grass | 0.6 km East of site perimeter | 2 | <30 | <22 | <1.2 | | 290 |
| Sediment | River Thames (upstream) | 2 | | | 5.3 | | |
| Sediment | River Thames (downstream) | 2 | | | 60 | | |
| Soil | 1 km East of site perimeter | 1 | <20 | <2.0 | 3.5 | | 430 |

[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 was less than 0.005 mSv and decreased in 2017
- Gaseous discharges of tritium decreased from Berkeley, and liquid discharges decreased from Oldbury, in 2017

### Bradwell, Essex

- *Total dose* for the representative person was 0.011 mSv and decreased in 2017
- Enhanced monitoring continued in 2017

### Chapelcross, Dumfries and Galloway

- *Total dose* for the representative person was 0.035 mSv and increased in 2017
- Gaseous discharges of "all other radionuclides" increased in 2017

### Dungeness, Kent

- *Total dose* for the representative person was 0.021 mSv and unchanged in 2017
- Gaseous discharges of tritium and of sulphur-35, and liquid discharges of sulphur-35, decreased from Dungeness B in 2017

### Hartlepool, County Durham

- *Total dose* for the representative person was 0.031 mSv and increased in 2017
- Gaseous discharges of carbon-14 increased, liquid discharges of tritium and sulphur-35 increased, in 2017
- Polonium-210 in winkles was enhanced above that value expected due to natural sources in 2017

### Heysham, Lancashire

- *Total dose* for the representative person was 0.025 mSv and increased in 2017
- Gaseous discharges of carbon-14 and sulphur-35 decreased at Heysham 1, liquid discharges of tritium and sulphur-35 decreased from Heysham 1 and tritium decreased from Heysham 2, in 2017

### Hinkley Point, Somerset

- *Total dose* for the representative person was 0.032 mSv and increased in 2017
- Gaseous discharges of carbon-14 increased from Hinkley Point B in 2017

### Hunterston, North Ayrshire

- *Total dose* for the representative person was 0.023 mSv and increased in 2017
- Gaseous discharges of carbon-14 increased from Hunterston B, liquid discharges of alpha and plutonium-241 decreased from Hunterston A, in 2017

### Sizewell, Suffolk

- *Total dose* for the representative person was 0.021 mSv and unchanged in 2017
- Liquid discharges of tritium increased from Sizewell B in 2017

### Torness, East Lothian

- *Total dose* for the representative person was 0.021 mSv and unchanged in 2017

### Trawsfynydd, Gwynedd

- *Total dose* for the representative person was 0.024 mSv and increased in 2017

### Wylfa, Isle of Anglesey

- *Total dose* for the representative person was less than 0.005 mSv and decreased in 2017
- Gaseous discharges of tritium, carbon-14 and sulphur-35 decreased, and liquid discharges of tritium increased, in 2017

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 the NDA. The 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 2018, the NDA published a business plan (2018 – 2021) which summarises the programme of work at each of the sites (NDA, 2018). Of the eleven sites that have Magnox reactors, only 2 have yet to complete de-fuelling (Wylfa in Wales and Calder Hall on the Sellafield site are both scheduled to complete in 2019).

In 2013, Magnox Limited managed ten nuclear sites and was owned and operated by Energy Solutions on behalf of the NDA. In 2014, the NDA formally appointed Cavendish Fluor Partnership (a joint venture between Cavendish Nuclear and Fluor Corporation) as the PBO for Magnox Limited (and RSRL). Thereafter, ONR received an application to relicense the ten Magnox sites into a single site licence company alongside the Harwell and Winfrith sites. In 2015, Harwell and Winfrith sites, previously operated by RSRL, merged to be part of Magnox Limited. Concurrently the EPR 2010 radioactive substances permits (EPR 16 in 2017) 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 2017; 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 2017.

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 2017, 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 2017 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 Section 4 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 2023. 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 achieved by 2079 (NDA, 2018).

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 achieved by 2103 (NDA, 2018).

Horizon Nuclear Power Limited intends to develop a twin UK ABWR based station at its site at Oldbury adjacent to the existing Magnox power station. Horizon's lead site is at Wylfa Newydd and it is focusing its resources there, in advance of developing plans for its Oldbury site.

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 less than 0.005 mSv in 2017 (Table 4.1), which was less than 0.5 per cent of the dose limit, and down from 0.006 mSv in 2016. In 2017, the representative person was adults who spent a large

amount of time over sediments, and was a change from that in 2016 (infants consuming milk). The trend in the *total dose* over the period 2004 – 2017 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.

The source specific assessments for a high-rate consumer of locally grown foods, and of fish and shellfish, in the vicinity of the Berkeley and Oldbury sites, give exposures that were also less than 0.005 mSv (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 small decrease in dose to a consumer of locally grown foods (from 0.006 mSv in 2016) was due to lower carbon-14 concentrations in milk in 2017. The dose for houseboat dwellers was 0.016 mSv in 2017. The reason for the decrease in estimated dose for houseboat dwellers (from 0.031 mSv in 2016) was due to an overall decrease in the gamma dose rates from sediments at Sharpness (over mud and saltmarsh), in comparison to those in 2016. 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).

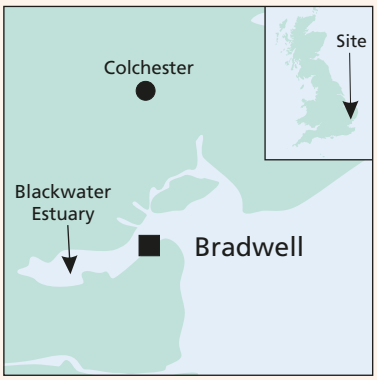
## Gaseous discharges and terrestrial monitoring

The Berkeley and Oldbury sites discharge gaseous radioactive wastes via separate stacks to the atmosphere. Discharges of tritium decreased by a small amount at Berkeley in 2017, in comparison to releases in 2016. The focus of the terrestrial sampling was for the analyses of tritium, carbon-14 and sulphur-35 in milk and crops. Local freshwater samples were also analysed. Data for 2017 are given in Table 4.2(a). Sulphur-35 was detected at very low levels in one terrestrial sample (grass). Carbon-14 concentrations in foodstuffs (milk) decreased in 2017 (in comparison to those in 2016) and the maximum value was close to the default values used to represent background levels. 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 decreased from Oldbury in 2017, in comparison to releases in 2016. Oldbury has ceased generation and was verified by ONR as fuel free in 2016. There are therefore no further sources of caesium-137 on site, and discharges will continue to decrease for this radionuclide. 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 2017 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 some evidence to suggest that caesium-137 concentrations in sediment have been generally decreasing over the period (Figure 4.2). As in 2016, the tritium concentrations in fish, shellfish and seawater are reported as less than values in 2017. 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 lower (where comparisons can be made), in comparison to those in 2016.

## 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 the programme of work. Bradwell is set to be the UK's first Magnox site to reach the stage of Care and Maintenance, which is expected to last for around 70 years. The Bradwell site will enter the Care and Maintenance phase between 2018 – 2019. Thereafter, the plan is for final site clearance to commence in 2083 and achieved by 2092 (NDA, 2018).

At the adjacent Bradwell B site, the Bradwell B Power Generation Company Limited (BrB) is in the early stages of developing its proposals for a new nuclear power station. The company is carrying out site assessment work to help inform the development of its proposals including better characterising the site's underlying geology.

During 2014, the Environment Agency carried out a review of their own environmental monitoring programme,

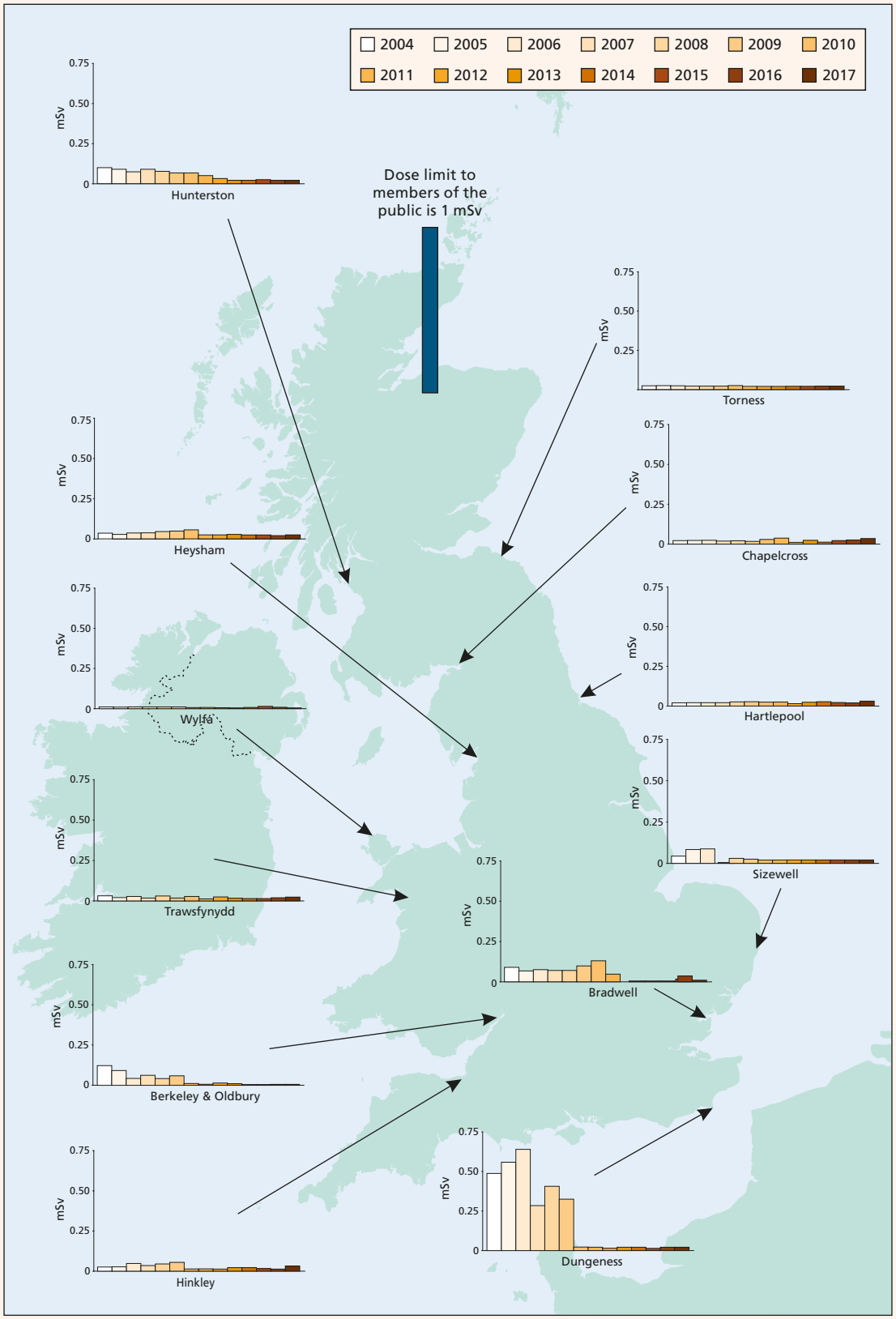



**Figure 4.1.** *Total dose* at nuclear power stations, 2004-2017
(Small doses less than or equal to 0.005 mSv are recorded as being 0.005 mSv)

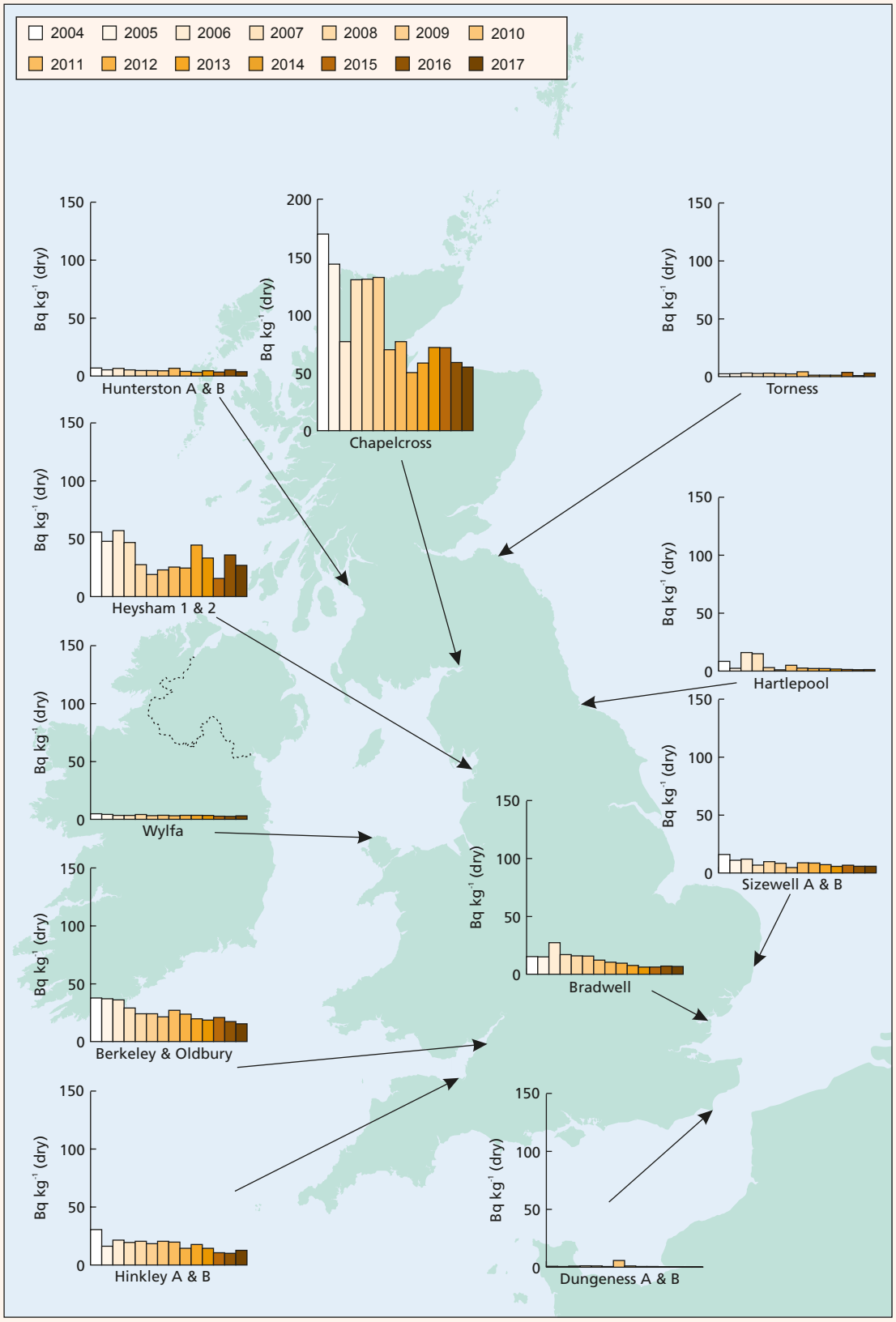



**Figure 4.2.** Caesium-137 concentration in marine sediments near nuclear power stations between 2004-2017

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 through to 2017. 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).

## Doses to the public

The *total dose* from all pathways and sources of radiation was 0.011 mSv in 2017 (Table 4.1), which was approximately 1 per cent of the dose limit for members of the public of 1 mSv, and down from 0.036 mSv in 2016. The representative person was prenatal children of local inhabitants. The decrease in *total dose* was due to a lower estimate of direct radiation from the site in 2017. The trend in *total dose* over the period 2004 – 2017 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 2017 (Table 4.1). The dose to a high-rate consumer of locally grown foods was estimated to be less than 0.005 mSv. The small decrease in dose (from 0.006 mSv in 2016) was due to lower carbon-14 concentrations in milk in 2017. As in 2016, an additional source specific assessment was undertaken to determine the external exposure based on the enhanced monitoring. The estimated dose was also less than 0.005 mSv in 2017. 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. 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 recent years, a number of grass samples were also collected and analysed, to enhance the environmental monitoring programme. Data for 2017 are given in Table 4.3(a). Activity concentrations were low in terrestrial samples. Carbon-14 was detected in locally produced milk at concentrations close to the expected background concentration and decreased by small amounts in comparison to those in 2016. Carbon-14 was enhanced in one grass sample (above the expected background concentration) in 2017. Tritium and caesium-137 concentrations in grass samples are all reported as less than values. As in 2016, strontium-90 was detected at a low level in one coastal ditch sample in 2017. 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. Aquatic sampling was directed at the consumption of locally caught fish and shellfish and external exposure over intertidal sediments. Seaweeds were also analysed as an environmental indicator material. As in recent years, 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 2017, together with routine annual survey monitoring, are shown in Figure 4.3. Data for 2017 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 2017 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 2017, were difficult to distinguish from natural background and generally similar to those in 2016.

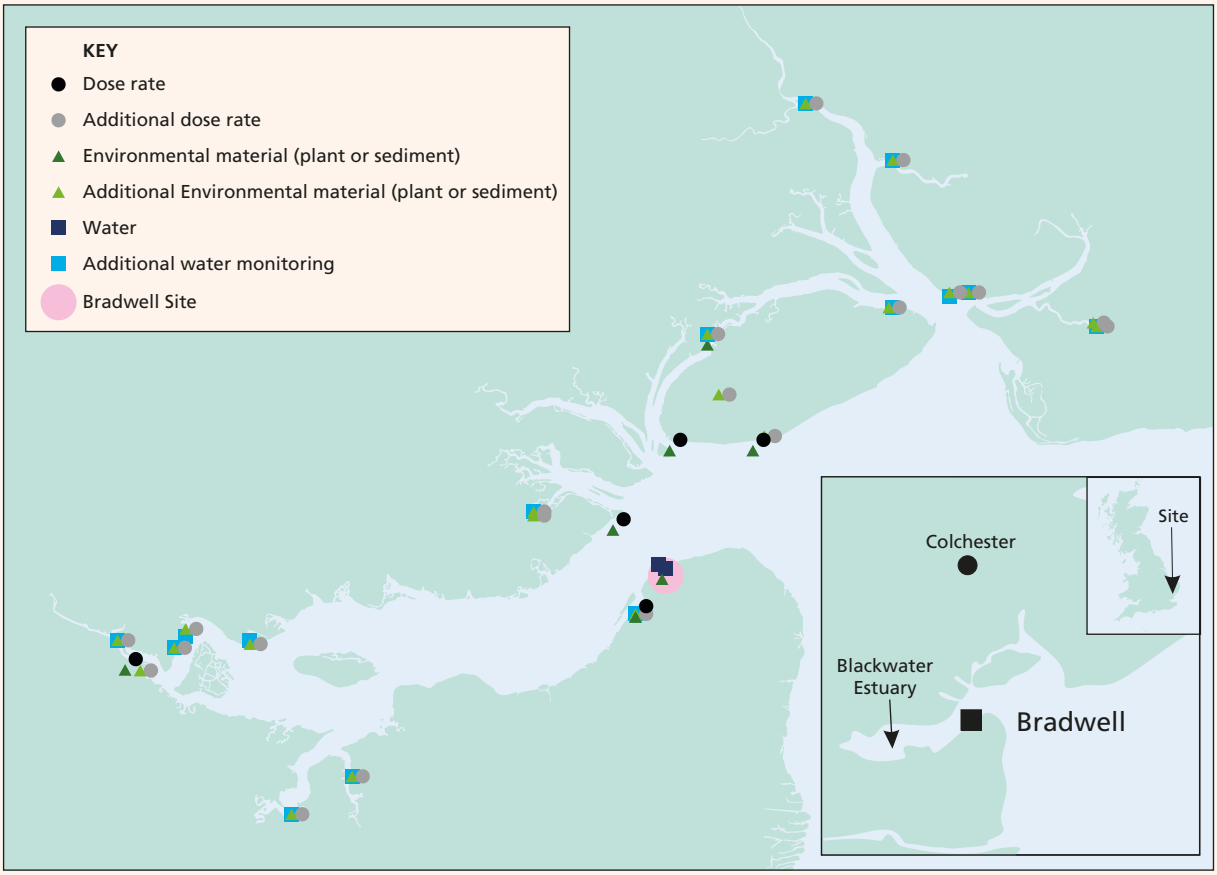
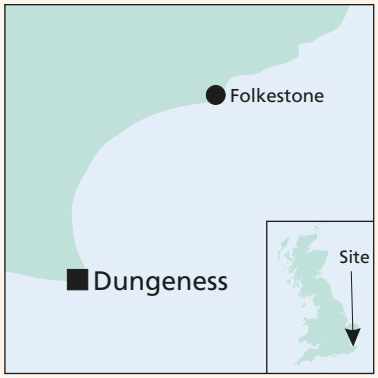



**Figure 4.3.** Aquatic monitoring locations (routine and enhanced) at Bradwell, 2017

## 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 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 achieved by 2097 (NDA, 2018). 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.*, 2011).

### Doses to the public

In 2017, 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 unchanged from 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 – 2017 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 for external exposure), 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 less than 0.005 mSv. The decrease in dose from 0.010 mSv (in 2016) was mostly due to lower carbon-14 concentrations in milk in 2017. The dose to a local seafood consumer was estimated to be 0.006 mSv in 2017. The increase in dose (from <0.005 mSv in 2016) was because gamma dose rates were measured on different types of ground type (at Pilot Sands) in 2017. The dose to a houseboat dweller from external exposure was 0.014 mSv.

The reason for the increase in dose from 0.009 mSv (in 2016) was also because gamma dose rates were measured on different types of ground type (at Rye Bay) in 2017.

## Gaseous discharges and terrestrial monitoring

Discharges of sulphur-35 from Dungeness B decreased in 2017, in comparison to releases in 2016. The focus of the terrestrial sampling was the analyses of tritium, carbon-14 and sulphur-35 in milk and crops. The results of monitoring for 2017 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 (wheat). Carbon-14 was detected in locally produced milk at concentrations close to the expected background concentration and decreased in comparison to those in 2016. 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 tritium and sulphur-35 increased from Dungeness B in 2017, in comparison to releases in 2016. Marine monitoring included gamma dose rate measurements, and analysis of seafood and sediments. The results of monitoring for 2017 are given in Tables 4.4(a) and (b). The caesium-137 concentrations in seafood is 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 in foods and marine materials, 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 (in seafood) and strontium-90 (in sediment) were detected in 2017. Caesium-137 concentrations in sediment have remained low over the last decade (Figure 4.2) and reported as less than values in 2017; 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. Gamma dose rates were generally difficult to distinguish from the natural background.

# 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. With effect from 9 October 2017, there was a variation in the site permit. The permit variation increased the annual permitted limit for sulphur-35 discharges to water by 20 per cent (from 3.0 TBq to 3.6 TBq). This increase was required to provide operational flexibility to allow future levels of carbonyl sulphide (COS) injection into the reactor coolant to be optimised. Previous elevations in COS usage, employed to reduce carbon deposition on the reactor internals and fuel, resulted in an increase in discharges of sulphur-35. This, in turn, caused the existing permit limit to be approached. The dose significance, from the increase in the limit, is minor.

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 0.031 mSv in 2017 (Table 4.1), which was approximately 3 per cent of the dose limit, and up from 0.020 mSv in 2016. The increase in *total dose* was mostly attributed to a higher estimate of direct radiation from the site in 2017 (in comparison to that in 2016). 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 – 2017 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 0.019 mSv in 2017, and similar to that in 2016 (0.018 mSv).

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 is in 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 assessed to be 0.16 mSv. 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 2017.

## Gaseous discharges and terrestrial monitoring

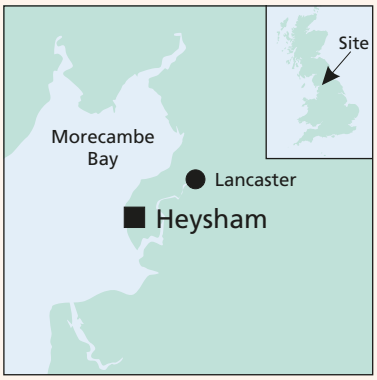
Gaseous radioactive waste is discharged via stacks to the local environment. Discharges of carbon-14 increased in 2017 (due to higher levels of power generation), in comparison to those in 2016. Analyses of tritium, carbon-14, sulphur-35 and gamma emitters were made in milk and crop samples. Samples of water were also taken from a borehole. Data for 2017 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 values) were measured in food (potatoes) and grass samples in 2017. 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. Liquid discharges of tritium and sulphur-35 increased in 2017 (the former due to higher levels of power generation), in comparison to those in 2016. The increase in sulphur-35 was associated with trials carried out on the effect of increased COS injection. Results of the aquatic monitoring programme conducted in 2017 are shown in Tables 4.5(a) and (b). As in previous years, a small enhancement of the carbon-14 concentration, above the expected background, was observed in mollusc 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. Carbon-14 concentrations in fish and crustaceans were lower in 2017, in comparison to those in 2016. 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 2.11). 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 2017. 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). Overall, gamma dose rates in 2017 were generally similar over sediment, although the dose rates over sand decreased (Carr House) and increased (North Gare) by small amounts, in comparison to those in 2016.

In 2017, the reported polonium-210 concentration in winkles from South Gare is 25 Bq $kg^{-1}$ and enhanced above the value expected due to natural sources. These samples (collected inside the Tees Estuary entrance) consisted of a mixture including some winkles collected from the estuary entrance near Paddy's Hole. The polonium-210 concentration (in 2017) is consistent with previously reported values prior to 2015 (mixed sample) and in winkles collected exclusively from Paddy's Hole.

## 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. The most recent habits survey was conducted in 2016 (Garrod *et al.*, 2017).

## Doses to the public

The *total dose* from all pathways and sources of radiation was 0.025 mSv in 2017 (Table 4.1), or approximately 2 per cent of the dose limit for members of the public, and up from 0.019 mSv in 2016. In 2017, the representative

person was adults living near to the site, and was a change from that in 2016 (adults spending time over sediments). The increase in *total dose*, and change in the representative person (from 2016), was mostly attributed to a higher estimate of direct radiation from the site in 2017. The trend in *total dose* over the period 2004 – 2017 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. In 2016, a lower *total dose* was due to both a reduction of the mollusc consumption rate (from the revised habits data) and lower concentrations of plutonium radionuclides and americium-241 in molluscs.

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 dose in 2017 from terrestrial food consumption was 0.005 mSv (0.007 mSv in 2016) and 0.008 mSv (0.010 mSv in 2016) from turf cutting over salt marsh. The small decreases in doses in 2017 were mostly attributed to lower carbon-14 concentrations in milk and lower gamma dose rates, respectively. 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 0.026 mSv in 2017, which was less than 3 per cent of the dose limit for members of the public of 1 mSv (Table 4.1). The dose in 2016 was 0.024 mSv. The small increase in dose was due to higher concentrations of plutonium radionuclides and americium-241 in molluscs in 2017 (in comparison to those in 2016).

## Gaseous discharges and terrestrial monitoring

In 2017, discharges of carbon-14 and sulphur-35 decreased at Heysham 1 (due to decreased power generation), in comparison to releases in 2016. The monitoring programme for the effects of gaseous disposals was similar to that for other power stations. Data for 2017 are given in Table 4.6(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 values) were measured in one food (potatoes) and grass samples in 2017. Carbon-14 concentrations in milk decreased by small amounts, but were enhanced in one grass sample, in comparison to those in 2016. 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 tritium and sulphur-35 decreased from Heysham 1 (due to the decreased power generation), and tritium decreased from Heysham 2, in 2017 (in comparison to those in 2016). The monitoring programme for the effects of liquid disposals included sampling of fish, shellfish, sediment, seawater and measurements of gamma dose rates. For completeness, the data considered in this section include all of those for Morecambe Bay. A substantial part of the programme is in place to monitor the effects of Sellafield disposals. The results for 2017 are given in Tables 4.6(a) and (b). In general, similar levels to those for 2016 were observed and the effect of liquid disposals from Heysham was difficult to detect above the Sellafield background. Concentrations of tritium in flounder and shrimps were not sufficiently high to demonstrate that any originated as a result of discharges from Heysham, although tritium concentrations were enhanced in winkles and mussels (in comparison to those in recent years). Iodine-129 was positively detected in seaweed (reported as just above the less than value) in 2017. Plutonium radionuclides and americium-241 concentrations in winkles and mussels were slightly higher in 2017 (in comparison to those in 2016). Concentrations of technetium-99 in marine samples remained at levels typical of recent years, caused by discharges from Sellafield. In 2017, 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 2017 were generally similar to those in 2016.

## 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 achieved by 2090 (NDA, 2018). 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, a planning consent order was granted to EDF Energy to build and operate Hinkley Point C and associated development. 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 2016, EDF's Board of Directors made the final investment decision to build two reactors at Hinkley Point C. Thereafter in 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) also in 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 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.

In July 2017, a habits survey was conducted to determine the consumption and occupancy rates by members of the public (Greenhill *et al.*, 2018). A large increase in the fish consumption rates has been observed, together with small changes in mollusc and crustacean consumption rates, and occupancy rates over mud, in comparison with those of the previous survey in 2010. Occupancy rates over sand and for a houseboat dweller were also determined in the 2017 habits survey. Revised figures for consumption rates, together with occupancy rates, are provided in Appendix 1 (Table X2.2).

## Doses to the public

In 2017, the *total dose* from all pathways and sources of radiation was 0.032 mSv (Table 4.1), or approximately 3 per cent of the dose limit, and up from 0.013 mSv in 2016. The representative person was prenatal children of occupants over sediment, and a change from that in 2016 (adults spending time over sediments). The increase in *total dose* was mostly due to the significant increase in occupancy rates (over sand) from the revised habits data, and to a much lesser extent to higher gamma dose rates measured (over mud), in 2017. The trend in *total dose* over the period 2004 – 2017 is given in Figure 4.1. The step decrease in *total dose* in 2011 (and continued thereafter, up to 2016) 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 0.007 mSv in 2017. The decrease in dose (from 0.011 mSv in 2016) was mostly due to lower carbon-14 concentrations in milk in 2017. The dose to a local fisherman, who consumed a large amount of seafood and was exposed to external radiation over intertidal areas, was 0.019 mSv in 2017, which was less than 2 per cent of the dose limit for members of the public of 1 mSv, and similar to that in 2016 (0.018 mSv). 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). An additional source specific assessment was undertaken to determine the external exposure to a houseboat dweller (identified in the habits survey) in 2017. The estimated dose was 0.027 mSv. This estimate is determined as a cautious value (due to direct measurements beneath houseboats not being available) and therefore not included in the *total dose* assessment.

## Gaseous discharges and terrestrial monitoring

Gaseous radioactive waste is discharged via separate stacks to the local environment. Discharges of carbon-14 increased, by a small amount, from Hinkley Point B in 2017, in comparison to releases in 2016. 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 2017 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 (blackberries and wheat). Carbon-14 was detected in locally produced milk at concentrations above the expected background concentration but decreased by small amounts in comparison to those in 2016. Carbon-14 was also detected in blackberries (as in 2016) above the expected background value in 2017. Tritium, gross alpha and gross beta concentrations in reservoir water were below the investigation levels for drinking water in the European Directive 2013/51.

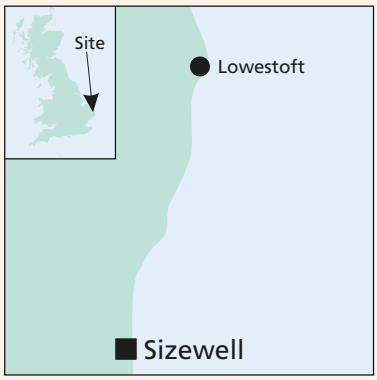
## Liquid waste discharges and aquatic monitoring

Regulated discharges of radioactive liquid effluent from both power stations are made via separate outfalls into the Bristol Channel. 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 2017 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 2017, tritium concentrations in fish and shellfish were higher (by small amounts), in comparison to those in 2016, but similar to those in previous years. 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 growing evidence to suggest that caesium-137 concentrations in sediment have been generally decreasing over the reported years (Figure 4.2). Overall, gamma dose rates over intertidal sediment in 2017 were generally similar (where comparisons can be made), although the dose rates at Stolford (mud) increased (by small amounts), in comparison to those in 2016.

## 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 achieved by 2097 (NDA, 2018). The most recent habits survey was conducted in 2015 (Garrod *et al.*, 2016).

NNB GenCo is developing its plans for a twin UK EPR reactor based station at the site and has undertaken initial consultations relating to its intended future application to the Planning Inspectorate for a Development Consent Order.

### Doses to the public

The *total dose* from all pathways and sources was 0.021 mSv in 2017 (Table 4.1) or approximately 2 per cent of the dose limit, and unchanged from 2016. 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 – 2017 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 2017 (Table 4.1). The dose to a consumer of locally grown foods was less than 0.005 mSv. The reason for the decrease from 0.006 mSv (in 2016) was due to lower carbon-14 concentrations in milk in 2017.

### Gaseous discharges and terrestrial monitoring

Gaseous wastes are discharged via separate stacks to the local environment. The results of the terrestrial monitoring in 2017 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 2017. Carbon-14 was detected in locally produced milk at concentrations just above the expected background concentration but the maximum concentration decreased in comparison to that in 2016. Sulphur-35 was positively detected at a very low concentration in food samples (potatoes and wheat) in 2017. Tritium concentrations in local freshwater were all reported as less than values, 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.

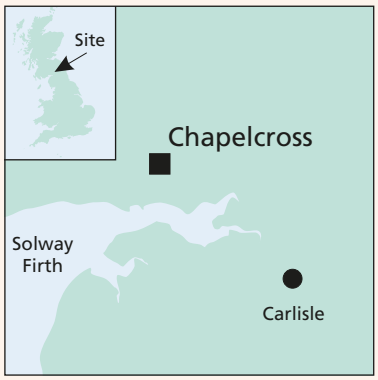
### Liquid waste discharges and aquatic monitoring

Regulated discharges of radioactive liquid effluent are made via outfalls to the North Sea. Discharges of tritium increased from Sizewell B in 2017, in comparison to those in 2016. Liquid tritium discharges from Sizewell B Power Station are cyclic with an 18-month period, reflecting the interval between refuelling outages (shutdowns). Consequently, the quantity of tritium discharged in two consecutive years will not be the same. The total quantity

of tritium discharged from the site remains within normally expected values. In the aquatic programme, analysis of seafood, sediment, and seawater, and measurements of gamma dose rates were conducted in intertidal areas. Data for 2017 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 and generally decreasing with time (Figure 4.2). Overall, gamma radiation dose rates over intertidal areas were difficult to distinguish from the natural background, although the dose rates generally increased in comparison to those in 2016 (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 2025. Final site clearance is expected to commence in 2085 and achieved by 2095 (NDA, 2018).

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 2017, a habits survey was also conducted to determine the consumption and occupancy rates by members of the public on the Dumfries and Galloway coast (SEPA, *in press*/a). 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 0.035 mSv in 2017 (Table 4.1), which was approximately 3 per cent of the dose limit, and up from 0.026 mSv in 2016. As in recent years, the representative person was infants consuming milk at high rates. The increase in *total dose* (from 2016) was mostly due to a positively detected maximum strontium-90 concentration in milk in 2017 (strontium-90 in milk was reported as a less than value in 2016). The trend in *total dose* over the period 2004 – 2017 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 consumer (crustaceans) and for a salmon, mollusc and wildfowl consumer, give exposures that were less than the *total dose* in 2017 (Table 4.1). The dose for the terrestrial food consumer was estimated to be 0.023 mSv in 2017. The reason for the increase in dose from 0.018 mSv (in 2016) is the same as that contributing to the maximum *total dose*. The dose for the salmon, mollusc and wildfowl consumer was 0.014 mSv in 2017, and up from 0.009 mSv in 2016. The increase in dose was mostly due to higher concentrations of americium-241 in molluscs (mostly cockles) in 2017.

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. Discharges of "all other radionuclides" increased in 2017, in comparison to those releases in 2016. Following de-fuelling of the reactors at Chapelcross (in 2013) the provision of dry air supply was withdrawn from the reactors. The reactors were configured to be ventilated so that the vessels' environment could equilibrate with atmospheric conditions. This has led to the exposure of the reactor vessels to atmospheric moisture which is believed (by Magnox Limited) to have resulted in an increased rate of dissolution of gaseous tritium and carbon-14 that had been in solid phases, either in the reactor graphite or 'plated out' on the vessel walls and pipework.

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 2017 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. Carbon-14 concentrations in milk decreased (in comparison to those in 2016) and were similar to the default values used to

represent background levels in 2017. Unlike in recent years, the maximum strontium-90 concentration value was positively detected in milk in 2017 (reported as just above the less than value). Sulphur-35 was detected at a very low concentration in a few food samples (brussel sprouts, cabbage and rosehips), and in grass and soil samples. 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 2017, tritium concentrations over the range of food samples, and most other samples, are reported as less than values (or close to). As in recent years, the tritium concentration was measured above the detection limit in one freshwater sample (Gullielands Burn). However, tritium, gross alpha and gross beta concentrations in all freshwaters were well below the investigation levels for drinking water in the European Directive 2013/51. Activity concentrations in air samples at locations near to the site (Table 4.9(c)) are reported as less than values (or close to the less than value). Solid waste transfers in 2017 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 seaweed (*Fucus vesiculosus*), as environmental indicators, were collected in addition to seafood, sediments and dose rates. Data for 2017 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 similar 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. In 2017, cobalt-60 was also detected in one food sample (cockles) just above the less than value. Concentrations of americium-241 (and plutonium-239+240, to a lesser extent) increased in mollusc samples (by small amounts) in 2017, in comparison to those in 2016.

As in previous years, concentrations of caesium-137, plutonium radionuclides and americium-241 were enhanced in sediment samples taken close to the pipeline. In 2017, these radionuclides were also enhanced in sediment taken from Priestside Bank (in comparison to those in recent years). Technetium-99 concentrations in seaweed and mussels were generally similar, in comparison to those in 2016, whilst concentrations in crustaceans (shrimps) are reported as less than values in 2017. Concentrations of caesium-137 in sediments, largely due to Sellafield, are generally in decline over the last decade (Figure 4.2). In 2017, gamma dose rates (where comparisons can be made) were generally similar to those in 2016; albeit with minor variations. Measurements of the contact beta dose rate on stake nets and sediment are reported as less than values in 2017.

Between 1992 and 2009, a number of particles were found at the end of the discharge outfall consisting of limescale originating from deposits within the pipeline. Magnox Limited continues to monitor this area frequently and no particles were found during 2017 (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: 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 achieved by 2080 (NDA, 2018).

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. However, the need remains to manage the remaining radioactive sludges from a number of areas associated with the pond.

In terms of safe management of legacy higher activity waste at Hunterston A, Magnox Limited are in the process of constructing and commissioning the Solid Intermediate Level Waste Encapsulation plant (SILWE). The Wet Intermediate Level Waste Retrieval and Encapsulation Plant (WILWREP) underwent active commissioning in early 2017. The legacy higher activity waste, present at the Hunterston A site, will be processed through either SILWE or WILWREP and made passively safe by encapsulating it in a grout mixture. The encapsulated waste will then be transferred to the Intermediate Level Waste Store (ILWS) for storage.

WILWREP has exported over 50 drums of higher activity packaged waste to date.

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.

Environmental monitoring in the area considers the effects of both Hunterston A and Hunterston B sites together. In 2017, 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 fish and mollusc consumption rates (and crustacean, to a lesser extent) have been observed, together with a small increase in the occupancy rate over salt marsh, in comparison with those of the previous survey in 2012. 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 is assessed to have been 0.023 mSv in 2017 (Table 4.1), which was approximately 2 per cent of the dose limit, and up from 0.021 mSv in 2016. In 2017, the representative person was adults who consumed root vegetables at high rates and a change from that in 2016 (prenatal children exposed to direct radiation). The apparent small increase in *total dose* in 2017, and change in the representative person (from 2016), was mostly attributed to the inclusion of americium-241 concentrations in food in the assessment. In line with the rules on use of the results for dose calculations, americium-241 was included in the assessment because detectable activity was observed in another terrestrial sample (rosehips) in 2017. The trend in *total dose* over the period 2004 – 2017 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 2017 (Table 4.1). The estimated dose to a terrestrial food consumer was 0.016 mSv in 2017 which was less than 2 per cent of the dose limit for members of the public of 1 mSv. The reason for the apparent increase in dose from 0.010 mSv (in 2016) was the same as that contributing to the maximum *total dose*. The dose to a fish and shellfish consumer was 0.005 mSv, and similar to that in 2016 (0.006 mSv).

## Gaseous discharges and terrestrial monitoring

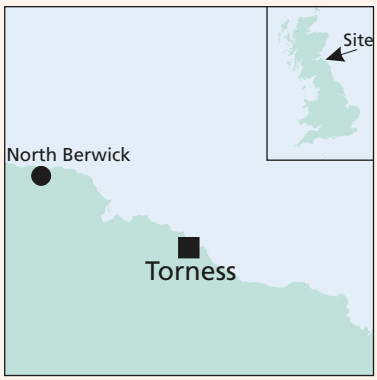
Gaseous discharges are made via separate discharge points from the Hunterston A and Hunterston B stations. Discharges of carbon-14 increased from Hunterston B in 2017, in comparison to those releases in 2016 (see Table A2.5 for further information). There is a substantial terrestrial monitoring programme 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 2017 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). Sulphur-35 was detected at very low concentrations in food samples (milk, lamb and rosehips) in 2017. As in previous years, some carbon-14 concentrations in foodstuffs were higher than the default values used to represent background values (apples and rosehips). Tritium, gross alpha and gross beta concentrations in freshwater were well below the investigation levels for drinking water in the European Directive 2013/51. Activity concentrations in air at locations near to the site are reported as less than values (Table 4.10(c)). Solid waste transfers in 2017 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 decreased from Hunterston A in 2017, in comparison to those releases in 2016. 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 2017 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 2017 and were generally similar to those reported in previous years. Small concentrations (above the less than value) of activation products (cobalt-60, manganese-54 and silver-110m) were also detected in seaweed, in winkles (silver-110m) and in sediment (cobalt-60), which were likely to have originated from the site, but these were of negligible radiological significance. Gamma dose rates were lower (by small amounts) in 2017, in comparison to those in 2016. Measurements of the beta dose rates over sand are reported as less than values in 2017. 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.

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 2017. This process was started in 2011 and discharges of sulphur-35 to the local environment (via liquid and gaseous routes) have stabilised following an anticipated initial increase. The gaseous and liquid discharges from the site are given in Appendix 2 (Tables A2.1 and A2.2).

The most recent habits survey was undertaken in 2016, to determine the consumption and occupancy rates by members of the public (SEPA, *in press*/c).

### Doses to the public

In 2017, 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 unchanged from 2016. Direct radiation was the dominant contributor to the dose. The representative person was adults living in the vicinity of the site and a change from that in 2016 (prenatal children of local inhabitants). The trend in *total dose* over the period 2004 – 2017 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 2017 (Table 4.1). The estimated dose to a terrestrial food consumer was 0.013 mSv in 2017, which was approximately 1 per cent of the dose limit for members of the public of 1 mSv. The apparent increase in dose (from 0.008 mSv in 2016) was mostly due to the inclusion of the less than value of americium-241 concentrations in food in the 2017 assessment. In line with the rules on use of the results for dose calculations, americium-241 was included in the 2017 assessment because detectable activity was observed in other terrestrial samples (soil). The dose to a fish and shellfish consumer was less than 0.005 mSv in 2017.

### 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 2017 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 decreased by small amounts in 2017, in comparison to those in 2016. The effects of discharges from the power station were detected in concentrations of sulphur-35 in a few terrestrial foods (milk, hare and wild mushrooms), but these were low (close to the less than values); concentrations in environmental indicator materials were also low. In 2017, caesium-137 in honey (not sampled in 2016) was positively detected at a low concentration (4.9 Bq $kg^{-1}$), but similar to the value reported in 2015 (4.3 Bq $kg^{-1}$). Americium-241 concentrations in terrestrial foods, measured by gamma–ray spectrometry, are reported as less than values but were positively detected at very low concentrations in soil samples. Tritium, gross alpha and gross beta concentrations in freshwater were well below the investigation levels for drinking water in the European Directive 2013/51. Measured concentrations of radioactivity (including cobalt-60) in air, at locations near to the site, are all reported as less than values in 2017 (Table 4.11(c)). It was previously reported (last year) that cobalt-60 was detected at a very low concentration in one air sample (Innerwick) in 2016. Solid waste transfers in 2017 are also given in Appendix 2 (Table A2.4).

### Liquid waste discharges and aquatic monitoring

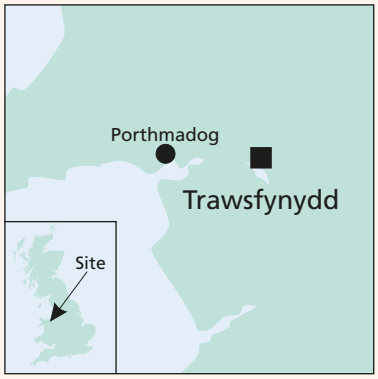
Discharges of authorised liquid radioactive wastes are made to the Firth of Forth. Seawater, sediment, seafood and seaweed samples were collected. Measurements were also made of gamma dose rates over intertidal areas, supported by analyses of sediment, and beta dose rates on fishing gear.

The results of the aquatic monitoring in 2017 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. As in recent years, a few low concentrations of activation products (manganese-54, cobalt-60 and silver-110m) were detected in environmental indicator samples. In 2017, cobalt-60 and silver-110m were also detected in one food sample (winkles) at low concentrations. These activation products were likely to have originated from the station. In the footnote of Table 4.11(a)), a relatively high concentration of tritium (2,600 Bq $l^{-1}$) is reported in seawater (at the pipeline) in 2017. This is likely due to a sample collection coinciding with a routine discharge, as sulphur-35 was also positively

detected (at low concentrations) in the same seawater sample (mean concentration reported as < 11 Bq $l^{-1}$, in the footnote). The activity concentrations of tritium in seawater was of low radiological significance. Technetium-99 concentrations in marine samples were similar to those in recent years. 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 2017.

# 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 achieved by 2083 (NDA, 2018). 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 0.024 mSv in 2017 (Table 4.1), which was approximately 2 per cent of the dose limit, and up from 0.019 mSv in 2016. The representative person in 2017 was adults exposed to external radiation over lake sediments, as opposed to infants living near to the site in 2016. The increase in *total dose* was attributed to higher concentrations (caesium-137) in lake sediments included in the assessment in 2017 (in comparison to those in 2016). The trend in *total dose* over the period 2004 – 2017 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 2017 (Table 4.1). The dose to an angler was 0.026 mSv in 2017, which was less than 3 per cent of the dose limit for members of the public of 1 mSv. The increase in dose (from less than 0.005 mSv in 2016) was the same as that contributing to the maximum *total dose*. 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 0.028 mSv, or less than 3 per cent of the dose limit. The dose in 2016 was 0.025 mSv, and the increase is mostly due to an increase in the reported less than value for americium-241 in milk in 2017.

### Gaseous discharges and terrestrial monitoring

The results of the terrestrial programme, for local food (including milk) and grass samples in 2017, 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 milk were lower in 2017 (in comparison to those in 2016) and close to the default values used to represent background levels. Measured activities for caesium-137 are reported as less than values in 2017. 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. In 2017, 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 2017.

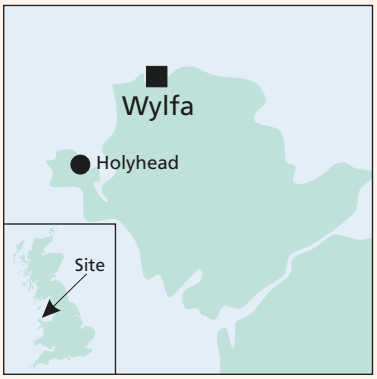
### Liquid waste discharges and aquatic monitoring

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 2017 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 2017. Caesium-137 concentrations in water samples are reported as less than values in 2017. Concentrations in the water column are predominantly maintained by processes that release activity (such as remobilisation) from near surface sediments. Overall, caesium-137 concentrations in the lake sediments were higher (where comparisons can be made), in comparison to those in 2016 (but generally similar to those in previous years). In 2017, the highest concentration of caesium-137 was in a sediment sample collected from the pipeline (sample not collected in 2016). Low concentrations of transuranic radionuclides were also detected in freshwater samples, particularly in lake sediments; in previous years' monitoring, it has been demonstrated that these concentrations increase with depth beneath the sediment surface. Sediment concentrations of strontium-90, plutonium-239+240 and americium-241 (where comparisons can be made) in 2017 were similar to those in recent years. Strontium-90 and transuranic concentrations in fish continued to be very low in 2017 and it is the effects of caesium-137 that dominate the external radiation pathways.

In the lake itself, there remains clear evidence of activity concentrations from the site's liquid discharges. However, gamma dose rates measured on the shoreline (where anglers fish) were difficult to distinguish from background levels, and rates in 2017 were generally similar (where comparisons can be made) to those in 2016. 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. 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 between 2018 and 2021 (NDA, 2018). Final site clearance is expected to commence in 2096 and achieved by 2105. The most recent habits survey was undertaken in 2013 (Garrod *et al*., 2014).

Horizon Nuclear Power Limited is continuing to develop its plans for a twin UK ABWR reactor based station at the Wylfa Newydd site adjacent to the existing Magnox station. Horizon applied for a nuclear site licence in March 2017 which ONR is assessing. Horizon are working with NRW as it develops its applications for operational and construction environmental permits and as it prepares its application to the Planning Inspectorate for a Development Consent Order for the site. The Environment Agency is providing support to NRW on discharges and disposals of radioactive waste from the proposed site.

### Doses to the public

The *total dose* from all pathways and sources of radiation was less than 0.005 mSv in 2017 (Table 4.1), which was less than 0.5 per cent of the dose limit, and down from 0.008 mSv in 2016. In 2017, the representative person was adults spending time over sediments. The decrease in *total dose* (from 2015) was due to a lower estimate of direct radiation from the site (indistinguishable from background, Table 1.1) in 2017. The trend in *total dose* over the period 2004 – 2017 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 also less than 0.005 mSv in 2017 (Table 4.1). The reason for the small decrease from 0.006 mSv (in 2016) was due to lower carbon-14 concentrations in milk in 2017. The dose to a high-rate consumer of fish and shellfish (including external radiation) was 0.007 mSv. The reason for the small decrease in dose from 0.009 mSv (in 2016) was because gamma dose rates were measured over different ground types from one year to next.

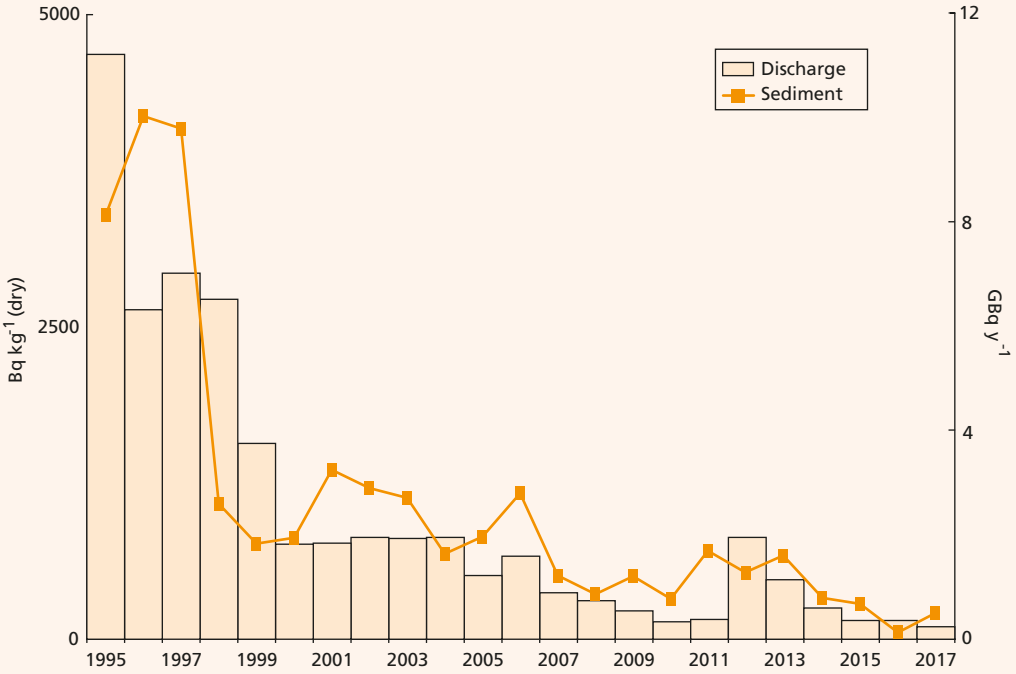



**Figure 4.4.** Caesium-137 liquid discharge from Trawsfynydd and concentration in sediment in Trawsfynydd lake, 1995-2017

## Gaseous discharges and terrestrial monitoring

Discharges of tritium, carbon-14 and sulphur-35 decreased in 2017, in comparison to releases in 2016. The focus of the terrestrial sampling was for the analyses of tritium, carbon-14 and sulphur-35 in milk and crops. Data for 2017 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 just above the expected background concentration and decreased by small amounts in comparison to those in 2016.

## Liquid waste discharges and aquatic monitoring

Discharges of tritium increased in 2017, in comparison to releases in 2016. However, tritium discharges were low in 2016, due to an operational issue with the active effluent treatment plant. 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 2017 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 2017 were similar to those in recent years. The reported concentration of technetium-99 in seaweed (due to the distant effects of discharges to sea from Sellafield) was higher in 2017, in comparison to those in previous years. 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.

## Table 4.1 Individual doses – nuclear power stations, 2017

| 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** | **Adult occupants over sediment** | **<0.005** | **<0.005** | **-** | **<0.005** | **-** | **-** |
| Source specific doses | Seafood consumers | <0.005 | <0.005 | - | <0.005 | - | - |
| | Houseboat occupants | 0.016 | - | - | 0.016 | - | - |
| | Infant inhabitants and consumers of locally grown food | <0.005 | - | <0.005 | - | <0.005 | - |
| Bradwell | | | | | | | |
| ***Total dose* - all sources** | **Prenatal children of local inhabitants (0–0.25km)** | **0.011** | **-** | **<0.005** | **-** | **<0.005** | **0.011** |
| 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 | |
| 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 | 0.006 | <0.005 | - | <0.005 | - | - |
| | Houseboat occupants | 0.014 | - | - | 0.014 | - | - |
| | Infant inhabitants and consumers of locally grown food | <0.005 | - | <0.005 | - | <0.005 | - |
| Hartlepool | | | | | | | |
| ***Total dose* - all sources** | **Local adult inhabitants (0–0.25km)** | **0.031** | **<0.005** | **-** | **0.010** | **<0.005** | **0.020** |
| Source specific doses | Seafood consumers[b] | 0.019 | <0.005 | - | 0.015 | - | - |
| | Infant inhabitants and consumers of locally grown food | <0.005 | - | <0.005 | - | <0.005 | - |
| Heysham | | | | | | | |
| ***Total dose* - all sources** | **Local adult inhabitants (0.25–0.5km)** | **0.025** | **<0.005** | **-** | **<0.005** | **<0.005** | **0.020** |
| Source specific doses | Seafood consumers | 0.026 | 0.009 | - | 0.017 | - | - |
| | Turf cutters | 0.008 | - | - | 0.008 | - | - |
| | Infant inhabitants and consumers of locally grown food | 0.005 | - | <0.005 | - | <0.005 | - |
| Hinkley Point | | | | | | | |
| ***Total dose* - all sources** | **Prenatal children of occupants over sediment** | **0.032** | **<0.005** | **<0.005** | **0.031** | **-** | **-** |
| Source specific doses | Seafood consumers | 0.019 | <0.005 | - | 0.018 | - | - |
| | Houseboat occupants | 0.027 | - | - | 0.027 | - | - |
| | Infant inhabitants and consumers of locally grown food | 0.007 | - | 0.007 | - | <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 | <0.005 | - | <0.005 | - | <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** | **0.035** | **<0.005** | **0.035** | **<0.005** | **-** | **-** |
| Source specific doses | Salmon, mollusc and wildfowl consumers | 0.014 | 0.010 | - | <0.005 | - | - |
| | Crustacean consumers | <0.005 | <0.005 | - | - | - | - |
| | Infant inhabitants and consumers of locally grown food | 0.023 | - | 0.023 | - | <0.005 | - |
| Hunterston | | | | | | | |
| ***Total dose* - all sources** | **Adult root vegetable consumers** | **0.023** | **-** | **<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 | 0.016 | - | 0.014 | - | <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 | 0.013 | - | 0.013 | - | <0.005 | - |
| | | | | | | | |
| **Wales** | | | | | | | |
| Trawsfynydd | | | | | | | |
| ***Total dose* - all sources** | **Prenatal children of occupants over sediment** | **0.024** | **<0.005** | **0.024** | **-** | **<0.005** | **-** |
| Source specific doses | Anglers | 0.026 | <0.005 | - | 0.024 | - | - |
| | Infant inhabitants and consumers of locally grown food | 0.028 | - | 0.028 | - | <0.005 | - |
| Wylfa | | | | | | | |
| ***Total dose* - all sources** | **Adult occupants over sediment** | **<0.005** | **<0.005** | **<0.005** | **<0.005** | **-** | **-** |
| Source specific doses | Seafood consumers | 0.007 | <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] *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 subtracting 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, 2017

| 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** | | | | | | | | |
| Elvers | Beachley | 1 | | | | 0.30 | | |
| Elvers | River Severn | 1 | | | | <0.12 | | |
| Mullet | River Severn | 1 | <25 | | | 0.33 | | |
| Shrimps | Guscar | 2 | <25 | 17 | | 0.16 | 0.00011 | 0.00093 |
| Seaweed | 2 km south west of Berkeley | 2[E] | | | <1.4 | <0.43 | | |
| Sediment | 0.5 km south of Oldbury | 2[E] | | | | 17 | | |
| Sediment | 2 km south west of Berkeley | 2[E] | | | | 18 | | |
| Sediment | Sharpness | 2[E] | | | | 12 | | |
| Sediment | Ledges | 2[E] | | | | 10 | | |
| Seawater | 2 km south west of Berkeley | 2[E] | <3.3 | | | <0.23 | | |

| 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** | | | | | | | |
| Elvers | Beachley | 1 | <0.13 | | | | |
| Elvers | River Severn | 1 | <0.10 | | | | |
| Mullet | River Severn | 1 | <0.21 | | | | |
| Shrimps | Guscar | 2 | 0.00087 | * | * | | |
| Seaweed | 2 km south west of Berkeley | 2[E] | <0.44 | | | | |
| Sediment | 0.5 km south of Oldbury | 2[E] | <0.77 | | | | |
| Sediment | 2 km south west of Berkeley | 2[E] | <0.79 | | | | |
| Sediment | Sharpness | 2[E] | <0.71 | | | | |
| Sediment | Ledges | 2[E] | <0.74 | | | | |
| Seawater | 2 km south west of Berkeley | 2[E] | <0.30 | | | <2.1 | 7.0 |

| 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 | <2.7 | 16 | <0.21 | <0.05 | | |
| Milk | max | | <3.5 | 19 | <0.23 | <0.06 | | |
| Apple | | 1 | <3.3 | 28 | <0.10 | <0.09 | | |
| Grass | | 1 | <2.4 | 13 | 1.2 | <0.08 | | |
| Freshwater | Gloucester and Sharpness Canal | 2[E] | <3.6 | | <0.19 | <0.20 | <0.052 | 0.23 |

* *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, 2017**

| Location | Ground type | No. of sampling observations | μGy $h^{-1}$ |
|---|---|---|---|
| **Mean gamma dose rates at 1m over substrate** | | | |
| 0.5 km south of Oldbury | Salt marsh | 2 | 0.081 |
| 2 km south west of Oldbury | Salt marsh | 2 | 0.076 |
| Guscar Rocks | Mud | 1 | 0.074 |
| Guscar Rocks | Mud and salt marsh | 1 | 0.085 |
| Lydney Rocks | Mud | 2 | 0.10 |
| Sharpness | Mud | 1 | 0.080 |
| Sharpness | Mud and salt marsh | 1 | 0.070 |
| Ledges | Mud | 1 | 0.082 |
| Ledges | Mud and salt marsh | 1 | 0.071 |

**Table 4.3(a) Concentrations of radionuclides in food and the environment near Bradwell nuclear power station, 2017**

| 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 | | | 0.23 | | | <0.06 | | | | |
| Lobster | West Mersea | 1 | | | 0.11 | | | <0.10 | | | | |
| Native oysters | Blackwater Estuary | 1 | | | <0.12 | 0.00029 | 0.0020 | 0.0012 | * | * | | |
| Samphire | Tollesbury | 1 | | <0.092 | <0.05 | | | <0.04 | | | | |
| Seaweed | Waterside | 2[E] | | 1.5 | <0.43 | | | <0.53 | | | | |
| Samphire | West Mersea | 1[E] | | <0.85 | <0.53 | | | <0.50 | | | | |
| Sediment | Bradwell Pipeline | 2[E] | | | 6.7 | | | <1.2 | | | | |
| Sediment | Bradwell Marina | 2[E] | | | 2.3 | | | <0.81 | | | | |
| Sediment | Waterside | 2[E] | | | 5.5 | | | <0.72 | | | | |
| Sediment | Steeple | 2[E] | | | 8.0 | | | <0.76 | | | | |
| Sediment | Maylandsea Bay | 2[E] | | | 8.6 | | | <0.76 | | | | |
| Sediment | Blackwater | 2[E] | | | 5.8 | | | <0.98 | | | | |
| Sediment | N side Blackwater Estuary | 2[E] | | | 6.1 | | | <1.6 | | | | |
| Sediment | Osea Causeway | 2[E] | | | 5.6 | | | <0.58 | | | | |
| Sediment | Maldon Harbour | 2[E] | | | 8.2 | | | <0.61 | | | | |
| Sediment | Maldon, Waterships Down | 2[E] | | | 18 | | | <0.78 | | | | |
| Sediment | Heybridge | 2[E] | | | 7.9 | | | <0.67 | | | | |
| Sediment | Strood Channel | 2[E] | | | 8.4 | | | <0.78 | | | | |
| Sediment | Tollesbury Boatyard | 2[E] | | | 7.4 | | | <1.2 | | | | |
| Sediment | Tollesbury saltwater pool | 2[E] | | | 2.9 | | | <0.53 | | | | |
| Sediment | West Mersea Beach Huts | 2[E] | | | 0.75 | | | <0.39 | | | | |
| Sediment | West Mersea Boatyard | 2[E] | | | 3.1 | | | <0.96 | | | | |
| Sediment | Pyefleet | 2[E] | | | 4.7 | | | <0.74 | | | | |
| Sediment | Rowhedge | 2[E] | | | 8.9 | | | <0.83 | | | | |
| Sediment | Alresford Creek | 2[E] | | | 5.4 | | | <0.70 | | | | |
| Sediment | Brightlingsea Bateman's Tower | 2[E] | | | <0.19 | | | <0.29 | | | | |
| Sediment | Brightlingsea saltwater pool | 2[E] | | | <0.19 | | | <0.29 | | | | |
| Sediment | St Osyth boat lake | 2[E] | | | 9.3 | | | <0.66 | | | | |
| Seawater | Bradwell Pipeline | 2[E] | <3.8 | | <0.23 | | | <0.30 | | | <3.9 | 13 |
| Seawater | Bradwell Marina | 2[E] | | | <0.20 | | | <0.31 | | | <3.8 | <8.9 |
| Seawater | Steeple | 2[E] | | | <0.23 | | | <0.31 | | | <3.4 | 17 |
| Seawater | Maylandsea Bay | 2[E] | | | <0.26 | | | <0.29 | | | <3.5 | 21 |
| Seawater | Blackwater | 2[E] | | | <0.25 | | | <0.30 | | | <3.2 | 15 |
| Seawater | Osea Causeway | 2[E] | | | <0.23 | | | <0.30 | | | <2.9 | 12 |
| Seawater | Maldon, Waterships Down | 2[E] | <3.7 | | <0.28 | | | <0.30 | | | <2.4 | 10 |
| Seawater | Heybridge | 2[E] | | | <0.26 | | | <0.29 | | | <2.6 | 8.9 |
| Seawater | Strood Channel | 2[E] | <4.0 | | <0.27 | | | <0.30 | | | <3.1 | 18 |
| Seawater | Tollesbury Boatyard | 2[E] | | | <0.23 | | | <0.30 | | | <3.4 | 13 |
| Seawater | Tollesbury saltwater pool | 2[E] | | | <0.27 | | | <0.30 | | | <3.4 | 13 |
| Seawater | Pyefleet | 2[E] | <3.9 | | <0.23 | | | <0.30 | | | <3.7 | 17 |
| Seawater | Rowhedge | 2[E] | | | <0.23 | | | <0.30 | | | <3.0 | 12 |
| Seawater | Alresford Creek | 2[E] | | | <0.23 | | | <0.30 | | | <2.9 | 11 |
| Seawater | Brightlingsea Bateman's Tower | 2[E] | | | <0.23 | | | <0.29 | | | <3.9 | 14 |
| Seawater | Brightlingsea saltwater pool | 2[E] | | | <0.24 | | | <0.30 | | | <4.1 | 14 |
| Seawater | St Osyth boat lake | 2[E] | | | <0.26 | | | <0.30 | | | <2.2 | 12 |

**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 | $^{241}$Am | Gross alpha | Gross beta |
| **Terrestrial samples** | | | | | | | | | |
| Milk | | 2 | <3.2 | 15 | | <0.05 | <0.15 | | |
| Milk | max | | | 18 | | | <0.20 | | |
| Cabbage | | 1 | <2.0 | 8.6 | | <0.06 | <0.17 | | |
| Grass | | 1 | <7.2 | 45 | | <0.08 | <0.09 | | |
| Grass | Maldon, Promenade Park | 2[E] | <12 | <7.2 | | <0.90 | | | |
| Grass | Strood Channel | 2[E] | <13 | <5.0 | | <1.8 | | | |
| Grass | Tollesbury | 2[E] | <12 | <12 | | <1.7 | | | |
| Grass | West Mersea, near Sewage Works | 2[E] | <16 | <7.9 | | <1.1 | | | |
| Grass | St Osyth | 2[E] | <12 | <9.0 | | <1.5 | | | |
| Freshwater | Coastal ditch, between power station and shore | 1[E] | 13 | | <0.025 | <0.25 | | <0.96 | 2.4 |
| Freshwater | Coastal ditch, east face of sector building | 1[E] | 8.2 | | | <0.20 | | <0.64 | 4.4 |
| Freshwater | Coastal ditch, east face of turbine hall | 1[E] | <8.5 | | 1.6 | <0.24 | | <0.48 | 8.2 |
| Freshwater | Coastal ditch, drain pit overflow | 2[E] | <7.7 | | | <0.23 | | <0.64 | 13 |

* *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, 2017

| Location | Ground type | No. of sampling observations | μGy $h^{-1}$ |
|---|---|---|---|
| **Mean gamma dose rates at 1m over substrate** | | | |
| Bradwell Beach | Mud and sand | 1 | 0.077 |
| Bradwell Beach | Mud and stones | 1 | 0.077 |
| Bradwell Beach opposite power station N side of estuary | Mud and salt marsh | 2 | 0.069 |
| Bradwell Marina | Mud | 1 | 0.094 |
| Bradwell Marina | Mud and salt marsh | 1 | 0.096 |
| Waterside | Mud | 2 | 0.071 |
| Steeple | Mud | 2 | 0.091 |
| Maylandsea Bay | Mud | 2 | 0.071 |
| Blackwater | Mud | 2 | 0.069 |
| Osea Causeway | Mud | 2 | 0.077 |
| Maldon Harbour | Mud and salt marsh | 2 | 0.071 |
| Maldon Promenade | Grass | 2 | 0.074 |
| Maldon Waterships Down | Mud | 1 | 0.077 |
| Maldon Waterships Down | Mud and salt marsh | 1 | 0.079 |
| Heybridge | Mud | 2 | 0.067 |
| Strood Channel | Grass | 2 | 0.082 |
| Strood Channel | Mud and salt marsh | 2 | 0.075 |
| Tollesbury | Grass | 2 | 0.093 |
| Tollesbury boatyard | Mud and salt marsh | 2 | 0.084 |
| Tollesbury saltwater pool | Mud | 1 | 0.080 |
| Tollesbury saltwater pool | Mud and sand | 1 | 0.070 |
| West Mersea Beach Huts | Mud | 1 | 0.050 |
| West Mersea Beach Huts | Sand and shingle | 1 | 0.053 |
| SE of West Mersea boatyard | Mud | 2 | 0.061 |
| West Mersea near Sewage Works | Grass | 2 | 0.081 |
| Pyefleet | Mud | 2 | 0.076 |
| Rowhedge | Grass and salt marsh | 1 | 0.077 |
| Rowhedge | Mud | 1 | 0.073 |
| Alresford Creek | Mud and salt marsh | 2 | 0.065 |
| Brightlingsea Bateman's Tower | Sand and shingle | 1 | 0.069 |
| Brightlingsea Bateman's Tower | Sand and stones | 1 | 0.058 |
| Brightlingsea saltwater pool | Sand and shingle | 2 | 0.061 |
| St Osyth | Grass | 2 | 0.078 |
| St Osyth boat lake | Mud | 1 | 0.072 |
| St Osyth boat lake | Mud and stones | 1 | 0.072 |

## Table 4.4(a) Concentrations of radionuclides in food and the environment near Dungeness nuclear power stations, 2017

| 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** | | | | | | | | | |
| Whiting | Pipeline | 1 | <25 | <25 | | <0.05 | | | 0.19 |
| Sole | Pipeline | 1 | <25 | <25 | | <0.04 | | | <0.04 |
| Spiny Spider Crab | Pipeline | 1 | <25 | <25 | | <0.05 | | | <0.05 |
| Scallop | Pipeline | 1 | <25 | <25 | 24 | <0.06 | <0.027 | | <0.05 |
| Sea kale | Dungeness Beach | 1 | | | | <0.10 | | | <0.08 |
| Seaweed | Folkestone Harbour | 2[E] | | | | <0.61 | | <0.77 | <0.42 |
| Sediment | Rye Harbour | 2[E] | | | | <0.41 | <3.1 | | <0.32 |
| Sediment | Camber Sands | 2[E] | | | | <0.30 | <2.0 | | <0.22 |
| Sediment | Pilot Sands | 2[E] | | | | <0.27 | <2.0 | | <0.19 |
| Seawater | Dungeness South | 2[E] | | <3.7 | | <0.30 | | | <0.24 |

| 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** | | | | | | | | | |
| Whiting | Pipeline | 1 | | | <0.05 | | | | |
| Sole | Pipeline | 1 | | | <0.09 | | | | |
| Spiny Spider Crab | Pipeline | 1 | | | <0.06 | | | | |
| Scallop | Pipeline | 1 | 0.00060 | 0.0027 | 0.0010 | * | 0.000051 | | |
| Sea kale | Dungeness Beach | 1 | | | <0.07 | | | | |
| Seaweed | Folkestone Harbour | 2[E] | | | <0.48 | | | | |
| Sediment | Rye Harbour | 2[E] | <0.37 | 0.27 | <0.71 | | | | 500 |
| Sediment | Camber Sands | 2[E] | | | <0.37 | | | | |
| Sediment | Pilot Sands | 2[E] | | | <0.36 | | | | |
| Seawater | Dungeness South | 2[E] | | | <0.29 | | | <3.9 | 14 |

| 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 | $^{241}$Am | Gross alpha | Gross beta |
| **Terrestrial Samples** | | | | | | | | | | |
| Milk | | 2 | <3.6 | 16 | <0.26 | <0.06 | <0.06 | <0.15 | | |
| Milk | max | | <4.2 | 18 | <0.30 | | <0.07 | <0.16 | | |
| Potato | | 1 | <4.0 | 19 | <0.10 | <0.12 | <0.09 | <0.10 | | |
| Wheat | | 1 | <6.3 | 73 | 0.60 | <0.05 | <0.05 | <0.15 | | |
| Grass | Lydd | 2[E] | <12 | <13 | | <1.4 | <1.1 | | | |
| Grass | Denge Marsh | 2[E] | <12 | <15 | | <0.95 | <0.78 | | | |
| Freshwater | Long Pits | 2[E] | <3.6 | | <0.19 | <0.30 | <0.23 | | <0.029 | 0.11 |
| Freshwater | Pumping station Well number 1 | 1[E] | <3.1 | | 0.19 | <0.34 | <0.22 | | <0.022 | 0.14 |
| Freshwater | Pumping station Well number 2 | 1[E] | <4.4 | | <0.20 | <0.28 | <0.22 | | <0.020 | 0.15 |
| Freshwater | Reservoir | 1[E] | <3.6 | | <0.20 | <0.26 | <0.21 | | <0.023 | 0.15 |

* *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, 2017**

| Location | Ground type | No. of sampling observations | μGy $h^{-1}$ |
|---|---|---|---|
| **Mean gamma dose rates at 1m over substrate** | | | |
| Littlestone on Sea | Mud and sand | 1 | 0.064 |
| Littlestone on Sea | Sand and pebbles | 1 | 0.054 |
| Greatstone on Sea | Mud and sand | 2 | 0.061 |
| Pilot Sands | Sand and pebbles | 1 | 0.062 |
| Pilot Sands | Shingle and silt | 1 | 0.057 |
| Dungeness West | Pebbles and sand | 1 | 0.054 |
| Dungeness West | Shingle | 1 | 0.052 |
| Jury's Gap | Mud and sand | 1 | 0.065 |
| Jury's Gap | Sand | 1 | 0.073 |
| Rye Bay | Mud and sand | 1 | 0.063 |
| Rye Bay | Sand and shingle | 1 | 0.063 |

## Table 4.5(a) Concentrations of radionuclides in food and the environment near Hartlepool nuclear power station, 2017

| Material | Location | No. of sampling observations | 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 | 22 | <0.07 | | <0.75 | 0.11 | |
| Crabs | Pipeline | 1 | <25 | <25 | 23 | <0.08 | | <0.82 | <0.08 | |
| Winkles | South Gare | 2 | <31 | <26 | 31 | <0.10 | | <3.3 | <0.09 | 1.1 |
| Seaweed | Pilot Station | 2[E] | | | | <0.56 | 2.9 | 18 | <0.38 | |
| Sediment | Old Town Basin | 2[E] | | | | <0.44 | | | 2.3 | |
| Sediment | Seaton Carew | 2[E] | | | | <0.27 | | | <0.20 | |
| Sediment | Paddy's Hole | 2[E] | | | | <0.34 | | | 1.3 | |
| Sediment | North Gare | 2[E] | | | | <0.25 | | | <0.19 | |
| Sediment | Greatham Creek | 2[E] | | | | <0.52 | | | 3.2 | |
| Sediment | Redcar Sands | 2[E] | | | | <0.27 | | | <0.30 | |
| Sea coal | Old Town Basin | 2[E] | | | | <0.38 | | | 1.0 | |
| Sea coal | Carr House Sands | 2[E] | | | | <0.41 | | | 1.0 | |
| Seawater[d] | North Gare | 2[E] | | <5.2 | | <0.26 | | | <0.22 | |

| Material | Location | No. of sampling observations | 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 | | | | <0.19 | | | | |
| Crabs | Pipeline | 1 | | | | <0.08 | | | | |
| Winkles | South Gare | 2 | 25 | 0.0027 | 0.020 | 0.0097 | * | * | | |
| Seaweed | Pilot Station | 2[E] | | | | <0.48 | | | | |
| Sediment | Old Town Basin | 2[E] | | | | <0.61 | | | | |
| Sediment | Seaton Carew | 2[E] | | | | <0.37 | | | | |
| Sediment | Paddy's Hole | 2[E] | | | | <0.61 | | | | |
| Sediment | North Gare | 2[E] | | | | <0.36 | | | | |
| Sediment | Greatham Creek | 2[E] | | | | <0.81 | | | | |
| Sediment | Redcar Sands | 2[E] | | | | <0.37 | | | | |
| Sea coal | Old Town Basin | 2[E] | | | | <0.60 | | | | |
| Sea coal | Carr House Sands | 2[E] | | | | <0.84 | | | | |
| Seawater[d] | North Gare | 2[E] | | | | <0.31 | | | <3.4 | 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 | $^{60}$Co | $^{137}$Cs | Gross alpha | Gross beta |
| **Terrestrial samples** | | | | | | | | | |
| Milk | | 2 | <3.0 | 17 | <0.34 | <0.05 | <0.05 | | |
| Milk | max | | <3.3 | 18 | <0.43 | | | | |
| Potatoes | | 1 | <3.3 | 15 | 0.30 | <0.05 | <0.04 | | |
| Grass | | 1 | <3.3 | 34 | 2.0 | <0.11 | <0.08 | | |
| Grass | 0.8km NW of site | 2[E] | <16 | 11 | 5.1 | <1.1 | <0.82 | | |
| Grass | 0.6km NE of site | 2[E] | <12 | 8.7 | 5.5 | <0.69 | <0.52 | | |
| Freshwater | Boreholes, Dalton Piercy | 2[E] | <3.3 | | <0.29 | <0.28 | <0.23 | <0.071 | <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 <1.3 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, 2017**

| Location | Ground type | No. of sampling observations | μGy $h^{-1}$ |
|---|---|---|---|
| **Mean gamma dose rates at 1m over substrate** | | | |
| Fish Sands | Sand | 1 | 0.062 |
| Fish Sands | Sand and seacoal | 1 | 0.064 |
| Old Town Basin | Mud and sand | 1 | 0.067 |
| Old Town Basin | Sand and seacoal | 1 | 0.072 |
| Carr House | Sand | 1 | 0.064 |
| Carr House | Sand and seacoal | 1 | 0.073 |
| Seaton Carew | Sand | 2 | 0.061 |
| North Gare | Sand | 2 | 0.074 |
| Paddy's Hole | Pebbles and rock | 1 | 0.17 |
| Paddy's Hole | Sand and pebbles | 1 | 0.17 |
| Greatham Creek nature reserve | Mud | 1 | 0.088 |
| Greatham Creek nature reserve | Mud and rock | 1 | 0.084 |
| Redcar Sands | Sand | 2 | 0.059 |

## Table 4.6(a) Concentrations of radionuclides in food and the environment near Heysham nuclear power stations, 2017

| 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 | $^{106}$Ru | $^{137}$Cs | $^{155}$Eu |
| **Marine samples** | | | | | | | | | | | |
| Flounder | Morecambe | 2 | <27 | <31 | 44 | <0.05 | <0.052 | 0.17 | <0.41 | 3.6 | <0.11 |
| Shrimps | Morecambe | 2 | <35 | 48 | 65 | <0.05 | <0.044 | 0.26 | <0.46 | 2.3 | <0.14 |
| Winkles[b] | Middleton Sands | 2 | 250 | 290 | 36 | <0.07 | 0.26 | 10 | <0.60 | 2.0 | <0.19 |
| Mussels[c] | Morecambe | 2 | 140 | 140 | 60 | <0.07 | 0.26 | 27 | <0.60 | 1.7 | <0.12 |
| Wildfowl | Morecambe | 1 | | | | <0.07 | | | <0.57 | 0.40 | <0.11 |
| Seaweed[e] | Half Moon Bay | 2[E] | | | | <0.55 | | 220 | <3.5 | 2.0 | |
| Sediment | Half Moon Bay | 2[E] | | | | <0.46 | | | | 59 | |
| Sediment | Pott's Corner | 2[E] | | | | <0.43 | | | | 13 | |
| Sediment | Morecambe central beach | 2[E] | | | | <0.33 | | | | 9.1 | |
| Sediment | Red Nab Point | 2[E] | | | | <0.48 | | | | 15 | |
| Seawater[f] | Shore adjacent to Northern Outfall | 2[E] | | 92 | | <0.33 | | | <2.5 | <0.27 | |

| 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 alpha | Gross beta |
| **Marine samples** | | | | | | | | | | |
| Flounder | Morecambe | 2 | 0.00042 | 0.0024 | | 0.0045 | * | * | | |
| Shrimps | Morecambe | 2 | 0.0034 | 0.022 | | 0.035 | * | * | | |
| Winkles[b] | Middleton Sands | 2 | 0.23 | 1.4 | 7.1 | 2.9 | * | * | | 150 |
| Mussels[c] | Morecambe | 2 | 0.34 | 2.0 | 10 | 3.9 | * | 0.0052 | | 120 |
| Wildfowl | Morecambe | 1 | | | | <0.07 | | | | |
| Seaweed[e] | Half Moon Bay | 2[E] | | | | <0.76 | | | | |
| Sediment | Half Moon Bay | 2[E] | 7.4 | 44 | | 95 | | | | |
| Sediment | Pott's Corner | 2[E] | | | | 14 | | | | |
| Sediment | Morecambe central beach | 2[E] | | | | 12 | | | | |
| Sediment | Red Nab Point | 2[E] | | | | 14 | | | | |
| Seawater[f] | Shore adjacent to Northern Outfall | 2[E] | | | | <0.30 | | | <2.7 | <8.3 |

| Material | Location or selection[d] | No. of sampling observ-ations[g] | Mean radioactivity concentration (fresh)[a], Bq kg$^{-1}$ | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | $^{3}$H | $^{14}$C | $^{35}$S | $^{60}$Co | $^{106}$Ru | $^{137}$Cs | Gross alpha | Gross beta |
| **Terrestrial samples** | | | | | | | | | | |
| Milk | | 2 | <5.0 | 18 | <0.30 | <0.06 | <0.46 | <0.09 | | |
| Milk | max | | <7.2 | | <0.43 | | <0.48 | <0.12 | | |
| Potatoes | | 1 | <5.6 | 18 | 0.50 | <0.08 | <0.68 | <0.09 | | |
| Grass | | 1 | <2.5 | 73 | 3.8 | <0.14 | <1.0 | 0.27 | | |
| Grass | Half Moon Bay, recreation ground | 2[E] | <16 | <8.9 | 1.5 | <0.72 | | <0.58 | | |
| Grass | Overton | 2[E] | <14 | 11 | 2.2 | <0.51 | | <0.37 | | |
| Freshwater | Damas Gill reservoir | 2[E] | <3.1 | <2.3 | <0.22 | <0.26 | | <0.24 | <0.034 | 0.041 |
| Freshwater | Lower Halton Weir | 2[E] | <3.2 | <2.5 | <0.21 | <0.24 | | <0.21 | <0.034 | 0.084 |

* *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 If no 'max' value is given the mean value is the most appropriate for dose assessments*

[e] *The concentrations of $^{35}$S was 9.4 Bq kg$^{-1}$ and $^{129}$I was 1.9 Bq kg$^{-1}$*

[f] *The concentrations of $^{35}$S was <0.53 Bq kg$^{-1}$*

[g] *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, 2017**

| Location | Ground type | No. of sampling observations | μGy $h^{-1}$ |
|---|---|---|---|
| **Mean gamma dose rates at 1m over substrate** | | | |
| Sand Gate Marsh | Grass | 1 | 0.079 |
| Sand Gate Marsh | Salt marsh | 1 | 0.070 |
| Arnside 2 | Grass | 2 | 0.084 |
| Morecambe central beach | Sand | 1 | 0.076 |
| Morecambe central beach | Sand and pebbles | 1 | 0.074 |
| Half Moon Bay | Sand | 1 | 0.081 |
| Half Moon Bay | Sand and stones | 1 | 0.081 |
| Red Nab Point | Sand and shingle | 1 | 0.074 |
| Red Nab Point | Sand and pebbles | 1 | 0.072 |
| Middleton sands | Sand | 2 | 0.074 |
| Sunderland Point | Sand | 2 | 0.092 |
| Colloway Marsh | Salt marsh | 2 | 0.11 |
| Lancaster | Grass | 1 | 0.078 |
| Aldcliffe Marsh | Salt marsh | 2 | 0.085 |
| Conder Green | Grass and salt marsh | 1 | 0.088 |
| Conder Green | Mud | 1 | 0.089 |

**Table 4.7(a) Concentrations of radionuclides in food and the environment near Hinkley Point nuclear power stations, 2017**

| Material | Location | No. of sampling observations | 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 | 33 | 21 | <0.04 | | | 0.26 |
| Shrimps | Stolford | 1 | 34 | 50 | 28 | <0.04 | | | 0.14 |
| Limpets | Stolford | 1 | <25 | <25 | 19 | <0.14 | | | 0.36 |
| Pacific Oyster | Stolford | 1 | <25 | <25 | 11 | <0.11 | | | <0.09 |
| Seaweed | Pipeline | 2[E] | | | | <0.65 | | 2.1 | <0.46 |
| Sediment | Pipeline | 2[E] | | | | <0.56 | <3.3 | | 7.1 |
| Sediment | Stolford | 2[E] | | | | <0.79 | <2.0 | | 15 |
| Sediment | Steart Flats | 2[E] | | | | <0.66 | <2.0 | | 11 |
| Sediment | River Parrett | 2[E] | | | | <0.88 | <2.0 | | 19 |
| Sediment | River Parrett Central 2 | 1[E] | | | | <0.57 | <2.0 | | 7.6 |
| Sediment | Weston-Super-Mare | 2[E] | | | | <0.43 | <2.0 | | 1.1 |
| Sediment | Burnham-On-Sea | 2[E] | | | | <0.34 | <2.0 | | 1.2 |
| Sediment | Kilve | 2[E] | | | | <0.42 | <2.0 | | 0.98 |
| Sediment | Helwell Bay | 2[E] | | | | <0.44 | <2.0 | | 1.4 |
| Sediment | Blue Anchor Bay | 2[E] | | | | <0.67 | <2.9 | | <1.5 |
| Seawater | Pipeline | 1[E] | <6.2 | | | <0.25 | <0.016 | | <0.21 |

| 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 |
| **Marine samples** | | | | | | | | | |
| Cod | Stolford | 1 | | | <0.04 | | | | |
| Shrimps | Stolford | 1 | 0.000053 | 0.00059 | 0.00055 | * | * | | |
| Limpets | Stolford | 1 | | | <0.11 | | | | |
| Pacific Oyster | Stolford | 1 | | | <0.07 | | | | |
| Seaweed | Pipeline | 2[E] | | | <0.54 | | | | |
| Sediment | Pipeline | 2[E] | | | <0.69 | | | | |
| Sediment | Stolford | 2[E] | | | <0.86 | | | | |
| Sediment | Steart Flats | 2[E] | | | <0.79 | | | | |
| Sediment | River Parrett | 2[E] | | | <0.92 | | | | |
| Sediment | River Parrett Central 2 | 1[E] | | | <0.78 | | | | |
| Sediment | Weston-Super-Mare | 2[E] | | | <0.48 | | | | |
| Sediment | Burnham-On-Sea | 2[E] | | | <0.45 | | | | |
| Sediment | Kilve | 2[E] | | | <0.52 | | | | |
| Sediment | Helwell Bay | 2[E] | | | <0.64 | | | | |
| Sediment | Blue Anchor Bay | 2[E] | | | <0.83 | | | | |
| Seawater | Pipeline | 1[E] | | | <0.31 | | | <2.3 | 11 |

## Table 4.7(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 | $^{137}$Cs | $^{241}$Am | Gross alpha | Gross beta |
| **Terrestrial samples** | | | | | | | | | | |
| Milk | | 2 | <4.4 | 21 | <0.39 | <0.05 | <0.05 | <0.25 | | |
| Milk | max | | <6.5 | 24 | <0.50 | <0.06 | <0.06 | <0.33 | | |
| Blackberries | | 1 | 10 | 24 | 1.2 | <0.06 | <0.06 | <0.18 | | |
| Honey | | 1 | <4.7 | 75 | <0.10 | <0.04 | <0.05 | <0.66 | | |
| Wheat | | 1 | <6.3 | 70 | 1.4 | <0.07 | <0.07 | <0.09 | | |
| Grass | Gunter's Grove | 2[E] | <13 | 18 | | <1.1 | <0.89 | | | |
| Grass | Wall Common | 2[E] | <14 | <13 | | <0.77 | <0.57 | | | |
| Freshwater | Durleigh Reservoir | 2[E] | <3.5 | | <0.19 | <0.29 | <0.23 | | <0.035 | 0.16 |
| Freshwater | Ashford Reservoir | 2[E] | <3.5 | | <0.51 | <0.27 | <0.23 | | <0.035 | 0.13 |

* *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, 2017

| Location | Ground type | No. of sampling observations | µGy h$^{-1}$ |
|---|---|---|---|
| **Mean gamma dose rates at 1m over substrate** | | | |
| Weston-super-Mare | Mud and sand | 1 | 0.055 |
| Weston-super-Mare | Sand | 1 | 0.067 |
| Burnham-on-Sea | Sand | 2 | 0.058 |
| River Parrett | Grass and mud | 1 | 0.077 |
| River Parrett | Mud | 1 | 0.071 |
| River Parrett Bridgwater Central 2 | Mud and salt marsh | 1 | 0.072 |
| Steart Flats | Mud | 2 | 0.073 |
| Stolford | Mud | 2 | 0.093 |
| Hinkley Point | Mud and rock | 2 | 0.086 |
| Kilve | Mud and rock | 1 | 0.088 |
| Kilve | Pebbles and silt | 1 | 0.067 |
| Helwell Bay | Pebbles and silt | 1 | 0.093 |
| Helwell Bay | Rock and sand | 1 | 0.071 |
| Blue Anchor Bay | Mud and sand | 1 | 0.084 |
| Blue Anchor Bay | Sand and shingle | 1 | 0.061 |

## Table 4.8(a) Concentrations of radionuclides in food and the environment near Sizewell nuclear power stations, 2017

| Material | Location | No. of sampling observ-ations | Mean radioactivity concentration (fresh)[a], Bq kg$^{-1}$ | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Organic $^{3}$H | $^{3}$H | $^{14}$C | $^{90}$Sr | $^{137}$Cs | $^{238}$Pu |
| **Marine samples** | | | | | | | | |
| Herring | Sizewell | 1 | <25 | <25 | | | 0.19 | |
| Thornback Ray | Sizewell | 1 | <25 | <25 | | | <0.15 | |
| Crabs | Sizewell | 1 | <25 | <25 | | | <0.05 | |
| Mussels | River Alde | 1 | <25 | <25 | 18 | | <0.04 | 0.00054 |
| Sediment | Aldeburgh | 2[E] | | | | <2.0 | <0.20 | |
| Sediment | Southwold harbour | 2[E] | | | | 11 | 5.8 | |
| Sediment | Minsmere river outfall | 2[E] | | | | <2.0 | 3.2 | |
| Seawater | Sizewell beach | 2[E] | | <5.2 | <5.3 | | <0.23 | |

| Material | Location | No. of sampling observ-ations | Mean radioactivity concentration (fresh)[a], Bq kg$^{-1}$ | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | $^{239}$Pu + $^{240}$Pu | $^{241}$Am | $^{242}$Cm | $^{243}$Cm + $^{244}$Cm | Gross alpha | Gross beta |
| **Marine samples** | | | | | | | | |
| Herring | Sizewell | 1 | | <0.10 | | | | |
| Thornback Ray | Sizewell | 1 | | <0.12 | | | | |
| Crabs | Sizewell | 1 | | <0.14 | | | | |
| Mussels | River Alde | 1 | 0.0041 | 0.0035 | 0.000097 | 0.000051 | | |
| Sediment | Aldeburgh | 2[E] | | <0.30 | | | | |
| Sediment | Southwold harbour | 2[E] | | <0.80 | | | | 850 |
| Sediment | Minsmere river outfall | 2[E] | | <0.48 | | | | |
| Seawater | Sizewell beach | 2[E] | | <0.29 | | | <4.4 | 13 |

| 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 | | 2 | <3.9 | 18 | <0.31 | <0.06 | | |
| Milk | max | | <4.6 | | <0.40 | | | |
| Potatoes | | 1 | <7.9 | 24 | 0.70 | <0.08 | | |
| Wheat | | 1 | <6.0 | 83 | 1.8 | <0.06 | | |
| Grass | Sizewell belts | 2[E] | <24 | <3.9 | | <0.58 | | |
| Grass | Sizewell common | 2[E] | <18 | <12 | | <0.49 | | |
| Freshwater | Minsmere nature reserve | 2[E] | <3.6 | | <0.26 | <0.24 | <0.034 | 0.26 |
| Freshwater | The Meare | 2[E] | <3.6 | | <0.22 | <0.19 | <0.031 | 0.29 |
| Freshwater | Leisure Park | 2[E] | <3.9 | | <0.22 | <0.21 | <0.091 | 0.40 |
| Freshwater | Farm reservoir | 2[E] | <3.7 | | <0.22 | <0.22 | <0.048 | 0.14 |

[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, 2017

| Location | Ground type | No. of sampling observations | μGy $h^{-1}$ |
|---|---|---|---|
| **Mean gamma dose rates at 1m over substrate** | | | |
| Sizewell Beach | Sand and shingle | 2 | 0.054 |
| Dunwich | Sand and shingle | 2 | 0.057 |
| Aldeburgh | Sand and shingle | 2 | 0.053 |
| Southwold Harbour | Mud | 1 | 0.069 |
| Southwold Harbour | Mud and salt marsh | 1 | 0.069 |

## Table 4.9(a) Concentrations of radionuclides in food and the environment near Chapelcross nuclear power station, 2017

| Material | Location | No. of sampling observations | Mean radioactivity concentration (fresh)[a], Bq $kg^{-1}$ | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $^{3}H$ | $^{14}C$ | $^{60}Co$ | $^{90}Sr$ | $^{95}Zr$ | $^{99}Tc$ | $^{106}Ru$ | $^{110m}Ag$ | $^{125}Sb$ |
| **Marine samples** | | | | | | | | | | | |
| Salmon | Inner Solway | 1 | <5.0 | | <0.10 | | <0.15 | | <0.36 | <0.10 | <0.10 |
| Sea trout | Inner Solway | 1 | <5.0 | | <0.10 | | <0.30 | | <0.57 | <0.10 | <0.15 |
| Shrimps | Inner Solway | 2 | <5.0 | | <0.10 | <0.10 | <0.35 | <0.31 | <0.89 | <0.12 | <0.24 |
| Cockles | North Solway | 1 | | | 0.17 | | <0.14 | | <0.41 | <0.10 | <0.13 |
| Mussels | North Solway | 2 | <5.0 | 60 | <0.10 | 0.33 | <0.15 | 19 | <0.40 | <0.10 | <0.12 |
| *Fucus vesiculosus* | Pipeline | 4 | | | <0.10 | | <0.17 | 140 | <0.48 | <0.11 | <0.15 |
| *Fucus vesiculosus*[d] | Browhouses | 2 | | | <0.10 | | <0.14 | 49 | <0.40 | <0.10 | <0.12 |
| *Fucus vesiculosus* | Dornoch Brow | 2 | | | <0.10 | | <0.20 | 56 | <0.58 | <0.12 | <0.18 |
| Sediment | Priestside Bank | 1 | | | <0.10 | | <0.10 | | <0.65 | <0.10 | <0.32 |
| Sediment | Pipeline | 4 | <5.4 | | 0.32 | | <0.29 | | <1.2 | <0.14 | <0.40 |
| Sediment | Dornoch Brow | 1 | | | 0.14 | | <0.34 | | 1.7 | <0.14 | <0.28 |
| Sediment | Powfoot | 1 | | | <0.10 | | <0.10 | | <0.38 | <0.10 | <0.13 |
| Sediment | Redkirk | 1 | | | <0.10 | | <0.23 | | <0.72 | <0.13 | <0.24 |
| Sediment | Stormont | 1 | | | <0.10 | | <0.20 | | <0.60 | <0.11 | <0.21 |
| Seawater | Pipeline | 2 | 3.0 | | <0.10 | | <0.11 | | <0.43 | <0.10 | <0.14 |

| Material | Location | No. of sampling observations | Mean radioactivity concentration (fresh)[a], Bq $kg^{-1}$ | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | $^{137}Cs$ | $^{154}Eu$ | $^{155}Eu$ | $^{238}Pu$ | $^{239}Pu$ + $^{240}Pu$ | $^{241}Am$ | Gross alpha | Gross beta |
| **Marine samples** | | | | | | | | | | |
| Salmon | Inner Solway | 1 | 0.15 | <0.10 | <0.10 | | | <0.10 | | |
| Sea trout | Inner Solway | 1 | 0.28 | <0.10 | <0.12 | | | <0.10 | | |
| Shrimps | Inner Solway | 2 | <0.10 | <0.13 | <0.22 | <0.00079 | 0.0022 | 0.0058 | | |
| Cockles | North Solway | 1 | 4.3 | <0.10 | <0.12 | 1.1 | 6.0 | 17 | | |
| Mussels | North Solway | 2 | 1.7 | <0.10 | <0.13 | 0.52 | 3.2 | 6.5 | | |
| *Fucus vesiculosus* | Pipeline | 4 | 4.7 | <0.10 | <0.27 | 0.31 | 2.1 | 4.6 | 11 | 460 |
| *Fucus vesiculosus*[d] | Browhouses | 2 | 6.5 | <0.10 | <0.29 | 0.54 | 3.4 | 6.1 | 12 | 300 |
| *Fucus vesiculosus* | Dornoch Brow | 2 | 5.5 | <0.11 | <0.22 | 0.53 | 3.3 | 5.6 | 9.5 | 380 |
| Sediment | Priestside Bank | 1 | 460 | 0.28 | 0.54 | 13 | 90 | 160 | | |
| Sediment | Pipeline | 4 | 110 | <0.25 | 1.6 | 14 | 79 | 140 | | |
| Sediment | Dornoch Brow | 1 | 64 | <0.19 | 1.4 | 7.3 | 45 | 78 | | |
| Sediment | Powfoot | 1 | 20 | <0.13 | 0.89 | 2.2 | 15 | 23 | | |
| Sediment | Redkirk | 1 | 24 | <0.17 | <0.31 | 2.6 | 12 | 24 | | |
| Sediment | Stormont | 1 | 36 | <0.18 | <0.32 | 2.8 | 20 | 28 | | |
| Seawater | Pipeline | 2 | <0.10 | <0.10 | <0.11 | | | <0.10 | | |

**Table 4.9(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 | $^{90}$Sr | $^{95}$Nb | $^{106}$Ru | $^{137}$Cs | $^{155}$Eu | $^{241}$Am | Gross alpha | Gross beta |
| **Terrestrial samples** | | | | | | | | | | | | | | |
| Milk | | 10 | <5.1 | <15 | <0.53 | <0.05 | <0.11 | <0.13 | <0.22 | <0.05 | | <0.05 | | |
| Milk | max | | 7.9 | 16 | <1.0 | | 0.38 | <0.30 | <0.41 | | | <0.06 | | |
| Apples | | 1 | <5.0 | <15 | <0.50 | <0.05 | <0.10 | <0.06 | <0.17 | <0.05 | | <0.05 | | |
| Beef | | 1 | <5.0 | 29 | <0.50 | <0.05 | <0.10 | <0.06 | <0.18 | <0.05 | | <0.05 | | |
| Beetroot | | 1 | <5.0 | <15 | <0.50 | <0.05 | 0.11 | <0.29 | <0.42 | 0.08 | | <0.06 | | |
| Broccoli | | 1 | <5.0 | <15 | <0.50 | <0.08 | <0.10 | <0.41 | <0.75 | <0.07 | | <0.10 | | |
| Brussel Sprouts | | 1 | <5.0 | 21 | 0.77 | <0.06 | <0.10 | <0.28 | <0.55 | <0.06 | | <0.07 | | |
| Cabbage | | 1 | <5.0 | <15 | 0.57 | <0.05 | <0.10 | <0.10 | <0.22 | <0.05 | | <0.05 | | |
| Carrots | | 1 | <5.0 | <15 | <0.50 | <0.05 | 0.16 | <0.19 | <0.31 | <0.05 | | <0.05 | | |
| Cauliflower | | 1 | <5.0 | <15 | <0.50 | <0.05 | <0.10 | <0.22 | <0.42 | <0.05 | | <0.07 | | |
| Eggs | | 1 | <5.0 | 23 | <0.50 | <0.05 | <0.10 | <0.11 | <0.39 | <0.05 | | <0.05 | | |
| Goose | | 1 | <5.0 | 27 | <0.50 | <0.05 | <0.10 | <0.09 | <0.29 | 0.08 | | <0.05 | | |
| Leeks | | 1 | <5.0 | <15 | <0.50 | <0.05 | 0.15 | <0.17 | <0.31 | <0.05 | | <0.05 | | |
| Pork | | 1 | <5.0 | 28 | <0.50 | <0.05 | <0.10 | <0.06 | <0.20 | <0.05 | | <0.05 | | |
| Potatoes | | 1 | <5.0 | <15 | <0.50 | <0.05 | <0.10 | <0.10 | <0.31 | <0.05 | | <0.05 | | |
| Rosehips | | 1 | <5.0 | <15 | 0.51 | <0.05 | 0.29 | <0.18 | <0.36 | <0.05 | | <0.05 | | |
| Grass | | 4 | <5.0 | <16 | <0.90 | <0.05 | 0.23 | <0.18 | <0.45 | <0.08 | | <0.07 | 1.5 | 310 |
| Grass | max | | | 20 | 1.9 | <0.06 | 0.34 | <0.29 | <0.58 | 0.18 | | <0.08 | 2.1 | 350 |
| Soil | | 4 | <5.0 | <15 | <1.2 | <0.05 | 0.96 | <0.37 | <0.38 | 11 | 1.6 | <0.91 | 200 | 1400 |
| Soil | max | | | | 1.4 | | 1.5 | <0.43 | <0.44 | 14 | | 2.1 | 230 | 1600 |
| Freshwater | Purdomstone | 1 | <1.1 | | | <0.01 | | <0.01 | <0.06 | <0.01 | | <0.01 | <0.010 | 0.062 |
| Freshwater | Winterhope | 1 | <1.1 | | | <0.01 | | <0.01 | <0.06 | <0.01 | | <0.01 | <0.010 | 0.056 |
| Freshwater | Black Esk | 1 | <1.1 | | | <0.01 | | <0.01 | <0.06 | <0.01 | | <0.01 | <0.010 | 0.017 |
| Freshwater | Gullielands Burn | 1 | 9.4 | | | <0.01 | | <0.01 | <0.07 | <0.01 | | <0.01 | 0.012 | 0.20 |

[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*
[d] *The concentrations of $^{234}$U, $^{235}$U and $^{238}$U were 5.5, 0.16 and 5.7 Bq kg$^{-1}$, respectively*

## Table 4.9(b) Monitoring of radiation dose rates near Chapelcross, 2017

| Location | Material or ground type | No. of sampling observations | µGy $h^{-1}$ |
|---|---|---|---|
| **Mean gamma dose rates at 1m over substrate** | | | |
| Glencaple Harbour | Salt marsh | 2 | 0.080 |
| Priestside Bank | Salt marsh | 2 | 0.073 |
| Powfoot Merse | Sand | 2 | 0.079 |
| Gullielands | Grass | 1 | 0.055 |
| Seafield | Sand | 2 | 0.072 |
| Woodhead | Grass | 1 | 0.059 |
| East Bretton | Grass | 1 | 0.067 |
| Pipeline | Salt marsh | 2 | 0.089 |
| Pipeline | Sand | 2 | 0.087 |
| Dumbretton | Grass | 1 | 0.065 |
| Battlehill | Sediment | 2 | 0.072 |
| Dornoch Brow | Sediment | 2 | 0.077 |
| Dornoch Brow | Salt marsh | 2 | 0.072 |
| Browhouses | Sediment | 2 | 0.070 |
| Redkirk | Sediment | 2 | 0.068 |
| Stormont | Sediment | 2 | 0.069 |
| | | | |
| **Mean beta dose rates** | | | µSv $h^{-1}$ |
| Pipeline | Stake nets | 3 | <1.0 |
| 500m East of pipeline | Sediment | 1 | <1.0 |
| 500m West of pipeline | Sediment | 1 | <1.0 |

## Table 4.9(c) Radioactivity in air near Chapelcross, 2017

| Location | No. of sampling observations | Mean radioactivity concentration, mBq $m^{-3}$ | | |
|---|---|---|---|---|
| | | $^{137}Cs$ | Gross alpha | Gross beta |
| Eastriggs | 11 | <0.010 | 0.011 | <0.20 |
| Kirtlebridge | 12 | <0.011 | <0.013 | <0.20 |
| Brydekirk | 12 | <0.010 | <0.012 | <0.20 |

## Table 4.10(a) Concentrations of radionuclides in food and the environment near Hunterston nuclear power station, 2017

| 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 | <0.15 | <0.26 | | <0.11 |
| Hake | Millport | 1 | | | <0.10 | <0.10 | <0.18 | <0.22 | | <0.10 |
| Crabs | Millport | 2 | | | <0.10 | <0.10 | <0.12 | <0.19 | 0.49 | <0.10 |
| *Nephrops* | Millport | 2 | | | <0.10 | <0.10 | <0.14 | <0.24 | | <0.10 |
| Lobsters | Largs | 1 | | | <0.10 | <0.10 | <0.16 | <0.15 | <0.11 | <0.10 |
| Squat lobsters | Largs | 2 | | | <0.10 | <0.10 | <0.16 | <0.27 | 2.4 | <0.10 |
| Winkles | Pipeline | 2 | | | <0.72 | <0.39 | <0.19 | <0.36 | | 0.70 |
| Scallops | Largs | 2 | | | <0.10 | <0.10 | <0.14 | <0.29 | | <0.10 |
| Oysters | Hunterston | 1 | | | <0.10 | <0.10 | <0.11 | <0.19 | | <0.10 |
| *Fucus vesiculosus* | N of pipeline | 2 | | | 0.48 | <0.15 | <0.16 | <0.19 | | <0.10 |
| *Fucus vesiculosus* | S of pipeline | 2 | | | 0.60 | 0.17 | <0.18 | <0.21 | | 0.13 |
| Sediment | Largs | 1 | | | <0.10 | <0.10 | <0.20 | <0.14 | | <0.11 |
| Sediment | Millport | 1 | | | <0.10 | <0.10 | <0.11 | <0.10 | | <0.10 |
| Sediment | Gull's Walk | 1 | | | <0.10 | 0.10 | <0.22 | <0.20 | | <0.12 |
| Sediment | Ardneil Bay | 1 | | | <0.10 | <0.10 | <0.13 | <0.10 | | <0.10 |
| Sediment | Fairlie | 1 | | | <0.10 | <0.10 | <0.17 | <0.28 | | <0.10 |
| Sediment | Pipeline | 1 | | | <0.10 | <0.10 | <0.16 | <0.11 | | <0.10 |
| Sediment | Ardrossan North Bay | 1 | | | <0.10 | <0.10 | <0.20 | <0.13 | | <0.10 |
| Sediment | Ardrossan South Bay | 1 | | | <0.10 | <0.10 | <0.15 | <0.10 | | <0.10 |
| Seawater | Pipeline | 2 | 3.0 | <0.50 | <0.10 | <0.10 | <0.13 | <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 | <0.14 | 0.74 | <0.10 | <0.13 | | | <0.10 |
| Hake | Millport | 1 | <0.16 | 0.81 | <0.10 | <0.15 | | | <0.10 |
| Crabs | Millport | 2 | <0.13 | 0.15 | <0.10 | <0.11 | 0.0075 | 0.046 | 0.031 |
| *Nephrops* | Millport | 2 | <0.12 | 0.24 | <0.10 | <0.12 | | | <0.10 |
| Lobsters | Largs | 1 | <0.18 | 0.11 | <0.10 | <0.13 | | | <0.10 |
| Squat lobsters | Largs | 2 | <0.15 | 0.27 | <0.10 | <0.13 | 0.0033 | 0.024 | 0.036 |
| Winkles | Pipeline | 2 | <0.21 | <0.17 | <0.12 | <0.16 | 0.10 | 0.50 | 1.3 |
| Scallops | Largs | 2 | <0.13 | 0.18 | <0.10 | <0.12 | 0.026 | 0.11 | 0.32 |
| Oysters | Hunterston | 1 | <0.11 | <0.10 | <0.10 | <0.10 | | | <0.10 |
| *Fucus vesiculosus* | N of pipeline | 2 | <0.14 | 0.30 | <0.10 | <0.13 | | | <0.10 |
| *Fucus vesiculosus* | S of pipeline | 2 | <0.16 | 0.26 | <0.10 | <0.13 | | | <0.10 |
| Sediment | Largs | 1 | <0.18 | 9.4 | <0.15 | <0.18 | | | <0.23 |
| Sediment | Millport | 1 | <0.11 | 3.1 | <0.10 | <0.10 | | | 0.32 |
| Sediment | Gull's Walk | 1 | <0.20 | 7.8 | <0.15 | <0.21 | | | 1.3 |
| Sediment | Ardneil Bay | 1 | <0.12 | 1.9 | <0.10 | <0.17 | | | <0.15 |
| Sediment | Fairlie | 1 | <0.14 | 4.1 | <0.10 | <0.19 | | | <0.17 |
| Sediment | Pipeline | 1 | <0.15 | 2.7 | <0.12 | <0.23 | | | <0.25 |
| Sediment | Ardrossan North Bay | 1 | <0.16 | 2.9 | <0.12 | <0.23 | | | <0.21 |
| Sediment | Ardrossan South Bay | 1 | <0.14 | 2.5 | <0.13 | <0.25 | | | 0.52 |
| Seawater | Pipeline | 2 | <0.13 | <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 | | 2 | <5.0 | <15 | <0.50 | <0.05 | <0.10 | <0.15 | <0.05 | <0.05 | | <0.05 | | |
| Milk | max | | | | 0.52 | | | <0.21 | | | | | | |
| Apples | | 1 | <5.0 | 18 | <0.50 | <0.05 | <0.16 | <0.11 | <0.06 | <0.05 | | <0.06 | | |
| Beef | | 1 | <5.0 | 27 | <0.50 | <0.05 | <0.10 | <0.22 | <0.06 | 0.44 | | <0.09 | | |
| Beetroot | | 1 | <5.0 | <15 | <0.50 | <0.05 | <0.10 | <0.24 | <0.05 | <0.05 | | <0.06 | | |
| Cabbage | | 1 | <5.0 | <15 | <0.50 | <0.05 | <0.10 | <0.24 | <0.05 | <0.05 | | <0.05 | | |
| Carrots | | 1 | <5.0 | <15 | <0.50 | <0.05 | <0.10 | <0.21 | <0.05 | <0.05 | | <0.05 | | |
| Eggs | | 1 | <5.0 | 26 | <1.4 | <0.05 | 0.14 | <0.43 | <0.07 | <0.05 | | <0.06 | | |
| Honey | | 1 | <5.0 | 39 | <2.7 | <0.05 | <0.10 | <0.15 | <0.09 | 3.0 | | <0.07 | | |
| Lamb | | 1 | <5.0 | 39 | 1.1 | <0.05 | <0.10 | <0.20 | <0.06 | 0.31 | | <0.11 | | |
| Leeks | | 1 | <5.0 | <15 | <0.50 | <0.05 | 0.11 | <0.18 | <0.05 | <0.05 | | <0.05 | | |
| Pheasant | | 1 | <5.0 | <15 | <0.50 | <0.05 | <0.10 | <0.31 | <0.08 | 0.22 | | <0.07 | | |
| Potatoes | | 1 | <5.0 | <15 | <0.50 | <0.05 | <0.10 | <0.16 | <0.06 | <0.05 | | <0.06 | | |
| Rosehips | | 1 | <5.0 | 27 | 0.67 | <0.05 | <0.10 | <0.24 | <0.07 | <0.05 | | 0.09 | | |
| Turnips | | 1 | <5.0 | <15 | <0.50 | <0.05 | 0.22 | <0.29 | <0.06 | <0.05 | | <0.06 | | |
| Grass | | 3 | <5.0 | <16 | 1.6 | <0.05 | <0.21 | <0.10 | <0.06 | <0.06 | | <0.07 | 1.2 | 360 |
| Grass | max | | | 18 | 1.7 | | 0.43 | | <0.07 | 0.08 | | <0.08 | 1.7 | 420 |
| Soil | | 3 | <5.0 | <15 | <0.92 | <0.05 | 0.47 | <0.13 | <0.07 | 11 | 0.49 | <0.18 | 160 | 1100 |
| Soil | max | | | | <0.99 | | 0.61 | <0.16 | <0.08 | 13 | | <0.22 | 180 | 1300 |
| Freshwater | Knockenden Reservoir | 1 | <1.0 | | | <0.01 | | <0.01 | <0.01 | <0.01 | | <0.01 | <0.01 | 0.023 |
| Freshwater | Loch Ascog | 1 | <1.0 | | | <0.01 | | | <0.01 | <0.01 | | <0.01 | <0.01 | 0.11 |
| Freshwater | Munnoch Reservoir | 1 | <1.0 | | | <0.01 | | <0.01 | <0.01 | <0.01 | | <0.01 | <0.01 | 0.039 |
| Freshwater | Camphill | 1 | <1.0 | | | <0.01 | | <0.01 | <0.01 | <0.01 | | <0.01 | <0.01 | 0.12 |
| Freshwater | Outerwards | 1 | <1.0 | | | <0.01 | | <0.01 | <0.01 | <0.01 | | <0.01 | <0.01 | 0.013 |

[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*

## Table 4.10(b) Monitoring of radiation dose rates near Hunterston nuclear power station, 2017

| Location | Ground type | No. of sampling observations | μGy $h^{-1}$ |
|---|---|---|---|
| **Mean gamma dose rates at 1m over substrate** | | | |
| Meigle Bay | Sand | 2 | 0.058 |
| Largs Bay | Stones and rocks | 2 | 0.062 |
| Kilchatten Bay | Sand | 2 | <0.047 |
| Millport | Sand | 2 | <0.047 |
| Gull's Walk | Sediment | 2 | 0.058 |
| Hunterston | Sand | 2 | 0.053 |
| 0.5 km north of pipeline | Sand | 2 | <0.047 |
| 0.5 km south of pipeline | Sand | 2 | <0.051 |
| Portencross | Grass | 1 | 0.067 |
| Ardneil Bay | Sand | 2 | <0.047 |
| Ardrossan North Bay | Sand | 2 | <0.049 |
| Ardrossan South Bay | Sand | 2 | <0.047 |
| Milstonford | Grass | 1 | 0.052 |
| Biglies | Grass | 1 | 0.056 |
| **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, 2017

| Location | No. of sampling observations | Mean radioactivity concentration, mBq $m^{-3}$ | | |
|---|---|---|---|---|
| | | $^{137}Cs$ | Gross alpha | Gross beta |
| Fairlie | 11 | <0.010 | <0.011 | <0.20 |
| West Kilbride | 12 | <0.013 | <0.013 | <0.20 |
| Low Ballees | 7 | <0.010 | <0.013 | <0.20 |

## Table 4.11(a) Concentrations of radionuclides in food and the environment near Torness nuclear power station, 2017

| Material | Location | No. of sampling observations | Mean radioactivity concentration (fresh)[a], Bq kg$^{-1}$ | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | $^{54}$Mn | $^{60}$Co | $^{65}$Zn | $^{95}$Nb | $^{99}$Tc | $^{110m}$Ag | $^{137}$Cs |
| **Marine samples** | | | | | | | | | |
| Cod | White Sands | 2 | <0.10 | <0.10 | <0.18 | <0.50 | | <0.11 | 0.21 |
| Mackerel | Pipeline | 2 | <0.10 | <0.10 | <0.15 | <0.37 | | <0.10 | <0.13 |
| Crabs[d] | Torness | 1 | <0.10 | <0.10 | <0.23 | <0.52 | <0.17 | <0.12 | 0.16 |
| Lobsters | Torness | 1 | <0.10 | <0.10 | <0.25 | <0.58 | 0.85 | <0.13 | 0.11 |
| *Nephrops* | Dunbar | 2 | <0.10 | <0.10 | <0.21 | <0.52 | | <0.10 | <0.10 |
| Winkles | Pipeline | 1 | <0.10 | 0.19 | <0.19 | <0.47 | | 1.2 | <0.10 |
| *Fucus vesiculosus* | Pipeline | 2 | <0.20 | 0.27 | <0.11 | <0.12 | | 0.29 | <0.10 |
| *Fucus vesiculosus* | Thornton Loch | 2 | 0.24 | <0.12 | <0.12 | <0.13 | 15 | <0.17 | <0.15 |
| *Fucus vesiculosus* | White Sands | 2 | <0.10 | <0.10 | <0.21 | <0.25 | | <0.10 | <0.15 |
| *Fucus vesiculosus* | Coldingham Bay | 2 | <0.10 | <0.10 | <0.12 | <0.11 | | <0.10 | <0.25 |
| *Fucus vesiculosus* | Pease Bay | 1 | <0.10 | <0.10 | <0.26 | <0.41 | | <0.10 | <0.10 |
| *Rhodymenia Palmata* | Pease Bay | 1 | <0.10 | <0.10 | <0.10 | <0.10 | | <0.10 | <0.10 |
| Sediment | Dunbar | 1 | <0.10 | <0.10 | <0.23 | <0.11 | | <0.10 | 1.4 |
| Sediment | Barns Ness | 1 | <0.10 | <0.10 | <0.11 | <0.10 | | <0.10 | 0.70 |
| Sediment | Thornton Loch | 1 | <0.10 | <0.10 | <0.10 | <0.10 | | <0.10 | 0.82 |
| Sediment | Heckies Hole | 1 | <0.10 | <0.10 | <0.12 | <0.68 | | <0.10 | 14 |
| Sediment | Belhaven Bay | 1 | <0.10 | <0.10 | <0.10 | <0.10 | | <0.10 | 0.30 |
| Sediment | Coldingham Bay | 1 | <0.10 | <0.10 | <0.10 | <0.10 | | <0.10 | 0.73 |
| Sediment | Pease Bay | 1 | <0.10 | <0.10 | <0.10 | <0.10 | | <0.10 | 1.5 |
| Seawater[e] | Pipeline | 2 | <0.10 | <0.10 | <0.11 | <0.16 | | <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 | <0.13 | | | <0.10 | | |
| Mackerel | Pipeline | 2 | <0.11 | | | <0.10 | | |
| Crabs[d] | Torness | 1 | <0.20 | | | <0.10 | | |
| Lobsters | Torness | 1 | <0.19 | | | <0.11 | | |
| *Nephrops* | Dunbar | 2 | <0.16 | 0.0026 | 0.0048 | 0.0066 | | |
| Winkles | Pipeline | 1 | <0.14 | | | <0.10 | 2.4 | 130 |
| *Fucus vesiculosus* | Pipeline | 2 | <0.10 | | | <0.10 | | |
| *Fucus vesiculosus* | Thornton Loch | 2 | <0.10 | | | <0.17 | | |
| *Fucus vesiculosus* | White Sands | 2 | <0.17 | | | <0.11 | | |
| *Fucus vesiculosus* | Coldingham Bay | 2 | <0.11 | | | <0.10 | | |
| *Fucus vesiculosus* | Pease Bay | 1 | <0.19 | | | <0.11 | | |
| *Rhodymenia Palmata* | Pease Bay | 1 | <0.10 | | | <0.10 | | |
| Sediment | Dunbar | 1 | <0.19 | | | <0.26 | | |
| Sediment | Barns Ness | 1 | 0.56 | | | 0.45 | | |
| Sediment | Thornton Loch | 1 | <0.10 | | | <0.11 | | |
| Sediment | Heckies Hole | 1 | 2.5 | | | 1.5 | | |
| Sediment | Belhaven Bay | 1 | 0.24 | | | <0.10 | | |
| Sediment | Coldingham Bay | 1 | <0.10 | | | 0.24 | | |
| Sediment | Pease Bay | 1 | <0.10 | | | <0.12 | | |
| Seawater[e] | Pipeline | 2 | <0.11 | | | <0.10 | | |

## 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 | $^{60}$Co | $^{90}$Sr | $^{95}$Nb |
| **Terrestrial Samples** | | | | | | | | |
| Milk | | 2 | <5.0 | <15 | <0.51 | <0.05 | <0.10 | <0.13 |
| Milk | max | | | 16 | 0.60 | | | <0.19 |
| Brussel sprouts | | 1 | <5.0 | <15 | <0.50 | <0.05 | <0.10 | 0.24 |
| Carrots | | 1 | <5.0 | <15 | <0.50 | <0.05 | 0.17 | <0.16 |
| Eggs | | 1 | <5.0 | 23 | <0.81 | <0.05 | 0.13 | <0.14 |
| Hare | | 1 | <5.0 | 24 | 0.69 | <0.05 | <0.10 | <0.05 |
| Honey | | 1 | <5.0 | 66 | <1.7 | <0.05 | <0.10 | <0.15 |
| Kale | | 1 | <5.0 | <15 | <1.1 | <0.05 | 0.78 | <0.15 |
| Leeks | | 1 | <5.0 | <15 | <0.5 | <0.05 | 0.19 | <0.07 |
| Partridge | | 1 | <5.0 | 23 | <0.61 | <0.05 | <0.10 | <0.05 |
| Pheasant | | 1 | <5.0 | 22 | <0.66 | <0.05 | <0.10 | <0.05 |
| Potatoes | | 1 | <5.0 | <15 | <0.50 | <0.05 | <0.10 | <0.07 |
| Rosehips | | 1 | <5.0 | 23 | <0.50 | <0.05 | 0.36 | <0.08 |
| Turnip | | 1 | <5.0 | <15 | <0.50 | <0.05 | 0.25 | <0.06 |
| Wild blackberries | | 1 | <5.0 | 21 | <0.50 | <0.05 | 0.36 | <0.08 |
| Wild mushrooms | | 1 | <5.0 | <15 | 0.66 | <0.05 | 0.10 | <0.18 |
| Grass | | 3 | <5.0 | <16 | <1.0 | <0.05 | <0.16 | <0.16 |
| Grass | max | | | 19 | 1.8 | | 0.20 | <0.22 |
| Soil | | 3 | <5.0 | <15 | <1.4 | <0.05 | 0.80 | <0.31 |
| Soil | max | | | | <1.5 | | 1.1 | <0.39 |
| Freshwater | Hopes Reservoir | 1 | <1.0 | | | <0.01 | | |
| Freshwater | Thorter's Reservoir | 1 | <1.0 | | | <0.01 | | <0.01 |
| Freshwater | Whiteadder | 1 | <1.0 | | | <0.01 | | <0.01 |
| Freshwater | Thornton Loch Burn | 1 | <1.0 | | | <0.01 | | <0.02 |

| Material | Location or Selection[b] | No. of sampling observations[c] | Mean radioactivity concentration (fresh)[a], Bq kg$^{-1}$ | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | $^{110m}$Ag | $^{137}$Cs | $^{155}$Eu | $^{241}$Am | Gross alpha | Gross beta |
| **Terrestrial Samples** | | | | | | | | |
| Milk | | 2 | <0.05 | <0.05 | | <0.05 | | |
| Brussel sprouts | | 1 | <0.05 | <0.05 | | <0.05 | | |
| Carrots | | 1 | <0.05 | <0.05 | | <0.05 | | |
| Eggs | | 1 | <0.05 | <0.05 | | <0.05 | | |
| Hare | | 1 | <0.05 | <0.05 | | <0.05 | | |
| Honey | | 1 | <0.07 | 4.9 | | <0.10 | | |
| Kale | | 1 | <0.05 | <0.05 | | <0.06 | | |
| Leeks | | 1 | <0.05 | <0.05 | | <0.05 | | |
| Partridge | | 1 | <0.05 | <0.05 | | <0.05 | | |
| Pheasant | | 1 | <0.05 | 0.07 | | <0.05 | | |
| Potatoes | | 1 | <0.05 | <0.05 | | <0.05 | | |
| Rosehips | | 1 | <0.05 | <0.05 | | <0.06 | | |
| Turnip | | 1 | <0.05 | <0.05 | | <0.06 | | |
| Wild blackberries | | 1 | <0.06 | <0.05 | | <0.07 | | |
| Wild mushrooms | | 1 | <0.06 | 0.13 | | <0.07 | | |
| Grass | | 3 | <0.05 | <0.05 | | <0.11 | 2.3 | 380 |
| Grass | max | | <0.06 | | | <0.12 | 3.6 | 480 |
| Soil | | 3 | <0.07 | 8.8 | 1.3 | <0.29 | 190 | 1200 |
| Soil | max | | <0.08 | 12 | 1.7 | 0.57 | 240 | 1600 |
| Freshwater | Hopes Reservoir | 1 | <0.01 | <0.01 | | <0.01 | <0.010 | 0.042 |
| Freshwater | Thorter's Reservoir | 1 | <0.01 | <0.01 | | <0.01 | <0.010 | 0.052 |
| Freshwater | Whiteadder | 1 | <0.01 | <0.01 | | <0.01 | <0.010 | 0.050 |
| Freshwater | Thornton Loch Burn | 1 | <0.01 | <0.01 | | <0.01 | <0.010 | 0.093 |

[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 33 Bq kg$^{-1}$*

[e] *The concentrations of $^{3}$H and $^{35}$S were 2600 and <11 Bq l$^{-1}$, respectively*

## Table 4.11(b) Monitoring of radiation dose rates near Torness nuclear power station, 2017

| Location | Ground type | No. of sampling observations | µGy $h^{-1}$ |
|---|---|---|---|
| **Mean gamma dose rates at 1m over substrate** | | | |
| Heckies Hole | Salt marsh | 2 | 0.053 |
| Dunbar Inner Harbour | Sand and stones | 2 | 0.080 |
| Belhaven Bay | Salt marsh | 1 | 0.047 |
| Belhaven Bay | Sand | 1 | 0.066 |
| Barns Ness | Sand | 2 | 0.050 |
| Skateraw | Sand | 2 | <0.055 |
| Thornton Loch | Grass | 1 | 0.049 |
| Thornton Loch beach | Sand | 2 | <0.047 |
| Ferneylea | Grass | 1 | 0.067 |
| Pease Bay | Sand | 2 | 0.057 |
| St Abbs Head | Rocks | 1 | 0.099 |
| St Abbs Head | Sand | 1 | 0.10 |
| Coldingham Bay | Sand | 2 | 0.050 |
| West Meikle Pinkerton | Grass | 1 | 0.062 |
| **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, 2017

| Location | No. of sampling observations | Mean radioactivity concentration, mBq $m^{-3}$ | | | |
|---|---|---|---|---|---|
| | | $^{60}Co$ | $^{137}Cs$ | Gross alpha | Gross beta |
| Innerwick | 11 | <0.010 | <0.010 | <0.010 | <0.31 |
| Cockburnspath | 12 | <0.010 | <0.010 | <0.013 | <0.20 |
| West Barns | 12 | <0.010 | <0.010 | <0.012 | <0.20 |

## Table 4.12(a) Concentrations of radionuclides in food and the environment near Trawsfynydd nuclear power station, 2017

| 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 | | 28 | <0.12 | 0.49 | <0.12 | 1.0 | <0.39 |
| Sediment | Pipeline | 1[E] | | | 0.91 | <2.0 | <0.63 | 690 | |
| Sediment | Lake shore near café | 2[E] | | | <0.62 | <2.0 | <0.58 | 300 | |
| Sediment | 1.5km SE of power station | 1[E] | | | <1.2 | <2.0 | <1.0 | 300 | |
| Sediment | SE of footbridge | 2[E] | | | <0.67 | <2.0 | <0.58 | 140 | |
| Sediment | Cae Adda | 2[E] | | | <0.50 | <2.0 | <0.44 | 92 | |
| Freshwater | Pipeline | 2[E] | <4.1 | | <0.28 | | <0.28 | <0.22 | |
| Freshwater | Gwylan Stream | 2[E] | <4.2 | | <0.28 | | <0.30 | <0.23 | |
| Freshwater | Afon Prysor | 2[E] | <4.2 | | <0.28 | | <0.30 | <0.23 | |
| Freshwater | 1.5km SE of power station | 2[E] | <4.2 | | <0.12 | | <0.13 | <0.11 | |
| Freshwater | Afon Tafarn-helyg | 2[E] | <4.0 | | <0.23 | | <0.26 | <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 | <0.000042 | 0.000022 | 0.00018 | * | * | | |
| Sediment | Pipeline | 1[E] | 1.7 | 5.3 | 1.1 | | | | |
| Sediment | Lake shore near café | 2[E] | <0.50 | 0.76 | <0.99 | | | | |
| Sediment | 1.5km SE of power station | 1[E] | <0.41 | 0.86 | 2.1 | | | | |
| Sediment | SE of footbridge | 2[E] | <0.48 | <0.34 | <0.86 | | | | |
| Sediment | Cae Adda | 2[E] | <0.47 | 0.54 | <0.85 | | | | |
| Freshwater | Pipeline | 2[E] | | | | | | <0.031 | 0.055 |
| Freshwater | Gwylan Stream | 2[E] | | | | | | <0.029 | 0.079 |
| Freshwater | Afon Prysor | 2[E] | | | | | | <0.029 | <0.050 |
| Freshwater | 1.5km SE of power station | 2[E] | | | | | | <0.029 | 0.037 |
| Freshwater | Afon Tafarn-helyg | 2[E] | | | | | | <0.022 | 0.068 |

| 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 | <4.2 | 18 | <0.043 | <0.10 | <0.098 | | | <0.16 |
| Milk | max | | <4.6 | 20 | 0.062 | <0.11 | <0.11 | | | <0.20 |
| Potatoes | | 1 | <2.7 | 20 | | <0.06 | | 0.0000081 | 0.00023 | 0.00014 |
| Grass | | 1 | <3.2 | 22 | | 0.07 | | 0.00059 | 0.0034 | 0.0056 |

* *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, 2017**

| Location | Ground type | No. of sampling observations | μGy $h^{-1}$ |
|---|---|---|---|
| **Mean gamma dose rates at 1m over substrate** | | | |
| Lake shore (pipeline) | Pebbles and stones | 1 | 0.11 |
| Lake shore (SE of footbridge) | Grass and rock | 1 | 0.087 |
| Lake shore (SE of footbridge) | Pebbles and stones | 1 | 0.11 |
| Lake shore (1.5 km SE) | Grass and shingle | 1 | 0.085 |
| Lake shore (1.5 km SE) | Pebbles and stones | 1 | 0.098 |
| Cae Adda | Pebbles and stones | 1 | 0.094 |
| Cae Adda | Shingle | 1 | 0.078 |
| Lake shore | Pebbles and rock | 1 | 0.081 |
| Lake shore | Pebbles and stones | 1 | 0.11 |

## Table 4.13(a) Concentrations of radionuclides in food and the environment near Wylfa nuclear power station, 2017

| Material | Location | No. of sampling observ-ations | 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 | 32 | | 0.58 | | |
| Crabs | Pipeline | 1 | <25 | <25 | 46 | | 0.32 | | |
| Lobsters | Pipeline | 1 | <25 | <25 | 53 | 14 | 0.36 | 0.0034 | 0.019 |
| Winkles | Cemaes Bay | 1 | <25 | <25 | 25 | 5.8 | 0.37 | 0.021 | 0.15 |
| Seaweed | Cemaes Bay | 2[E] | | | | 89 | <0.34 | | |
| Sediment | Cemaes Bay | 2[E] | | | | | 3.8 | | |
| Sediment | Cemlyn Bay West | 2[E] | | | | | 2.2 | | |
| Seawater | Cemaes Bay | 2[E] | | <4.3 | | | <0.21 | | |

| Material | Location | No. of sampling observ-ations | 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 | | <0.11 | | | | |
| Crabs | Pipeline | 1 | | <0.09 | | | | |
| Lobsters | Pipeline | 1 | 0.21 | 0.26 | * | 0.00019 | | 100 |
| Winkles | Cemaes Bay | 1 | 0.87 | 0.19 | * | * | | 100 |
| Seaweed | Cemaes Bay | 2[E] | | <0.41 | | | | |
| Sediment | Cemaes Bay | 2[E] | | 1.4 | | | | |
| Sediment | Cemlyn Bay West | 2[E] | | <0.43 | | | | |
| Seawater | Cemaes Bay | 2[E] | | <0.30 | | | <3.4 | 14 |

| 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 | $^{241}$Am |
| **Terrestrial samples** | | | | | | | |
| Milk | | 2 | <4.4 | 17 | <0.31 | <0.06 | <0.13 |
| Milk | max | | <5.0 | 19 | <0.43 | <0.07 | |
| Potatoes | | 1 | <2.8 | 17 | 0.40 | 0.13 | <0.15 |
| Grass | | 1 | <3.3 | 25 | 2.7 | <0.11 | <0.10 |
| Grass | Foel Fawr | 2[E] | <12 | <6.8 | | <0.38 | |

* *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, 2017**

| Location | Ground type | No. of sampling observations | µGy $h^{-1}$ |
|---|---|---|---|
| **Mean gamma dose rates at 1m over substrate** | | | |
| Cemaes Bay | Sand and pebbles | 1 | 0.074 |
| Cemaes Bay | Sand and shingle | 1 | 0.062 |
| Cemlyn Bay West | Pebbles and shingle | 1 | 0.065 |
| Cemlyn Bay West | Shingle | 1 | 0.075 |

# 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 (e.g. DSTL Radiological Protection Services, 2016).

In 2017, 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 2017 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 3 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

- *Total dose* for the representative person was 0.010 mSv and increased in 2017
- Gaseous discharges of carbon-14 decreased in 2017

### Barrow, Cumbria

- *Total dose* for the representative person was 0.074 mSv and decreased in 2017

### Derby, Derbyshire

- *Total dose* for the representative person was less than 0.005 mSv and unchanged in 2017

### Devonport, Devon

- *Total dose* for the representative person was less than 0.005 mSv and unchanged in 2017

### Faslane and Coulport, Argyll and Bute

- *Total dose* for the representative person was less than 0.005 mSv and decreased in 2017

### Rosyth, Fife

- *Total dose* for the representative person was 0.026 mSv and increased in 2017

## 5.1 Aldermaston, Berkshire


AWE 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 (a wholly owned subsidiary of AWE Management Limited). 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 2017, the *total dose* from all pathways and sources of radiation was 0.010 mSv (Table 5.1), or approximately 1 per cent of the dose limit, and up from less than 0.005 mSv in 2016. The representative person was adults living near to the site and was a change from that in 2016 (infants consuming milk). The increase in *total dose*, and change in representative person, was due to a higher estimate of direct radiation from the site in 2017.

Source specific assessments for high-rate consumers of locally grown foods, for sewage workers and for anglers, give exposures that were less than 0.005 mSv in 2017 (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. Gaseous discharges of carbon-14 decreased (reported as nil) and "activation products" increased in 2017, in comparison to those in 2016. Samples of milk, terrestrial foodstuffs, grass and soil were taken from locations close to the site (Figure 3.4) and the results of the terrestrial monitoring in 2017 are given in Table 5.2(a). In 2017, activity concentrations of tritium, and other radionuclides, in foodstuffs (including milk) were reported as very low or as less than values. 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 those values in 2016. Levels of uranium isotopes also remained similar to values in 2016. 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 2017 were similar to those reported in 2016; discharges of tritium to Aldermaston Stream were very low and similar to those in previous years.

A time-series trend of tritium discharges from Aldermaston is shown in Figure 5.1. The longer-term decline in discharges is due to the replacement of the original tritium facility (the replacement facility uses sophisticated abatement technology that resulted in significantly less tritium discharged into the environment) and the reduction of historical groundwater contamination 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). As in 2016, the Environment Agency continued their enhanced environmental monitoring of sediments and freshwater samples in 2017. The concentrations of artificial radioactivity detected in the Thames catchment were very low and generally similar to those in 2016. Iodine-131 was not positively detected in crayfish in 2017; in recent years iodine-131 has been detected in sediments and sludges (most likely due to waste discharges from the therapeutic use in medicine). Activity concentrations of artificial radionuclides in shellfish were measured at very low levels and similar to those reported in 2016. Analyses of caesium-137 and uranium activity concentrations in River Kennet sediments were broadly consistent with those in recent years. Caesium-137 concentrations in gully pot samples, and tritium concentrations in all collected samples, were reported as less than values in 2017. 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. Gaseous and liquid discharges may be made under permit but were both reported as nil in 2017. 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. The most recent habits survey was undertaken in 2012 (Garrod *et al.*, 2013).

The BAE Systems permit was varied in June 2016 and included a new discharge limit for cobalt-60, and an increase in the existing carbon-14 limit, for liquid disposals to sewer. The discharge limits of the revised permit cover the disposals of liquid radioactive waste arising from the flushing of the primary circuit from submarines which contain refurbished main coolant pumps. These are pumps which have been used in previous submarines but have undergone an extensive decontamination and refurbishment process. Flushing of the primary circuit is an essential part of the submarine build process to remove any swarf/debris prior to operation of the nuclear propulsion plant. The first disposal of the flush water occurred in 2017.

The *total dose* from all pathways and sources of radiation was 0.074 mSv (Table 5.1) in 2017, or approximately 7 per cent of the dose limit, and down from 0.082 mSv in 2016. The representative person was adults living on a local houseboat. Virtually all of this dose was due to the effects of Sellafield discharges. The apparent decrease in *total dose* is mostly because gamma dose rates were measured on different ground types (at Roa Island), 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

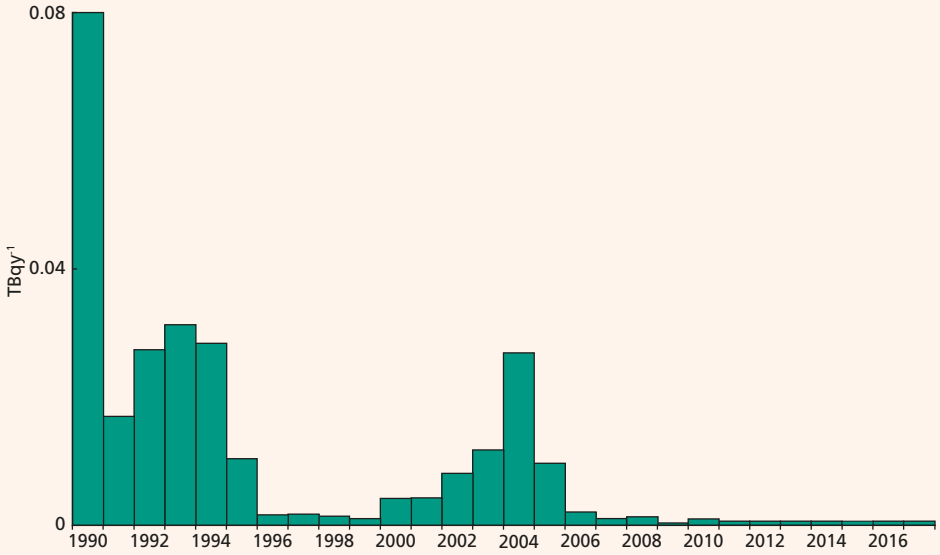



**Figure 5.1.** Trends in liquid discharges of tritium from Aldermaston, Berkshire 1990-2017
(including discharges to River Thames at Pangbourne, Silchester sewer and Aldermaston Stream)

houseboat give exposures that were less than the *total dose* (Table 5.1). No assessment of seafood consumption was undertaken in 2017 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. Most results are reported as less than values (Table 5.3(a)).

## 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. In August 2018, RRMPOL changed their name and are now Rolls-Royce Submarines Limited (RRSL). Small discharges of liquid effluent are made via the Megaloughton Lane STW 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). The most recent habits survey was undertaken in 2009 (Elliott *et al*., 2010).

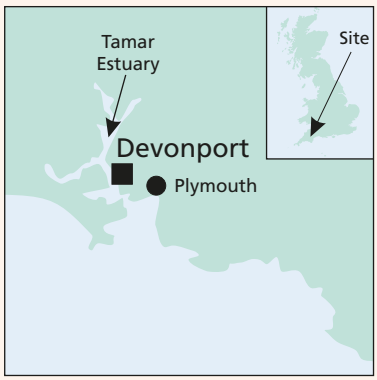
### Doses to the public

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, and unchanged in 2017. 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 2017 (Table 5.1).

Results of the routine monitoring programme at Derby are given in Table 5.3(a). Concentrations of uranium in samples taken around the site in 2017 were generally similar to those in 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 was most likely to have been from fallout from overseas sources (such as from weapon tests etc.).

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 2017 were broadly similar to those reported elsewhere in Derbyshire (Table 8.7).

## 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 August 2017, a habits survey was undertaken to determine the consumption and occupancy rates by members of the public (Moore *et al.*, 2018b). The revised figures for consumption rates, together with the occupancy rates are given in Appendix 1 (Table X2.2). An increase in the fish consumption rate and in the occupancy over intertidal areas (over mud, sand and stones) have been observed, together with small increases in crustacean and mollusc consumption rates, in comparison to the previous survey in 2011. The routine monitoring programme in 2017 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

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, and unchanged in 2017. The representative person was adults consuming locally harvested marine plants at high rates, who also consumed fish and spent time in intertidal areas (which largely determined the received dose). 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.

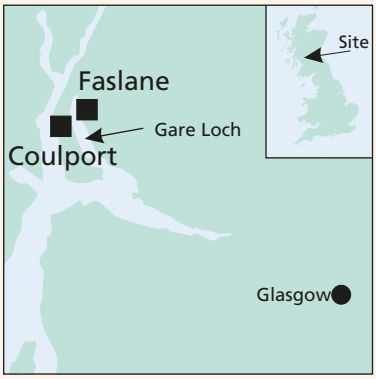
### Gaseous discharges and terrestrial monitoring

Discharges of carbon-14 increased in 2017, in comparison to those releases in 2016, due to the periodic nature of routine submarine refit operations. Samples of grass and vegetables were analysed for a number of radionuclides, and all activity concentrations in terrestrial samples are reported as less than values in 2017.

### Liquid waste discharges and marine monitoring

Discharges to the Hamoaze in 2017 were similar to those reported in 2016. The trends of tritium and cobalt-60 discharges with time (1990 – 2017) are given in Figure 5.2. 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, concentrations of tritium and cobalt-60 are reported as less than values. Trace amounts of caesium-137, likely to originate from Chernobyl and global weapon test fallout, were measured in sediment samples. Carbon-14 concentrations in seafood species were similar to natural background levels. Iodine-131 was detected in fish and shellfish samples, 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 in 2017, were similar to those in 2016, and 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

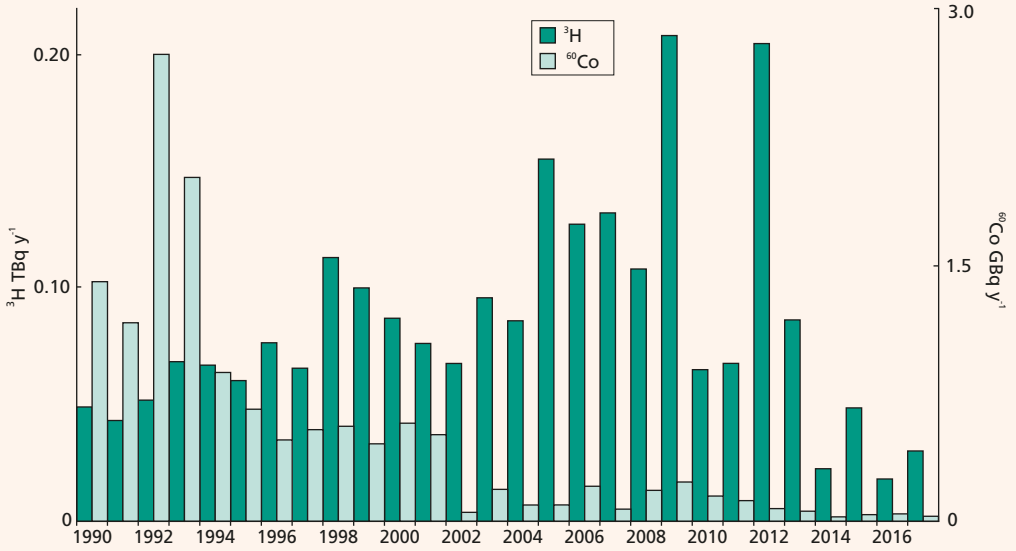



**Figure 5.2.** Trends in liquid discharges of tritium and cobalt-60 from Devonport, Devon 1990-2017

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).

During 2017, the construction of a new radioactive waste treatment facility at Faslane began and is expected to take 2-3 years to complete. An application to cover waste disposed of from the new facilities is expected during 2018.

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. The gaseous and liquid discharges are given in Appendix 2 (Tables A2.1 and A2.2, respectively). The disposal of solid radioactive waste from each site is also made under letters of agreement between SEPA and the MoD. There were no solid waste transfers from Faslane and Coulport in 2017.

The most recent habits survey to determine the consumption and occupancy rates by members of the public was undertaken in 2016 (SEPA, *in press*/d).

The *total dose* from all pathways and sources of radiation was less than 0.005 mSv in 2017 (Table 5.1), which is less than 0.5 per cent of the dose limit, and down from 0.009 mSv in 2016. The assessment of *total dose* is conservative by estimating activities in fish using reported environmental data in 2017. The representative person was adults consuming fish at high rates. The decrease in *total dose* was mostly because gamma dose rates were measured on different ground types (at Rhu and Rosneath Bay), from one year to the next. 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 0.005 mSv and less than 0.005 mSv, respectively. The reason for the decrease in dose (from 0.006 mSv in 2016) to the consumer of fish and shellfish is the same as that contributing to the maximum *total dose*.

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 2016. Caesium-137 was positively detected at a low concentration in one local food sample (honey). Radionuclide concentrations were generally reported as less than values. Caesium-137 concentrations in sediment are consistent with the distant effects of discharges from Sellafield, and with weapon testing and Chernobyl fallout. Unlike in previous years, iodine-131 was positively detected in seaweed samples at very low concentrations. 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 concentrations. 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 2017 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 over intertidal areas (Table 5.3(b)) were generally lower to those values reported in 2016. The external radiation dose to a person spending time on the loch shore was 0.009 mSv in 2017, which was less than 1 per cent of the dose limit for members of the public of 1 mSv (Table 5.1), and down from 0.013 mSv in 2016. This decrease was due to lower gamma dose rates over intertidal areas (Mid-loch and North Sandbank).

## 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, the 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 2016, SEPA granted RRDL an authorisation, under RSA 93, to dispose of radioactive waste arising on the Rosyth dockyard site. This allows RRDL to dispose of LLW that arises from the decommissioning of the Rosyth premises and from former submarine re-fitting operations and from waste transferred from the MoD from the dismantling of the seven redundant nuclear submarines currently stored afloat on the dockyard site. A Letter of Approval (effective from 1st December 2016) to the MoD allows the transfer of LLW from the seven nuclear submarines berthed at the Rosyth dockyard site to RRDL. 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.

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.

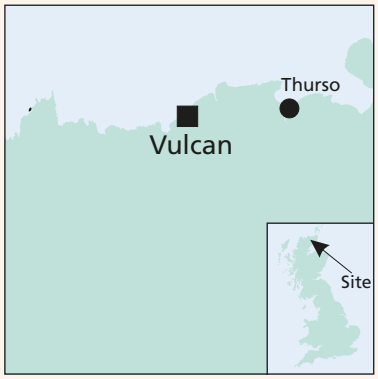
The *total dose* from all pathways and sources was 0.026 mSv in 2017 (Table 5.1), which was less than 3 per cent of the dose limit, and up from 0.017 mSv in 2016. In 2017, the representative person was adults who spend a large amount of time over marine sediments. The increase in *total dose* from 2016 was mostly due to higher gamma dose rates over sand in 2017. The source specific assessment for marine pathways (fishermen and beach users) was estimated to be 0.026 mSv in 2016. The reason for the increase in the source specific assessment is the same as that contributing to the maximum *total dose*.

The gaseous and liquid discharges from the site in 2017 are given in Appendix 2 (Tables A2.1 and A2.2), and solid waste transfers in Table A2.4. Gaseous discharges from Rosyth are 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 concentrations measured were low, and similar to those

in 2016, 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 includes the 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.

Gaseous discharges, and solid waste transfers, from Vulcan NRTE in 2017 are given in Appendix 2 (Table A2.1 and Table A2.4, respectively).

## Table 5.1 Individual doses - defence sites, 2017

| Site | Representative person[a] | 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 | Direct radiation from site |
| Aldermaston and Burghfield | | | | | | | | |
| ***Total dose* - all sources** | **Local adult inhabitants (0.5–1km)** | **0.010[c]** | **-** | **<0.005** | **-** | **-** | **<0.005** | **0.010** |
| Source specific doses | Anglers | <0.005[c] | <0.005 | - | <0.005 | - | - | - |
| | Infant inhabitants and consumers of locally grown food | <0.005[c] | - | <0.005 | - | - | <0.005 | - |
| | Workers at Silchester STW | <0.005 | - | - | <0.005[d] | <0.005[c] | - | - |
| Barrow | | | | | | | | |
| ***Total dose* - all sources** | **Adult occupants on houseboats[g]** | **0.074** | **-** | **-** | **0.074** | **-** | **-** | **-** |
| Source specific doses | Houseboat occupants | 0.071 | - | - | 0.071 | - | - | - |
| | 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[c] | - | <0.005 | - | - | <0.005 | - |
| Devonport | | | | | | | | |
| ***Total dose* - all sources** | **Adult consumers of marine plants and algae** | **<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** | **<0.005** | **<0.005** | **-** | **<0.005** | **-** | **-** | **-** |
| Source specific doses | Seafood consumers | 0.005 | <0.005 | - | <0.005 | - | - | - |
| | Consumers of locally grown food | <0.005 | - | <0.005 | - | - | - | - |
| Holy Loch | | | | | | | | |
| Source specific doses | Anglers | 0.009 | - | - | 0.009 | - | - | - |
| Rosyth | | | | | | | | |
| ***Total dose* - all sources** | **Adult occupants over sediment** | **0.026** | **<0.005** | **-** | **0.026** | **-** | **-** | **-** |
| Source specific doses | Fishermen and beach users | 0.026 | <0.005 | - | 0.026 | - | - | - |

[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*

[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 subtracting background and cosmic sources from measured gamma dose rates)*

## Table 5.2(a) Concentrations of radionuclides in food and the environment near Aldermaston, 2017

| Material | Location | No. of sampling observ-ations | 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 | * | 0.09 | | | |
| Signal crayfish | Ufton Bridge - Theale | 1 | <25 | <25 | <0.22 | <0.03 | 0.027 | 0.00088 | 0.020 |
| Sediment | Pangbourne | 2[E] | | | | <2.8 | 15 | <0.67 | 17 |
| Sediment | Mapledurham | 2[E] | | | | 21 | 11 | <1.0 | 12 |
| Sediment | Aldermaston | 4[E] | | | | 5.0 | 27 | <1.3 | 24 |
| Sediment | Spring Lane | 4[E] | | | | <1.0 | 9.4 | <0.59 | 9.3 |
| Sediment | Stream draining south | 4[E] | | | | <0.39 | 23 | <1.1 | 24 |
| Sediment | Near Chamber 39 of PPL | 3[E] | | | | <2.9 | 14 | <0.95 | 14 |
| Sediment | Oval pond near Chamber 14 | 4[E] | | | | <2.1 | 16 | <1.2 | 16 |
| Sediment | River Kennet | 4[E] | | | | <1.1 | 14 | <0.80 | 13 |
| Sediment | Hosehill Lake | 3[E] | | | | <1.3 | 21 | <1.1 | 21 |
| Gullypot sediment | Falcon Gate | 1[E] | | <13 | | <3.7 | 17 | <0.99 | 15 |
| Gullypot sediment | Main Gate | 1[E] | | <15 | | <1.6 | 15 | <0.83 | 14 |
| Gullypot sediment | Tadley Entrance | 1[E] | | <16 | | <4.9 | 15 | <0.57 | 17 |
| Gullypot sediment | Burghfield Gate | 1[E] | | <13 | | <1.6 | 26 | 1.2 | 26 |
| Freshwater | Pangbourne | 2[E] | | <3.1 | | <0.21 | 0.0078 | <0.0016 | <0.0030 |
| Freshwater | Mapledurham | 2[E] | | <3.3 | | <0.22 | 0.0092 | <0.0012 | 0.0073 |
| Freshwater | Aldermaston | 4[E] | | <3.7 | | <0.26 | 0.0055 | <0.0015 | 0.0050 |
| Freshwater | Spring Lane | 4[E] | | <3.5 | | <0.25 | <0.0023 | <0.0013 | <0.0015 |
| Freshwater | Stream draining south | 4[E] | | <3.7 | | <0.24 | <0.0028 | <0.0019 | <0.0031 |
| Freshwater | Near Chamber 39 of PPL | 3[E] | | <3.6 | | <0.21 | 0.0071 | <0.0014 | 0.0052 |
| Freshwater | Oval pond near Chamber 14 | 4[E] | | <3.1 | | <0.23 | <0.0015 | <0.0014 | <0.0013 |
| Freshwater | River Kennet | 4[E] | | <3.5 | | <0.25 | <0.0050 | <0.0013 | <0.0041 |
| Freshwater | Hosehill Lake | 4[E] | | <3.5 | | <0.21 | 0.0048 | <0.0012 | 0.0039 |
| Crude liquid effluent | Silchester treatment works | 2[E] | | <3.9 | | <0.23 | 0.0030 | <0.00076 | 0.0023 |
| Final Liquid effluent | Silchester treatment works | 2[E] | | <3.8 | | <0.25 | <0.0024 | <0.0014 | <0.0012 |
| Sewage sludge | Silchester treatment works | 2[E] | | <12 | | <0.33 | 0.89 | <0.047 | 0.87 |

| 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** | | | | | | | | | |
| Flounder | Woolwich Reach | 1 | | | <0.07 | | | | |
| Signal crayfish | Ufton Bridge - Theale | 1 | <0.000023 | 0.000056 | 0.000083 | * | * | | |
| Sediment | Pangbourne | 2[E] | <0.48 | <0.50 | <0.41 | | | 230 | 400 |
| Sediment | Mapledurham | 2[E] | <0.37 | <0.41 | <0.57 | | | <130 | 380 |
| Sediment | Aldermaston | 4[E] | <0.50 | 4.7 | <1.6 | | | 300 | 670 |
| Sediment | Spring Lane | 4[E] | <0.44 | <0.39 | <0.73 | | | <150 | 410 |
| Sediment | Stream draining south | 4[E] | <0.52 | <1.3 | <0.83 | | | 380 | 890 |
| Sediment | Near Chamber 39 of PPL | 3[E] | <0.41 | <0.39 | <0.90 | | | <130 | 350 |
| Sediment | Oval pond near Chamber 14 | 4[E] | <0.45 | <0.43 | <0.95 | | | 140 | 540 |
| Sediment | River Kennet | 4[E] | <0.42 | <1.1 | <0.88 | | | <120 | 260 |
| Sediment | Hosehill Lake | 3[E] | <0.49 | <2.1 | <0.92 | | | 170 | 610 |
| Gullypot sediment | Falcon Gate | 1[E] | <0.46 | <0.27 | <3.5 | | | 160 | 740 |
| Gullypot sediment | Main Gate | 1[E] | <0.21 | 0.34 | <1.8 | | | 320 | 610 |
| Gullypot sediment | Tadley Entrance | 1[E] | <0.44 | <0.26 | <4.2 | | | 290 | 810 |
| Gullypot sediment | Burghfield Gate | 1[E] | <0.49 | <0.24 | <1.8 | | | 150 | 650 |
| Freshwater | Pangbourne | 2[E] | <0.0032 | <0.0025 | <0.0053 | | | <0.062 | 0.31 |
| Freshwater | Mapledurham | 2[E] | <0.0029 | <0.0020 | <0.0057 | | | <0.056 | 0.35 |
| Freshwater | Aldermaston | 4[E] | <0.0028 | <0.0014 | <0.0048 | | | <0.034 | 0.18 |
| Freshwater | Spring Lane | 4[E] | <0.0023 | <0.0014 | <0.0031 | | | <0.031 | 0.16 |
| Freshwater | Stream draining south | 4[E] | <0.0022 | <0.0016 | <0.0056 | | | <0.035 | 0.19 |
| Freshwater | Near Chamber 39 of PPL | 3[E] | <0.0025 | <0.0016 | <0.0038 | | | <0.040 | 0.13 |
| Freshwater | Oval pond near Chamber 14 | 4[E] | <0.0025 | <0.0017 | <0.0059 | | | <0.031 | 0.067 |
| Freshwater | River Kennet | 4[E] | <0.0023 | <0.0014 | <0.0038 | | | <0.042 | 0.13 |
| Freshwater | Hosehill Lake | 4[E] | <0.0022 | <0.0013 | <0.0036 | | | <0.032 | <0.33 |
| Crude liquid effluent | Silchester treatment works | 2[E] | <0.0020 | <0.0014 | <0.32 | | | <0.077 | 0.84 |
| Final Liquid effluent | Silchester treatment works | 2[E] | <0.0018 | <0.0014 | <0.32 | | | <0.073 | <0.38 |
| Sewage sludge | Silchester treatment works | 2[E] | <0.064 | <0.043 | <0.41 | | | <6.9 | 18 |

## 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 | <4.0 | <0.05 | <0.00043 | <0.00043 | <0.00043 |
| Milk | max | | <5.2 | <0.06 | <0.00044 | <0.00044 | <0.00044 |
| Potatoes | | 1 | <2.7 | <0.06 | 0.0041 | <0.00033 | 0.0035 |
| Wheat | | 1 | <4.6 | <0.04 | 0.0033 | 0.00027 | 0.0032 |
| Grass | 0.25km east of Main gate | 1[E] | 18 | <0.72 | <0.098 | <0.081 | <0.074 |
| Grass | Opposite Gate 36 | 1[E] | 31 | <0.78 | <0.24 | <0.33 | <0.32 |
| Grass | Opposite Gate 26A | 1[E] | 69 | <1.9 | <0.18 | <0.15 | <0.14 |
| Grass | Tadley | 1[E] | <18 | <0.93 | <0.33 | <0.21 | <0.28 |
| Soil | 0.25km east of Main gate | 1[E] | <15 | 10 | 15 | 0.84 | 19 |
| Soil | Opposite Gate 36 | 1[E] | <15 | 6.5 | 13 | <0.96 | 13 |
| Soil | Opposite Gate 26A | 1[E] | 28 | 18 | 11 | <0.93 | 12 |
| Soil | Tadley | 1[E] | <21 | 10.0 | 22 | 1.3 | 26 |

| 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 | <0.000027 | <0.000018 | <0.000039 | | |
| Milk | max | | <0.000029 | <0.000024 | <0.000047 | | |
| Potatoes | | 1 | 0.000013 | 0.000063 | 0.000089 | | |
| Wheat | | 1 | 0.0000038 | 0.00013 | 0.00018 | | |
| Grass | 0.25km east of Main gate | 1[E] | <0.20 | <0.14 | | 1.4 | 160 |
| Grass | Opposite Gate 36 | 1[E] | <0.38 | <0.22 | | 3.5 | 240 |
| Grass | Opposite Gate 26A | 1[E] | <0.089 | 0.17 | | <1.8 | 170 |
| Grass | Tadley | 1[E] | <0.15 | 0.29 | | <4.4 | 300 |
| Soil | 0.25km east of Main gate | 1[E] | <0.48 | 0.46 | | 150 | 420 |
| Soil | Opposite Gate 36 | 1[E] | <0.54 | <0.37 | | 130 | 450 |
| Soil | Opposite Gate 26A | 1[E] | <0.18 | 1.0 | | <110 | 330 |
| Soil | Tadley | 1[E] | <0.23 | 0.45 | | 200 | 620 |

* *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*

[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, 2017

| Location | Ground type | No. of sampling observations | µGy h$^{-1}$ |
|---|---|---|---|
| **Mean gamma dose rates at 1m over substrate** | | | |
| Pangbourne, riverbank | Grass and mud | 2 | 0.064 |
| Mapledurham, riverbank | Grass and mud | 2 | 0.068 |

## Table 5.3(a) Concentrations of radionuclides in food and the environment near defence establishments, 2017

| 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 | $^{95}$Nb | $^{125}$Sb | $^{131}$I | $^{137}$Cs |
| **Barrow** | | | | | | | | | | |
| Potatoes | Barrow | 1[F] | | <2.4 | | <0.05 | <0.05 | <0.10 | <0.20 | <0.04 |
| Grass | Barrow | 1[F] | | <2.9 | | <0.08 | <0.09 | <0.12 | <0.30 | 0.15 |
| Sediment | Walney Channel - N of discharge point | 2 | | | | <0.44 | <0.36 | <1.5 | | 62 |
| **Derby** | | | | | | | | | | |
| Barley | Derby | 1[F] | | | | <0.12 | <0.14 | <0.23 | <0.33 | 0.14 |
| Potatoes | Derby | 1[F] | | | | <0.05 | <0.10 | <0.13 | <0.11 | <0.07 |
| Sediment | River Derwent, upstream | 1 | | | | <0.73 | | | | 2.8 |
| Sediment | Fritchley Brook | 1 | | | | <0.55 | | | | |
| Sediment | River Derwent, downstream | 4 | | | | <2.0 | | | | 5.4 |
| Water | River Derwent, upstream | 1 | | | | <0.26 | | | | |
| Water[c] | Fritchley Brook | 1 | | <2.9 | | <0.25 | | | | <0.22 |
| Water | River Derwent, downstream | 4 | | | | <0.24 | | | | |
| **Devonport** | | | | | | | | | | |
| Ballan wrasse | Plymouth Sound | 1[F] | 26 | <25 | 19 | <0.05 | <0.07 | <0.10 | <0.47 | 0.13 |
| Crabs | Plymouth Sound | 1[F] | | | 17 | <0.04 | <0.11 | <0.08 | * | <0.04 |
| Shrimp | River Lynher | 1[F] | | | 26 | <0.06 | <0.11 | <0.13 | * | <0.05 |
| Mussels | River Lynher | 1[F] | <25 | <25 | 19 | <0.15 | <0.26 | <0.29 | <3.0 | <0.12 |
| Seaweed[d] | Kinterbury | 2 | | | | <1.0 | | | | |
| Sediment[e] | Kinterbury | 2 | | <20 | | <0.56 | | | | 1.4 |
| Sediment | Torpoint South | 2 | | <6.1 | | <1.0 | | | | 0.87 |
| Sediment | Lopwell | 2 | | <9.0 | | <1.2 | | | | 3.9 |
| Seawater | Torpoint South | 1 | | <3.9 | <2.1 | <0.29 | | | | |
| Seawater | Millbrook Lake | 1 | | <3.9 | <1.7 | <0.29 | | | | |
| Sludge | Camel's Head Sewage Treatment Works | 1 | | <14 | | <0.49 | | | | |
| Potatoes | | 1[F] | | <2.8 | | <0.06 | <0.04 | <0.14 | <0.09 | <0.05 |
| Grass | | 1[F] | | <2.7 | | <0.08 | <0.08 | <0.16 | <0.09 | <0.08 |
| **Faslane** | | | | | | | | | | |
| Mussels | Rhu | 1 | | | | <0.10 | <0.31 | <0.16 | | 0.11 |
| Winkles | Rhu | 1 | | | | <0.10 | <0.41 | <0.18 | | 0.19 |
| *Fucus vesiculosus* | Rhu | 1 | | | | <0.10 | <0.10 | <0.10 | 1.4 | 0.29 |
| *Fucus vesiculosus* | Garelochhead | 1 | | | | <0.10 | <0.10 | <0.11 | | 0.24 |
| *Fucus vesiculosus* | Carnban | 1 | | | | <0.10 | <0.10 | <0.10 | 0.54 | 0.12 |
| Sediment | Rhu | 1 | | | | <0.10 | <0.11 | <0.18 | | 5.3 |
| Sediment | Garelochhead | 1 | | | | <0.10 | <0.10 | <0.15 | | 2.6 |
| Sediment | Carnban | 1 | | | | <0.10 | <0.10 | <0.13 | | 3.1 |
| Seawater | Carnban | 2 | | <1.1 | | <0.10 | <0.10 | <0.10 | | <0.10 |
| Beef muscle | Faslane | 1 | | <5.0 | | <0.05 | <0.24 | | | <0.05 |
| Honey | Faslane | 1 | | <5.0 | | <0.05 | <0.28 | | | 0.68 |
| Grass | Auchengaich Reservoir | 1 | | <5.0 | | <0.05 | <0.43 | | | 0.44 |
| Grass | Lochan Ghlas Laoigh | 1 | | <5.0 | | <0.05 | <0.33 | | | 0.08 |
| Soil | Auchengaich | 1 | | <5.0 | | <0.05 | <0.39 | <0.17 | | 51 |
| Soil | Lochan Ghlas Laoigh | 1 | | <5.0 | | <0.05 | <0.32 | | | 3.4 |
| Freshwater | Helensburgh Reservoir | 1 | | <1.1 | | <0.01 | <0.01 | | | <0.01 |
| Freshwater | Loch Finlas | 1 | | <1.1 | | <0.01 | <0.01 | | | <0.01 |
| Freshwater | Auchengaich Reservoir | 1 | | <1.1 | | <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 | <0.02 | | | <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 | $^{95}$Nb | $^{125}$Sb | $^{131}$I | $^{137}$Cs |
| **Holy Loch** | | | | | | | | | | |
| Sediment | Mid-Loch | 1 | | | | <0.10 | 0.14 | 0.17 | | 7.3 |
| **Rosyth** | | | | | | | | | | |
| Mackerel | Rosyth | 1 | | | | <0.10 | <0.60 | <0.19 | | <0.10 |
| Winkles | St David's Bay | 1 | | | | <0.10 | <0.72 | <0.23 | | <0.10 |
| *Fucus vesiculosus* | East of dockyard | 1 | | | | <0.10 | <0.13 | <0.16 | | <0.10 |
| Sediment | East of dockyard | 1 | | | | <0.10 | <0.35 | <0.14 | | 2.0 |
| Sediment | Port Edgar | 1 | | | | <0.10 | <0.10 | <0.14 | | 2.7 |
| Sediment | West of dockyard | 1 | | | | <0.10 | <0.10 | <0.12 | | 1.2 |
| Sediment | East Ness Pier | 1 | | | | <0.10 | <0.10 | <0.12 | | 4.5 |
| Sediment | Blackness Castle | 1 | | | | <0.10 | <0.10 | <0.12 | | 1.8 |
| Sediment | Charlestown Pier | 1 | | | | <0.10 | <0.10 | <0.12 | | 0.63 |
| Seawater | East of dockyard | 2 | | <1.1 | | <0.10 | <0.11 | <0.10 | | <0.10 |
| Freshwater | Castlehill Reservoir | 1 | | <1.0 | | <0.01 | <0.01 | | | <0.01 |
| Freshwater | Holl Reservoir | 1 | | <1.1 | | <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] | <0.16 | <0.13 | | | | <0.13 | | |
| Grass | Barrow | 1[F] | <0.24 | <0.18 | | | | <0.11 | | |
| Sediment | Walney Channel - N of discharge point | 2 | <1.1 | <0.79 | | | | 160 | 370 | 750 |
| **Derby** | | | | | | | | | | |
| Barley | Derby | 1[F] | <0.37 | <0.28 | 0.029 | 0.00084 | 0.025 | <0.14 | | |
| Potatoes | Derby | 1[F] | <0.19 | <0.23 | 0.014 | 0.00062 | 0.016 | <0.06 | | |
| Sediment | River Derwent, upstream | 1 | | | 34 | <1.4 | 35 | | 370 | 720 |
| Sediment | Fritchley Brook | 1 | | | 39 | <1.5 | 40 | | 260 | 550 |
| Sediment | River Derwent, downstream | 4 | | | 35 | <1.7 | 34 | | 390 | 730 |
| Water | River Derwent, upstream | 1 | | | | | | | <0.046 | 0.14 |
| Water[c] | Fritchley Brook | 1 | | | 0.0082 | <0.0010 | 0.0054 | | <0.041 | 0.15 |
| Water | River Derwent, downstream | 4 | | | | | | | <0.061 | 0.18 |
| **Devonport** | | | | | | | | | | |
| Ballan wrasse | Plymouth Sound | 1[F] | <0.16 | <0.08 | | | | <0.05 | | |
| Crabs | Plymouth Sound | 1[F] | <0.13 | <0.07 | | | | <0.04 | | |
| Shrimp | River Lynher | 1[F] | <0.17 | <0.12 | | | | <0.15 | | |
| Mussels | River Lynher | 1[F] | <0.41 | <0.19 | | | | <0.10 | | |
| Seaweed[d] | Kinterbury | 2 | | | | | | | | |
| Sediment[e] | Kinterbury | 2 | | | | | | <0.43 | | |
| Sediment | Torpoint South | 2 | | | | | | | | |
| Sediment | Lopwell | 2 | | | | | | | | |
| Seawater | Torpoint South | 1 | | | | | | | | |
| Seawater | Millbrook Lake | 1 | | | | | | | | |
| Sludge | Camel's Head Sewage Treatment Works | 1 | | | | | | | | |
| Potatoes | | 1[F] | <0.18 | <0.13 | | | | <0.09 | | |
| Grass | | 1[F] | <0.30 | <0.17 | | | | <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 | $^{234}$U | $^{235}$U | $^{238}$U | $^{241}$Am | Gross alpha | Gross beta |
| **Faslane** | | | | | | | | | | |
| Mussels | Rhu | 1 | <0.10 | <0.13 | | | | <0.10 | | |
| Winkles | Rhu | 1 | <0.10 | <0.15 | | | | <0.10 | | |
| *Fucus vesiculosus* | Rhu | 1 | <0.10 | <0.10 | | | | <0.10 | | |
| *Fucus vesiculosus* | Garelochhead | 1 | <0.10 | <0.10 | | | | <0.10 | | |
| *Fucus vesiculosus* | Carnban | 1 | <0.10 | <0.10 | | | | <0.10 | | |
| Sediment | Rhu | 1 | <0.15 | 0.80 | | | | 0.87 | | |
| Sediment | Garelochhead | 1 | <0.12 | <0.16 | | | | <0.23 | | |
| Sediment | Carnban | 1 | <0.11 | 0.53 | | | | <0.20 | | |
| Seawater | Carnban | 2 | <0.10 | <0.10 | | | | <0.10 | | |
| Beef muscle | Faslane | 1 | | | | | | <0.07 | | |
| Honey | Faslane | 1 | | | | | | <0.08 | | |
| Grass | Auchengaich Reservoir | 1 | | | | | | <0.09 | | |
| Grass | Lochan Ghlas Laoigh | 1 | | | | | | <0.05 | | |
| Soil | Auchengaich | 1 | <0.13 | 1.8 | | | | <0.27 | | |
| Soil | Lochan Ghlas Laoigh | 1 | | | | | | 0.69 | | |
| Freshwater | Helensburgh Reservoir | 1 | | | | | | <0.01 | <0.010 | 0.028 |
| Freshwater | Loch Finlas | 1 | | | | | | <0.01 | <0.010 | 0.027 |
| Freshwater | Auchengaich Reservoir | 1 | | | | | | <0.01 | <0.010 | 0.023 |
| Freshwater | Lochan Ghlas Laoigh | 1 | | | | | | <0.01 | 0.010 | 0.048 |
| Freshwater | Loch Eck | 1 | | | | | | <0.01 | <0.010 | 0.046 |
| Freshwater | Loch Lomond | 1 | | | | | | <0.01 | <0.010 | 0.028 |
| **Holy Loch** | | | | | | | | | | |
| Sediment | Mid-Loch | 1 | <0.10 | <0.13 | | | | 0.83 | | |
| **Rosyth** | | | | | | | | | | |
| Mackerel | Rosyth | 1 | <0.11 | <0.16 | | | | <0.10 | | |
| Winkles | St David's Bay | 1 | <0.11 | <0.18 | | | | <0.10 | | |
| *Fucus vesiculosus* | East of dockyard | 1 | <0.10 | <0.16 | | | | <0.11 | | |
| Sediment | East of dockyard | 1 | <0.11 | 0.53 | | | | <0.17 | | |
| Sediment | Port Edgar | 1 | <0.14 | <0.15 | | | | <0.26 | | |
| Sediment | West of dockyard | 1 | <0.11 | <0.21 | | | | <0.23 | | |
| Sediment | East Ness Pier | 1 | <0.12 | <0.16 | | | | <0.22 | | |
| Sediment | Blackness Castle | 1 | <0.10 | <0.12 | | | | <0.16 | | |
| Sediment | Charlestown Pier | 1 | <0.10 | <0.12 | | | | <0.17 | | |
| Seawater | East of dockyard | 2 | <0.10 | <0.10 | | | | <0.10 | | |
| Freshwater | Castlehill Reservoir | 1 | | | | | | <0.01 | <0.010 | 0.025 |
| Freshwater | Holl Reservoir | 1 | | | | | | <0.01 | <0.010 | 0.037 |
| Freshwater | Gartmorn Dam | 1 | | | | | | <0.01 | <0.010 | 0.11 |
| Freshwater | Morton No. 2 Reservoir | 1 | | | | | | <0.01 | <0.010 | 0.046 |

* *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 <0.013, <0.0033 and <0.0027 Bq l$^{-1}$ respectively*

[d] *The concentration of $^{99}$Tc was <1.1 Bq kg$^{-1}$*

[e] *The concentrations of $^{238}$Pu and $^{239+240}$Pu were <0.34 and <0.29 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, 2017

| 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 | 4 | 0.085 |
| Devonport | Torpoint South | Mud and shingle | 1 | 0.11 |
| Devonport | Torpoint South | Pebbles and shingle | 1 | 0.11 |
| Devonport | Kinterbury Access Gate | Mud | 1 | 0.084 |
| Devonport | Kinterbury Access Gate | Rock and mud | 1 | 0.11 |
| Devonport | Lopwell | Mud | 1 | 0.098 |
| Devonport | Lopwell | Mud and stones | 1 | 0.075 |
| Faslane | Garelochhead | Rocks | 2 | <0.047 |
| Faslane | Gulley Bridge Pier | Rocks | 2 | 0.055 |
| Faslane | Rhu | Rocks | 2 | 0.051 |
| Faslane | Helensburgh | Rocks | 2 | <0.049 |
| Faslane | Carnban | Rocks | 2 | 0.068 |
| Faslane | Rahane | Rocks | 2 | 0.063 |
| Faslane | Rosneath Bay | Sand | 2 | <0.049 |
| Faslane | Auchengaich | Grass | 1 | 0.062 |
| Faslane | Lochan Ghlas | Grass | 1 | 0.062 |
| Holy Loch | Kilmun Pier | Sediment | 1 | 0.074 |
| Holy Loch | Mid-Loch | Sediment | 1 | 0.060 |
| Holy Loch | North Sandbank | Sediment | 1 | 0.061 |
| Rosyth | Blackness Castle | Sediment | 2 | 0.065 |
| Rosyth | Charlestown Pier | Sand | 2 | 0.064 |
| Rosyth | East Ness Pier | Sediment | 2 | 0.068 |
| Rosyth | East of Dockyard | Rocks | 2 | 0.070 |
| Rosyth | Port Edgar | Sediment | 2 | 0.077 |
| Rosyth | West of Dockyard | Sediment | 2 | <0.066 |

# 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. In 2018, the FSA carried out a review of their environmental monitoring programme for the sites at Amersham and Cardiff (operated by GE Healthcare Limited). This part of the programme will be changed to reflect the review outcomes and reported in next year's RIFE report.

## 6.1 Grove Centre, Amersham, Buckinghamshire


GE Healthcare Limited's principal establishment is located at Amersham, in Buckinghamshire. It consists of a range of plants for manufacturing diagnostic imaging products for use in medicine and research.

The licensee is carrying out a project which will remove approximately half of the site from regulatory control. The project will remove the residual radioactive contamination from the part of the site to be de-licensed.

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. The most recent habits survey was undertaken in 2016 (Clyne *et al.*, 2017).

## 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

- *Total dose* for the representative person was 0.15 mSv and unchanged in 2017
- The highest dose was due to direct radiation from the site
- Liquid discharges were less than 1 per cent of the limit in 2017

### Maynard Centre, Cardiff

- *Total dose* for the representative person was less than 0.005 mSv and unchanged in 2017
- Carbon-14 concentrations in fish and molluscs species continued their long-term decline; the levels were the lowest in recent years
- Tritium concentrations in sediments were the lowest values in 2017 for many years

## Doses to the public

The *total dose* from all pathways and sources of radiation was 0.15 mSv in 2017 (Table 6.1) or 15 per cent of the dose limit, and unchanged from 2016. 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 in 2017. 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 – 2017 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 2017 (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 0.011 mSv, or approximately 1 per cent of the dose limit to members of the public of 1 mSv, and similar to that

in 2016 (0.009 mSv). As in previous years, atmospheric discharges of radon-222 remain the dominant contributor in 2017. 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 was less than 0.005 mSv in 2017.

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 2017 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.

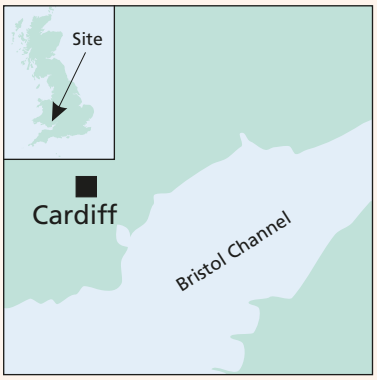
## Gaseous discharges and terrestrial monitoring

The Amersham facility is permitted to discharge gaseous radioactive wastes via stacks on the site. The results for the terrestrial monitoring for 2017 are given in Table 6.2(a). Low concentrations of sulphur-35 were detected in crop samples (potato and wheat) in 2017, similar to those in recent years. Caesium-137 was detected in soil near the site (as in previous years), 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. All values of liquid discharges were less than 1 per cent of the limit in 2017. The results of the aquatic monitoring programme for 2017 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 2017. The effluent and 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. Tritium, gross alpha and gross beta concentrations in water were below (or just above, for gross beta downstream of outfall) the investigation levels for drinking water in the European Directive 2013/51. Gamma dose rates over grass were generally indistinguishable from natural background in 2017 (Table 6.2(b)), and were similar to those measured in recent years.

## 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. Radioactive liquid wastes that were previously discharged from the site in relatively large quantities have now ceased. 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 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 2017, or less than 0.5 per cent of the dose limit, and unchanged from 2016. This dose estimate takes 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 prenatal children of occupants over sediment in 2017 and a change from that in 2016 (infants consuming milk). Trends in *total doses* over time (2004 – 2017) 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 and a recreational user of the River Taff give doses that were also less than 0.005 mSv in 2017 (Table 6.1). The dose to a high-rate consumer of seafood was 0.006 mSv. The reason for the small increase in dose (from < 0.005 mSv in 2016) was due to higher gamma dose rates (at east of pipeline) in 2017.

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 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 2017.

The focus of the terrestrial sampling was for the analyses 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. Further information on previously reported monitoring and assessment, concerning effluents and use of sludge pellets for agricultural uses, is available in earlier RIFE reports (e.g. Environment Agency, FSA, NIEA, NRW and SEPA, 2014).

Tritium concentrations in terrestrial food samples are reported as less than values in 2017 (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 (potatoes) and grass samples (and were generally similar to those in recent years). Phosphorus-32 and iodine-125 concentrations in foods samples, and tritium concentrations in sediments (marine and terrestrial) are all reported as less than values in 2017.

In 2017, there was no evidence of tritium being detected in sediment and freshwater from the Glamorganshire Canal (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 also reported as less than values. Freshwater samples from the outfall were not collected in 2017, as run-off water originating from the site is not continuous (no flow of water occurred during the planned bi-annual sampling visits). The trend of discharges, with tritium concentrations in sediment from the marine and freshwater environments, over time (2004 – 2017) 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. In 2017, tritium concentrations in sediments (marine and terrestrial) are the lowest values reported for many years.

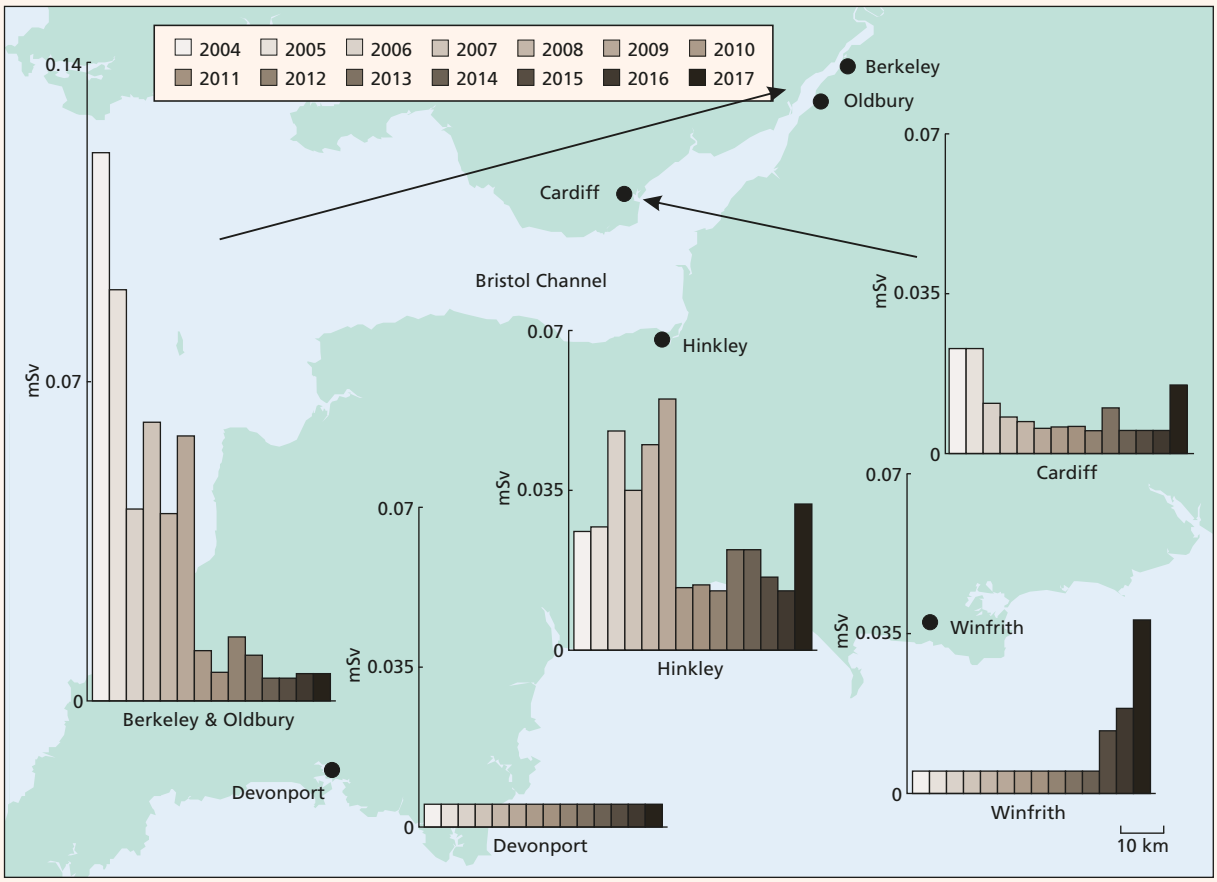



**Figure 6.1.** *Total dose* for major sites in the Severn Estuary and south coast, 2004-2017
(Note small doses, less than or equal to 0.005 mSv, are recorded as being 0.005 mSv)

## Liquid waste discharges and aquatic monitoring

Radioactive liquid wastes that were previously discharged from the site, in relatively large quantities, have now ceased. Minimal discharges from a single change room sink are covered by exemption conditions with which the operator must comply. The bulk of the radioactivity previously discharged was tritium and carbon-14. Recent trends over time (2004 – 2017) 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 2017 are given in Tables 6.3(a) and (b). Tritium concentrations were enhanced by small amounts in fish samples (dogfish), as in recent years. 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 and OBT concentrations in flounder in 2017 are reported as less than values. The continued overall decline in tritium concentrations in fish from the Cardiff area is 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.

Figure 6.4 indicates that the overall tritium concentrations in fish and mollusc samples have decreased significantly over time. The trend of carbon-14 concentrations and the relationship to discharges is shown in Figure 6.5 (overall, concentrations in both species declining). Mean concentrations of carbon-14 concentrations in fish and mollusc samples were lower in 2017 (compared with those in 2016) and these are the lowest reported values 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 2017 were generally higher (by small amounts), in comparison to those in 2016. These rates are not (in the main) attributable to discharges from the Maynard Centre or Pharmaron.

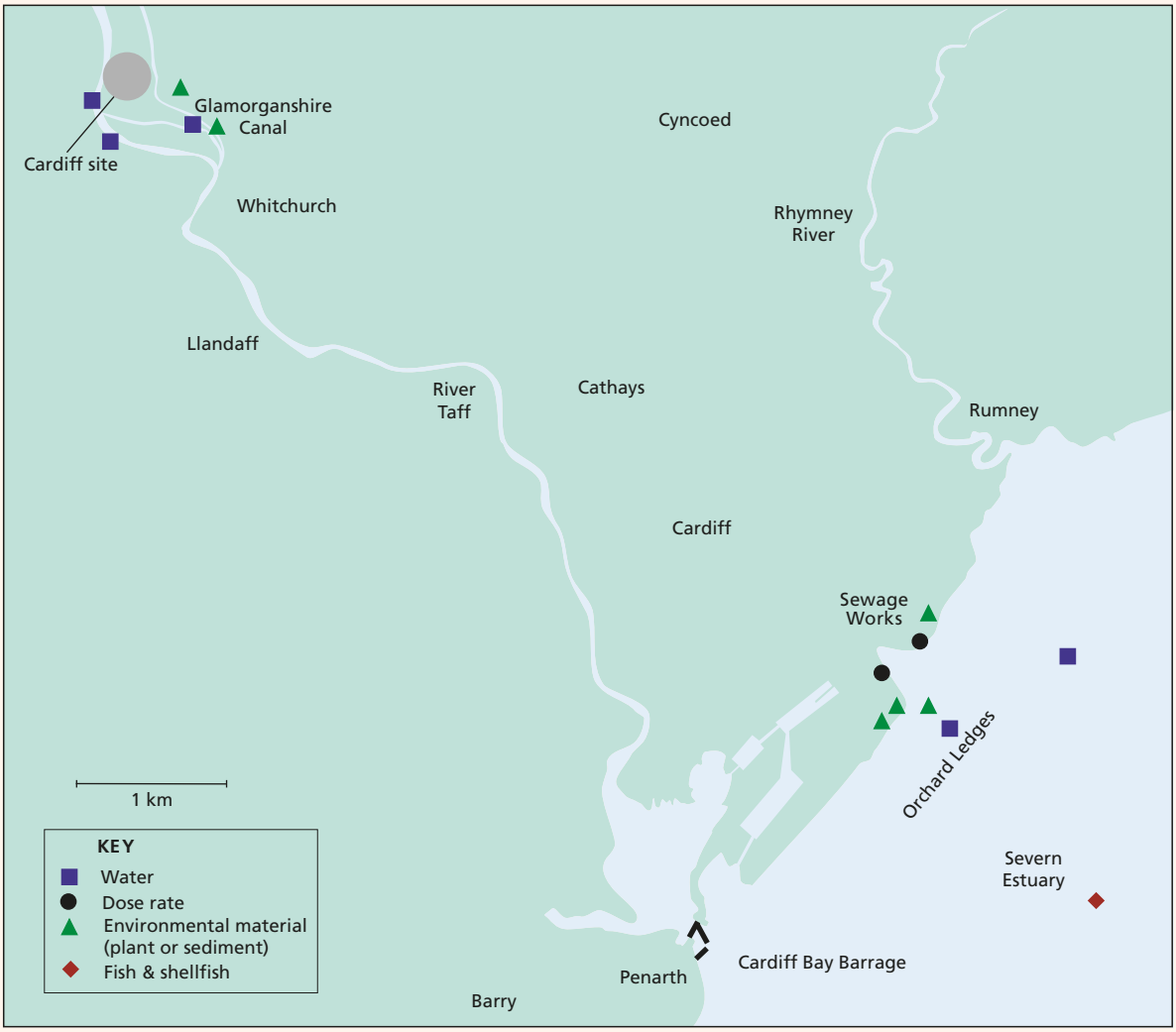



**Figure 6.2.** Monitoring locations at Cardiff, 2017 (not including farms)

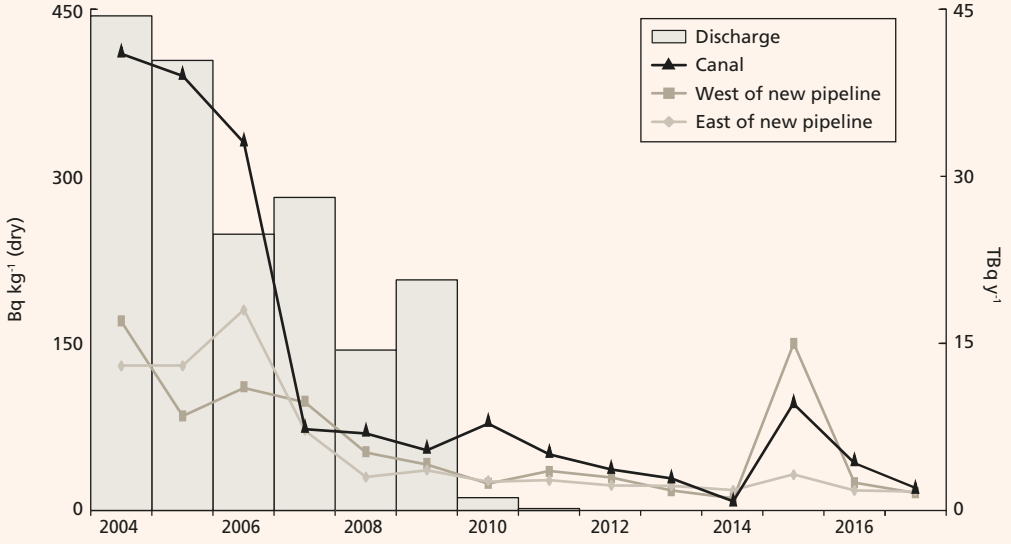



**Figure 6.3.** Tritium liquid discharge from Cardiff and mean concentrations in sediment near Cardiff, 2004-2017

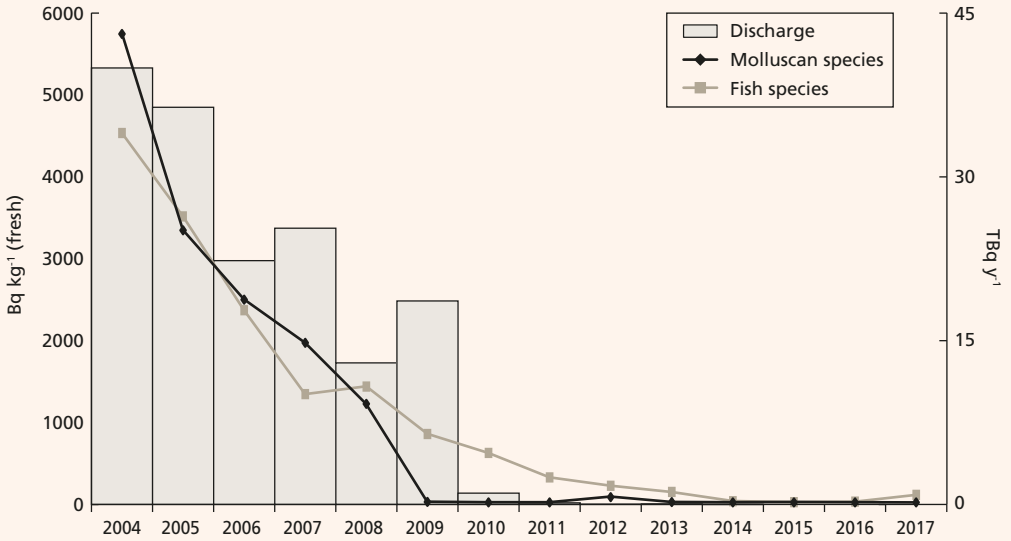



**Figure 6.4.** Tritium liquid discharge from Cardiff and mean concentrations in fish and molluscs near Cardiff, 2004-2017 (species include all those reported in RIFE for the given year)

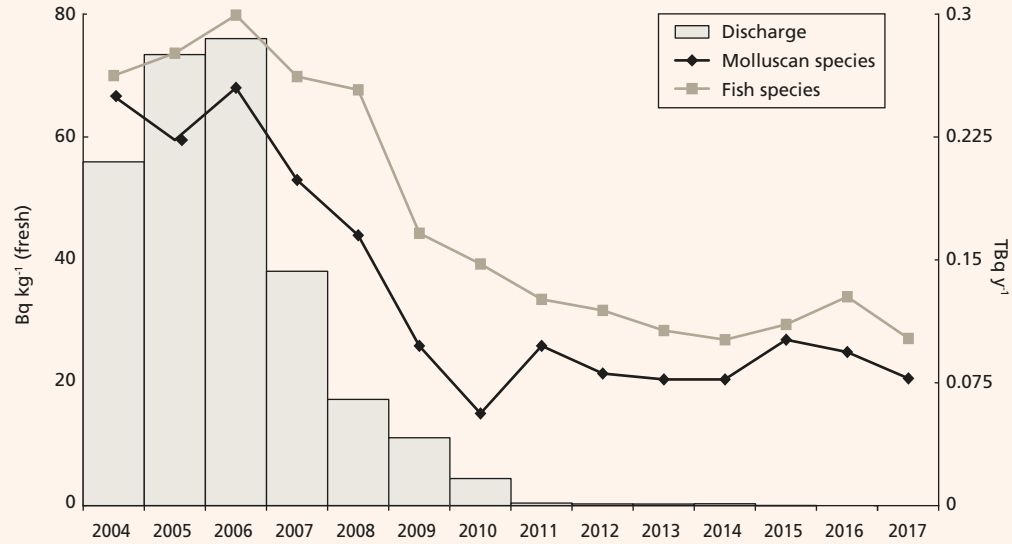



**Figure 6.5.** Carbon-14 liquid discharge from Cardiff and mean concentrations in fish and molluscs near Cardiff, 2004-2017 (species include all those reported in RIFE for the given year)

## Table 6.1 Individual doses - radiochemical sites, 2017

| 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** | **-** | **0.007** | **0.14** |
| Source specific doses | Anglers | <0.005 | <0.005 | - | <0.005 | - | - | - |
| | Infant inhabitants and consumers of locally grown food | 0.011[d] | - | <0.005 | - | - | 0.009 | - |
| | Workers at Maple Lodge STW | <0.005 | - | - | <0.005[c] | <0.005[d] | - | - |
| | | | | | | | | |
| Cardiff | | | | | | | | |
| ***Total dose* - all sources** | **Prenatal children of occupants over sediment** | **<0.005** | **<0.005** | **-** | **<0.005** | **-** | **-** | **-** |
| Source specific doses | Prenatal children of seafood consumers | 0.006 | <0.005 | - | 0.006 | - | - | - |
| | 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 subtracting background and cosmic sources from measured gamma dose rates)*

## Table 6.2(a) Concentrations of radionuclides in food and the environment near Amersham, 2017

| 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 | * | 0.09 | | |
| Sediment | River Colne (Grand Union Canal) | 2[E] | | <2.2 | <3.6 | 170 | 400 |
| Sediment | Upstream of outfall (Grand Union Canal) | 2[E] | | <2.4 | <2.9 | 120 | 290 |
| Freshwater | Downstream of outfall (Grand Union Canal) | 1[E] | <3.7 | <0.18 | <0.19 | <0.11 | 2.9 |
| Freshwater | River Chess | 1[E] | <3.6 | <0.22 | <0.26 | <0.039 | <0.032 |
| Freshwater | River Misbourne - downstream | 1[E] | <3.3 | <0.19 | <0.19 | <0.035 | 0.071 |
| Crude effluent[d] | Maple Lodge Sewage Treatment Works | 2[E] | <10 | 1.5 | <0.24 | <0.073 | 0.71 |
| Digested sludge[e] | Maple Lodge Sewage Treatment Works | 2[E] | <11 | 3.1 | <0.26 | <2.4 | 6.3 |
| Final effluent[f] | Maple Lodge Sewage Treatment Works | 2[E] | <15 | | <0.20 | <0.069 | 0.77 |

| 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 | <3.4 | <0.23 | <0.0063 | <0.0018 | <0.06 | | |
| Potato | | 1 | <2.8 | 0.50 | <0.041 | | <0.07 | | |
| Wheat | | 1 | <4.5 | 1.2 | <0.030 | | <0.05 | | |
| Grass | Orchard next to site | 1[E] | | | | <0.76 | <0.73 | <1.5 | 180 |
| Grass | Water Meadows (River Chess) | 1[E] | | | | <0.63 | <0.58 | <1.5 | 210 |
| Soil | Orchard next to site | 1[E] | | | | <0.43 | 3.5 | 250 | 640 |
| Soil | Water Meadows (River Chess) | 1[E] | | | | <0.49 | 5.9 | 250 | 490 |

* *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 <3.7 Bq l$^{-1}$*

[e] *The concentration of $^{3}$H as tritiated water was <4.3 Bq l$^{-1}$*

[f] *The concentration of $^{3}$H as tritiated water was <3.9 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, 2017

| 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 | 0.066 |
| Downstream of outfall (Grand Union Canal) | Grass | 2 | 0.064 |
| Upstream of outfall (Grand Union Canal) | Grass | 2 | 0.059 |
| Water Meadows (River Chess) | Grass | 1 | 0.060 |
| Orchard next to site | Grass | 1 | 0.077 |

## Table 6.3(a) Concentrations of radionuclides in food and the environment near Cardiff, 2017

| 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 | <25 | <25 | | 26 | <0.16 |
| Lesser spotted dogfish | Off Orchard Ledges | 1 | 99 | 110 | | 27 | 0.30 |
| Limpets | Lavernock Point | 1 | <25 | <25 | | 20 | <0.18 |
| Seaweed | Orchard Ledges | 2[E] | | <13 | | <5.6 | |
| Sediment | East of sewage outfall | 2[E] | | <14 | | <6.8 | |
| Sediment | West of sewage outfall | 2[E] | | <12 | | <4.9 | |
| Seawater | West of sewage outfall | 1[E] | | <14 | <2.7 | <1.7 | |

| 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] | | 2 | <2.7 | <2.7 | | 18 | <0.28 | <0.0049 | <0.06 |
| Milk[f] | max | | | | | 19 | | <0.0053 | <0.07 |
| Potato | | 1 | <2.7 | 2.7 | | 20 | 1.1 | <0.033 | <0.06 |
| Grass | | 1 | <3.4 | 3.4 | | 11 | 2.1 | <0.041 | 0.11 |
| Grass | 0.5km north east of site | 1[E] | | <13 | | <2.2 | | | |
| Grass | 0.5km north west of site | 1[E] | | <15 | | <2.3 | | | |
| Sediment | Glamorgan canal | 2[E] | | <16 | | 5.7 | | | |
| Freshwater | River Taff upstream | 1[E] | | <9.1 | | <1.4 | | | |
| Freshwater | River Taff downstream | 1[E] | | <11 | <2.8 | <2.3 | | | |
| Freshwater | Glamorgan canal | 1[E] | | <9.7 | <2.8 | <1.3 | | | |

[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 <0.18 (max <0.21) 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, 2017

| Location | Ground type | No. of sampling observations | µGy h$^{-1}$ |
|---|---|---|---|
| **Mean gamma dose rates at 1m over substrate** | | | |
| East of Pipeline | Mud | 2 | 0.084 |
| West of Pipeline | Mud and sand | 2 | 0.097 |
| Peterstone Wentlooge | Mud | 1 | 0.088 |
| Peterstone Wentlooge | Salt marsh | 1 | 0.076 |

# 7. Industrial, landfill, legacy and other non-nuclear sites

This section considers the results of monitoring by the Environment Agency, FSA and SEPA for industrial, landfill, legacy and other non-nuclear sites that may have introduced radioactivity into the environment:

(i) the main disposal landfill site for solid radioactive wastes in the UK, at the LLWR near Drigg in Cumbria, as well as a recycling facility and other landfill sites that received small quantities of solid wastes;
(ii) one legacy site near Whitehaven (Cumbria), in England, which used to manufacture phosphoric acid from imported phosphate ore;
(iii) two legacy sites at Dalgety Bay (Fife) and Kinloss (Moray), in Scotland;
(iv) other non-nuclear sites

## Key points

- Doses (dominated by the effects of legacy discharges from other sources) decreased at the LLWR in 2017
- Doses at landfill sites (excluding the LLWR) were less than 0.5 per cent of the dose limit in 2017
- A dose value is reported (for the first time) for direct radiation (Metals Recycling Facility)
- Doses (dominated by the effects of naturally occurring radionuclides from legacy discharges) decreased at Whitehaven in 2017

## 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, 2018).

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 2017, be distinguished from those due to Sellafield.

In 2017, LLWR published guidance on customers accessing the VLLW service (LLWR, 2017). 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).

In 2015, site operators were granted a new permit to allow for continued waste disposal at the site. 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 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 2017/18, 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. 1,810 $m^3$ of waste was received by the site with the intention of disposal in financial year 2017/18, bringing the cumulative total to 249,000 $m^3$. As initiated in 2016, the radiological data, given in Table A2.3, 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 2016. 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 2017 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 in the drain were also below 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 2017 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 2017 (as in 2016). Concentrations of radionuclides were generally similar to (or lower than) those measured near Sellafield (Section 2). The *total dose* from all pathways and sources was 0.25 mSv (values are rounded to two significant figures), or 25 per cent of the dose limit for members of the public of 1 mSv (Table 7.1) and includes a component due to Chernobyl and weapon test fallout. This dose was dominated by the effects of naturally occurring radionuclides and the legacy of discharges into the sea at Sellafield, 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 *total dose* was 0.056 mSv (Table 1.2) in 2017. The representative person was adults living near the site and a change from that in 2016 (adults consuming molluscs). The increase in *total dose* (from 2016) and change in the representative person was due to a higher estimate of direct radiation from the site in 2017. A source specific assessment of exposure for consumers of locally grown terrestrial food gives an exposure that was 0.005 mSv, and similar to recent years.

## 7.2 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.

In 2017, the permit for disposal of radioactive waste from the site was updated to implement the change in company name, from Studsvik UK Limited to Cycliffe UK Limited, following the company's sale to EDF Développement Environnement. 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 2017 (Appendix 2). The permit includes conditions requiring Cyclife UK Limited to monitor discharges and undertake environmental monitoring. In 2017, a value is reported (for the first time) for direct radiation from the site (0.001 mSv, Table 1.1), showing that the radiological impact is very low.

## 7.3 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 2017 are 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

* *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.*

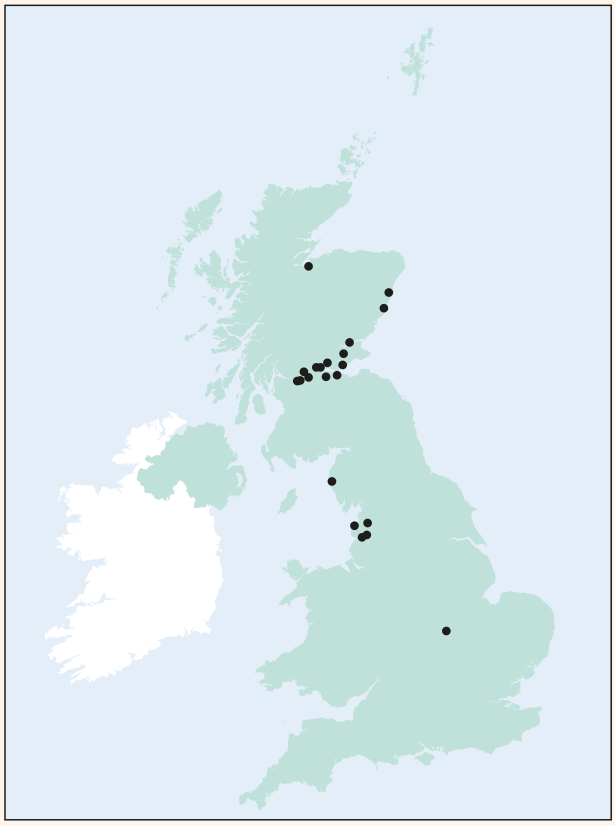


**Figure 7.1.** Landfill sites monitored in 2017

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 2016, allows the disposal of low activity LLW and VLLW. This permit also 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.

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 was 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 2017, samples were taken, filtered and analysed for radiological composition from groundwater boreholes and off-site watercourses. 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 are generally reported as less than values. Naturally occurring radionuclides were present at levels expected due to natural sources. Gross alpha and gross beta concentrations in off-site watercourses 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. Based on inadvertent ingestion of borehole or surface water at concentrations presented in Table 7.5, the dose was estimated to be 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 is homeostatically controlled in the body.

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 the authorisation granted in 2012.

## 7.4 Past phosphate processing, Whitehaven, Cumbria


An important historical man-made source of naturally occurring radionuclides in the marine environment was the chemical plant near Whitehaven in Cumbria, which used to manufacture phosphoric acid (for use in detergents) from imported phosphate ore (Rollo *et al*., 1992). Processing of ore resulted in a liquid waste slurry (phosphogypsum) containing most of the thorium, uranium and radioactive daughter products (including polonium-210 and lead-210) originally present in the ore, and this was discharged by pipeline to Saltom Bay.

The slurry could be regarded as Technologically enhanced Naturally Occurring Radioactive Material (TNORM). The environmental legacy resulting from these past discharges continues to have an impact (close to the former discharge point), through the production of the daughter products (from the decay of the long-lived parent radionuclides, previously discharged to sea). Polonium-210 (and lead-210) are important radionuclides in that small changes in levels above background significantly influence the dose contribution from these radionuclides (due to a relatively high dose coefficient used in converting the activity concentration to a dose value) and therefore the value of the estimated dose. Processing of phosphoric acid at the plant ceased at the end of 2001 and the plant was subsequently decommissioned and demolished. The authorisation to discharge radioactive wastes was revoked by the Environment Agency.

The results of routine monitoring for naturally occurring radioactivity near the site in 2017 are shown in Table 7.6. Analytical effort is 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 small variations in concentrations of polonium-210 in local samples in 2017 compared with 2016. In particular, there were decreases in concentrations in lobsters and mussels. However, polonium-210 concentrations in these samples continued to be within or close to the expected range due to natural sources in 2017. 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. Further 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 2.3 and 7.1). The estimated contribution due to background median concentrations of naturally occurring radionuclides is subtracted from the measured activity concentration. Consumption rates for people who eat at high rates were reviewed and revised in 2017 (Moore *et al.*, 2018a). Revised figures for consumption rates, together with occupancy rates, are provided in Appendix 1 (Table X2.2). 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 0.25 mSv in 2017 (Table 7.1), or 25 per cent of the dose limit to members of the public. The value for 2016 was 0.41 mSv. The dose includes the effects of all sources near the site: technically enhanced naturally occurring radionuclides from the non-nuclear industrial activity (i.e. TNORM) and Sellafield operations. The source specific dose assessment, targeted directly at local consumers of seafood (at high rates), confirms the *total dose* assessment and gives a similar result of 0.27 mSv in 2017 (Table 2.17).

The contribution to the *total dose* from enhanced natural radionuclides was 0.18 mSv, and was lower in 2017, in comparison to that in 2016 (0.34 mSv). The decrease in the *total dose* was mostly attributable to lower concentrations of polonium-210 in locally caught crustaceans (lobsters) in 2017, in comparison to those in 2016. The largest contribution to dose to a seafood consumer near Whitehaven and Sellafield is now from the legacy of historical discharges near Whitehaven. The longer-term trend in *total dose* over the period 2004 – 2017 is shown in Figure 7.4. The overall reduction in *total dose* (with some

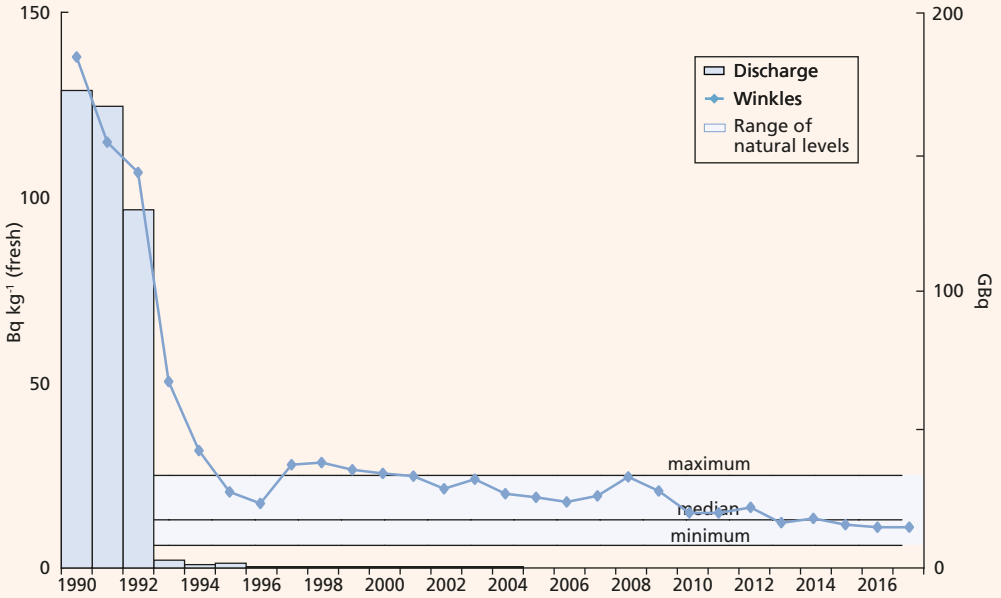



**Figure 7.2.** Polonium-210 discharge from Whitehaven and concentration in winkles at Parton, 1990-2017

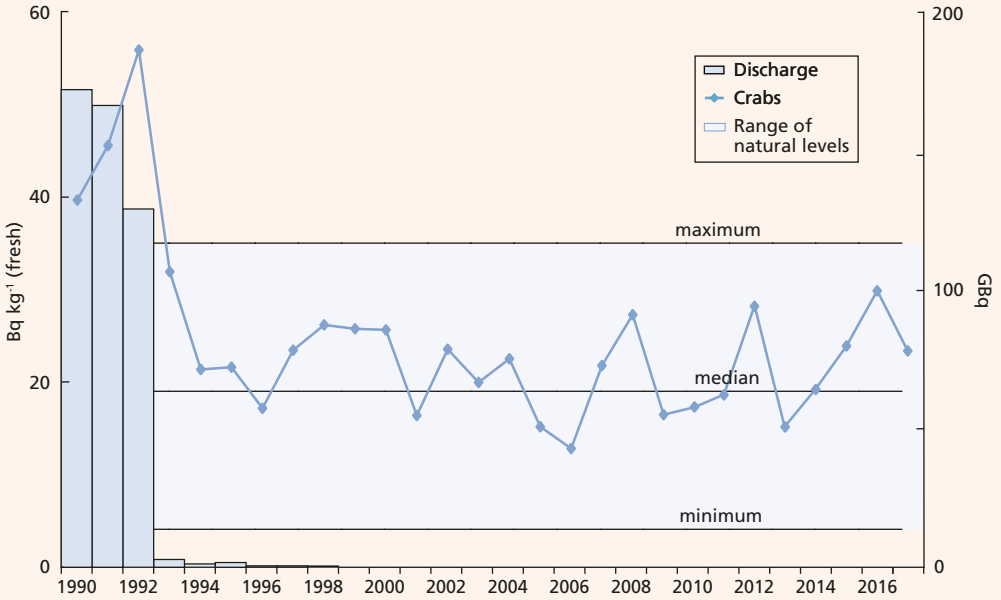



**Figure 7.3.** Polonium-210 discharge from Whitehaven and concentration in crabs at Parton, 1990-2017

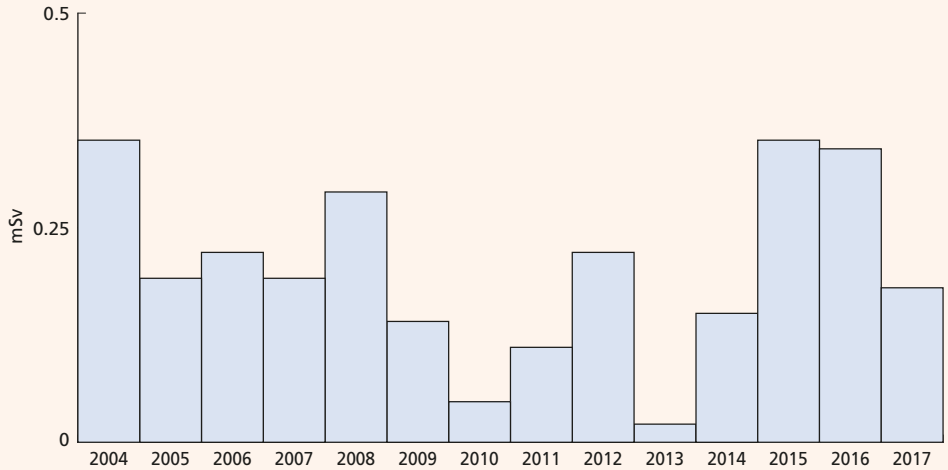



**Figure 7.4.** Trend in *total dose* to seafood consumers from naturally-occurring radionuclides near Whitehaven, 2004-2017

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 – 2017 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 Former military airbase, 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. In March 2017, SEPA issued guidance on monitoring for heterogeneous radium-226 sources resulting from historic luminising or waste disposal sites (SEPA, 2017a).

Following the increased number of particle finds and the discovery of the high activity particles in 2011, additional public protection measures were established. These were maintained during 2017 and into 2018. 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 detected, 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 reported as less than values. 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 (Committee on Medical Aspects of Radiation in the Environment) 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: **https://www.gov.uk/government/groups/committee-on-medical-aspects-of-radiation-in-the-environment-comare**.

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 contamination issue to be addressed. The Environmental Impact Assessment (EIA) in support of the Planning Application for the remediation works was submitted to Fife Council for consideration. In February 2017, the planning application for the remediation works was submitted to Fife Council and approved in October 2017.

Further details on the work at Dalgety Bay can be found on the Radioactive Substances pages on SEPA's website: **https://www.sepa.org.uk/regulations/radioactive-substances/dalgety-bay-updates/**.

## 7.6 Former military airbase, Kinloss Barracks, 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 (SEPA, 2016). 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 (Scottish Executive, 2006; Scottish Government, 2009).

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**).

## 7.7 Other non-nuclear sites

Small quantities of gaseous and liquid radioactive wastes are routinely discharged from a wide range of other non-nuclear sites in the UK on land (including to air from incinerators), 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. 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).

In 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 radiological risk to human health. For this reason, the use (i.e. burning of coal) is not controlled under radioactive substances control legislation. A variety of publications exist relating to the concentrations of radionuclides expected to be present in coal, coal ash and bottom ash. These are available on the IAEA's website (**www.iaea.org/**). Based on information available from the IAEA, and that radioactivity concentrations in coal burned in the UK were believed to be so low (that it did not warrant control under radioactive legislation), SEPA formed the view that the exposure to dust from the ash lagoon would have a negligible effect on human health from the radionuclides within the ash.

Although SEPA considered that the ash could not pose a significant health impact from the radionuclides, SEPA undertook sampling and analysis of ash from the lagoons in order to provide further data to support the international understanding of the range of radionuclides within coal ash. The results of the analyses are given in Table 7.11. As expected, natural radionuclides were detected in the ash samples, but these were detected at very low concentrations and towards the lower activity range reported by the IAEA. These data will be offered to the IAEA to improve the knowledge base for typical ranges of radioactivity concentrations in coal ash.

In order to assess the potential impact of radionuclides to members of the public, information is needed to define and quantify the exposure pathways (e.g. inhalation or ingestion of re-suspended material that could potentially enter the body). Although specific information is not available, the concentrations of natural radionuclides in the ash samples indicate that the external exposure pathway would not be discernible from that of natural background. For internal exposure pathways (e.g. inhalation or ingestion), and assuming maxima radionuclide concentrations in the samples for the most vulnerable age

group, kilograms of dust would be required to be inhaled and/or ingested for an individual to be at any risk of exposure from radioactivity.

In a wider response to the incident, SEPA served Scottish Power with two enforcement notices for the suppression of ash and dust from the lagoons. As also expected, concentrations of non-radioactive elements were measured at low concentrations in ash samples. The public health response was made by NHS Scotland and Health Protection Scotland.

The dust suppression and return of heavier rainfall reduce the resuspension of ash from the lagoons into the local environment. SEPA will continue to work with the operator to ensure the permit conditions are suitable and that the public are protected.

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 2017, 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 7.12. 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 2016. 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.

Scotoil, in Aberdeen City, 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 the marine environment within the limitations and conditions of the authorisation, which includes limits for radium-226, radium-228, lead-210 and polonium-210 discharges. 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.

Monitoring of seaweed (*Fucus vesiculosus*) from Aberdeen Harbour was not carried out in 2017. Results up to 2016 are included in earlier RIFE reports (e.g. Environment Agency, FSA, FSS, NIEA, NRW and SEPA, 2017). In 2017, the dose rate on sediment was 0.082 μGy $h^{-1}$ and similar to background.

## Table 7.1 Individual doses - industrial and landfill sites, 2017

| 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** | **0.25**[d] | **0.061** | **0.18** | **-** | **0.016** | - |
| | | | | | | | |
| **Source specific doses** | | | | | | | |
| LLWR near Drigg | Infant consumers of locally grown food | 0.005 | - | - | 0.005 | - | - |
| | 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 2013-17) | Seafood consumers | 0.27[d] | 0.058 | 0.18 | - | 0.028 | - |

[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 subtracting background and cosmic sources from measured gamma dose rates)*

## Table 7.2 Concentrations of radionuclides in terrestrial food and the environment near Drigg, 2017

| 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 | <4.0 | 18 | <0.05 | 0.031 | <0.13 | <0.12 | <0.024 | <0.48 | <0.13 |
| Deer muscle | | 1 | <3.9 | 28 | <0.05 | <0.048 | <0.07 | <0.04 | <0.16 | <0.33 | <0.10 |
| Eggs | | 1 | <10 | 41 | <0.08 | <0.045 | <0.16 | <0.10 | | <0.59 | <0.18 |
| Potatoes | | 1 | <3.0 | 13 | <0.05 | <0.048 | <0.07 | <0.05 | <0.11 | <0.33 | <0.09 |
| Sheep muscle | | 1 | <6.3 | 29 | <0.06 | <0.039 | <0.08 | <0.05 | <0.085 | <0.46 | <0.13 |
| Sheep offal | | 1 | <5.1 | 27 | <0.05 | 0.028 | <0.04 | <0.04 | <0.12 | <0.30 | <0.09 |
| Grass | | 1 | <3.6 | 17 | <0.10 | 0.39 | <0.14 | <0.12 | <0.085 | <0.45 | <0.16 |
| Sediment | Drigg Stream | 4[E] | | | <0.59 | <2.4 | <1.8 | <0.41 | | <4.5 | <2.3 |
| Freshwater | Drigg Stream | 4[E] | <4.7 | | <0.25 | <0.060 | | | | | |
| Freshwater | Railway drain | 1[E] | <2.9 | | <0.32 | 0.029 | | | | | |

| 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 | <0.0045 | <0.06 | <0.11 | | <0.40 | | | | |
| Deer muscle | | 1 | <0.015 | <0.04 | 2.0 | 2.0 | <0.25 | | | | |
| Eggs | | 1 | <0.026 | <0.10 | <0.08 | <0.084 | <0.38 | | | | |
| Potatoes | | 1 | <0.013 | <0.04 | 0.10 | 0.099 | <0.24 | | | | |
| Sheep muscle | | 1 | <0.028 | <0.05 | 0.86 | 0.86 | <0.37 | | | | |
| Sheep offal | | 1 | <0.018 | <0.05 | 0.16 | 0.16 | <0.34 | | | | |
| Grass | | 1 | <0.027 | <0.09 | 0.14 | 0.14 | <0.46 | | | | |
| Sediment | Drigg Stream | 4[E] | | <0.56 | 81 | | <2.4 | 7.2 | 18 | 11 | 13 |
| Freshwater | Drigg Stream | 4[E] | | <0.26 | <0.21 | | | <0.0034 | <0.0093 | <0.0024 | <0.0017 |
| Freshwater | Railway drain | 1[E] | | <0.33 | <0.26 | | | <0.0042 | <0.0052 | <0.0010 | <0.0014 |

| 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 | | | | <0.000035 | <0.000056 | <0.15 | <0.000044 | | |
| Deer muscle | | 1 | | | | <0.00081 | 0.000055 | <0.23 | 0.000095 | | |
| Eggs | | 1 | | | | 0.00054 | 0.0031 | <0.35 | 0.0054 | | |
| Potatoes | | 1 | | | | <0.00015 | 0.00085 | <0.31 | 0.00065 | | |
| Sheep muscle | | 1 | | | | 0.00051 | 0.0027 | <0.25 | 0.0051 | | |
| Sheep offal | | 1 | | | | 0.0012 | 0.0061 | <0.31 | 0.0084 | | |
| Grass | | 1 | | | | 0.00088 | 0.0050 | <0.25 | 0.011 | | |
| Sediment | Drigg Stream | 4[E] | 23 | <1.5 | 22 | 4.2 | 31 | <100 | 36 | <200 | 590 |
| Freshwater | Drigg Stream | 4[E] | 0.0082 | <0.0014 | 0.0081 | <0.0026 | <0.0016 | <0.31 | <0.0041 | <0.048 | 0.37 |
| Freshwater | Railway drain | 1[E] | 0.0060 | <0.0015 | 0.0042 | <0.0018 | <0.0014 | <0.29 | 0.0080 | 0.061 | 0.62 |

[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, 2017

| 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 | 5.2 | <15 | <0.05 | <0.05 |
| City of Glasgow | Summerston landfill | 1 | 120 | <15 | <0.05 | <0.05 |
| City of Glasgow | Cathkin | 1 | 150 | <15 | <0.05 | <0.05 |
| Clackmannanshire | Black Devon | 1 | 14 | <15 | <0.05 | <0.05 |
| Dunbartonshire | Birdston | 1 | <5.0 | <15 | <0.05 | <0.05 |
| Dundee City | Riverside | 1 | 14 | <15 | <0.05 | <0.05 |
| Edinburgh | Braehead | 1 | <5.0 | <15 | <0.05 | <0.05 |
| Fife | Balbarton | 1 | 39 | <15 | <0.05 | <0.05 |
| Fife | Melville Wood | 1 | <5.0 | <15 | <0.05 | <0.05 |
| Highland | Longman landfill | 1 | <5.0 | <15 | <0.05 | <0.05 |
| North Lanarkshire | Dalmacoulter | 1 | 270 | <15 | <0.05 | <0.05 |
| North Lanarkshire | Kilgarth | 1 | <5.0 | <15 | <0.05 | <0.05 |
| Stirling | Lower Polmaise | 1 | 160 | <15 | 0.08 | <0.05 |

## Table 7.4 Concentrations of radionuclides in water from landfill sites in England and Wales, 2017

| 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 | <3.4 | <5.7 | <0.30 | <0.26 | <0.011 | <0.0026 |
| Clifton Marsh | Borehole 19 | 2 | <4.2 | <5.9 | <0.31 | <0.28 | <0.0064 | <0.0036 |
| Clifton Marsh | Borehole 40 | 2 | <3.9 | <5.6 | <0.29 | <0.24 | <0.0098 | <0.0036 |
| Clifton Marsh | Borehole 59 | 2 | <9.6 | <4.4 | <0.29 | <0.25 | <0.021 | <0.0057 |

| 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 | <0.0017 | 0.16 | 0.0055 | 0.15 | <0.33 | 1.1 |
| Clifton Marsh | Borehole 19 | 2 | <0.0079 | 0.052 | <0.0030 | 0.046 | <1.3 | 6.3 |
| Clifton Marsh | Borehole 40 | 2 | <0.0029 | <0.0028 | <0.0021 | <0.0026 | <0.099 | 1.3 |
| Clifton Marsh | Borehole 59 | 2 | <0.0044 | 0.0087 | <0.00085 | 0.0080 | <0.16 | 1.4 |

## Table 7.5 Concentrations of radionuclides in water near the East Northants Resource Management Facility landfill site, 2017

| Site reference | Mean radioactivity concentration[a], Bq $kg^{-1}$ | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $^{3}H$ | $^{40}K$ | $^{137}Cs$ | $^{226}Ra$ | $^{228}Th$ | $^{230}Th$ | $^{232}Th$ | $^{234}U$ | $^{235}U$ | $^{238}U$ | Gross alpha | Gross beta |
| K13A Groundwater borehole | <2.6 | <4.6 | <0.22 | 0.01 | <0.0054 | <0.0024 | <0.0011 | 0.031 | <0.0013 | 0.033 | <0.23 | 0.25 |
| K15A Groundwater borehole | <2.6 | <4.8 | <0.22 | 0.01 | <0.0050 | <0.0013 | <0.00091 | 0.017 | <0.0017 | 0.014 | <0.13 | 0.090 |
| K17 Northern perimeter Groundwater borehole | <2.5 | <4.7 | <0.22 | 0.01 | <0.0054 | <0.0017 | <0.00044 | 0.022 | <0.0016 | 0.020 | <0.22 | 0.48 |
| Horse Water spring | | <4.7 | <0.22 | | | | | | | | <0.046 | 0.66 |
| Willow brook | | <4.7 | <0.20 | | | | | | | | <0.094 | 0.73 |

[a] *Except for $^{3}H$ where units are Bq $l^{-1}$*

## Table 7.6 Concentrations of naturally occurring radionuclides in the environment, 2017[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 | 1.3 | | | | | | |
| Winkles | Nethertown | 4 | 12 | 1.5 | 0.94 | 0.77 | 0.59 | 0.86 | 0.033 | 0.77 |
| Mussels | Whitehaven | 2 | 39 | 1.4 | | | | | | |
| Mussels | Ravenglass | 2 | 24 | 0.99 | | | | | | |
| Prawns | Seascale | 2 | 4.8 | <0.013 | | | | | | |
| Crabs | Parton | 2 | 23 | 0.14 | | | | | | |
| Crabs | Sellafield coastal area | 2 | 20 | 0.053 | 0.23 | 0.026 | 0.013 | 0.13 | 0.0037 | 0.11 |
| Lobsters | Parton | 2 | 13 | 0.071 | | | | | | |
| Lobsters | Sellafield coastal area | 2 | 11 | 0.070 | | | | | | |
| *Nephrops* | Whitehaven | 2 | 1.2 | 0.11 | 0.063 | 0.035 | 0.023 | 0.031 | 0.0010 | 0.029 |
| Cod | Parton | 2 | 0.56 | 0.023 | | | | | | |
| Cod | Whitehaven | 2 | 0.41 | 0.012 | | | | | | |
| Plaice | Whitehaven | 2 | 1.8 | 0.20 | 0.065 | <0.000074 | 0.00028 | 0.019 | 0.00075 | 0.017 |
| Plaice | Drigg | 2 | 2.4 | 0.20 | 0.064 | 0.0025 | 0.0025 | 0.026 | 0.00083 | 0.024 |
| **Other samples** | | | | | | | | | | |
| Winkles | South Gare (Hartlepool) | 2 | 25 | 1.1 | | | | | | |
| Winkles | Middletons Sands | 2 | 11 | | | | | | | |
| Winkles | Kirkcudbright | 1[S] | 2.9 | | | | | | | |
| Mussels | Morecambe | 2 | 41 | | | | | | | |
| Mussels | Ribble Estuary | 1 | | | 0.20 | 0.19 | 0.12 | | | |
| Limpets | Kirkcudbright | 1[S] | 2.3 | | | | | | | |
| Crabs | Kirkcudbright | 1[S] | 5.2 | | | | | | | |
| Lobsters | Kirkcudbright | 1[S] | 1.8 | | | | | | | |
| Shrimps | Ribble Estuary | 1 | | | 0.018 | 0.0021 | 0.0012 | | | |
| Wildfowl | Ribble Estuary | 1 | | | | 0.0066 | 0.0054 | | | |
| Sediment | Kirkcudbright | 2[S] | | | | | | 10 | 0.46 | 9.5 |

[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, 2017[a]**

| | Discharges during 2017, Bq | | | | | |
|---|---|---|---|---|---|---|
| | Education (Universities and Colleges) | | Hospitals | | Other (Research, manufacturing and public sector) | |
| | England and Wales | Northern Ireland | England and Wales | Northern Ireland | England and Wales | Northern Ireland |
| $^{3}H$ | 1.6E+11 | | | | 2.4E+12 | |
| $^{14}C$ | 4.5E+08 | | | | 2.5E+13 | 2.1E+09 |
| $^{18}F$ | 3.0E+11 | | | | 4.2E+11 | |
| $^{35}S$ | | | 1.8E+08 | | 3.5E+08 | |
| $^{99m}Tc$ | | | 1.8E+08 | | 2.3E+05 | |
| $^{125}I$ | 5.5E+05 | | 4.3E+07 | | 2.6E+08 | |
| $^{129}I$ | | | | | 6.8E+06 | |
| $^{131}I$ | | | 1.7E+08 | | 3.7E+08 | |
| $^{131m}Xe$ | | | 1.2E+05 | | | |
| $^{137}Cs$ | | | | | 5.5E+08 | |
| Uranium Alpha | | | | | 2.0E+00 | |
| Plutonium Alpha | | | | | 3.4E+02 | |
| $^{241}Am$ | | | | | 6.4E+02 | |
| Other Alpha particulate | | | 9.5E+06 | | 4.8E+10 | |
| Other Beta/Gamma | | | | 3.8E+11 | | |
| Other Beta/Gamma Particulate | 8.3E+12 | | 1.2E+08 | | 4.4E+11 | |

[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 2016*

**Table 7.8 Discharges of liquid radioactive waste from non-nuclear establishments in England, Northern Ireland and Wales, 2017[a]**

| | Discharges during 2017, Bq | | | | | | |
|---|---|---|---|---|---|---|---|
| | Education (Universities and Colleges) | | Hospitals | | Other (Research, manufacturing and public sector) | | Oil and gas (off-shore) |
| | England and Wales | Northern Ireland | England and Wales | Northern Ireland | England and Wales | Northern Ireland | United Kingdom |
| $^{3}$H | 7.2E+09 | 3.7E+07 | 6.3E+08 | 1.2E+08 | 3.8E+12 | | |
| $^{14}$C | 5.6E+10 | | 9.3E+05 | | 2.9E+11 | 5.0E+05 | |
| $^{18}$F | 5.8E+11 | | 3.7E+12 | 1.7E+11 | 2.5E+12 | | |
| $^{22}$Na | 4.0E+07 | | | | | | |
| $^{32}$P | 1.7E+10 | 1.5E+06 | 5.2E+09 | 6.1E+08 | 1.7E+09 | | |
| $^{33}$P | 1.4E+08 | | | | 1.1E+09 | | |
| $^{35}$S | 9.4E+09 | | 6.6E+08 | | 4.2E+09 | | |
| $^{51}$Cr | 4.9E+08 | | 4.5E+10 | 6.5E+08 | 1.4E+09 | | |
| $^{67}$Ga | 1.7E+08 | | 6.2E+09 | | | | |
| $^{75}$Se | 2.1E+07 | | 4.1E+09 | 7.4E+07 | 9.0E+07 | | |
| $^{89}$Sr | | | 6.3E+08 | | | | |
| $^{90}$Sr | | | | | 1.1E+01 | | |
| $^{90}$Y | | | 7.4E+11 | 8.8E+08 | 2.0E+09 | | |
| $^{99}$Tc | 4.0E+07 | | | | 8.7E+02 | | |
| $^{99m}$Tc | 5.8E+10 | | 4.8E+13 | 1.6E+12 | 6.0E+11 | | |
| $^{111}$In | 2.4E+09 | | 3.4E+11 | 1.7E+10 | 4.4E+09 | | |
| $^{125}$Sb | 5.0E+04 | | | | | | |
| $^{123}$I | | | 1.1E+12 | 6.5E+10 | 2.2E+10 | | |
| $^{125}$I | 4.1E+09 | 1.3E+08 | 1.4E+09 | 1.1E+07 | 1.4E+10 | | |
| $^{129}$I | 6.1E+03 | | | | 1.0E+00 | | |
| $^{131}$I | | | 2.0E+13 | 3.4E+11 | 2.9E+11 | | |
| $^{134}$Cs | 1.5E+07 | | | | 2.2E+07 | | |
| $^{137}$Cs | 3.1E+07 | | | | 3.2E+09 | | |
| $^{153}$Sm | | | 4.6E+09 | 2.8E+09 | | | |
| $^{201}$Tl | | | 1.6E+10 | | | | |
| $^{230}$Th | | | | | 4.0E+00 | | |
| $^{232}$Th | | | | | 1.7E+10 | | |
| Uranium Alpha | 2.5E+03 | | | | 3.6E+10 | | |
| $^{237}$Np | | | | | 2.0E+00 | | |
| $^{241}$Pu | 8.1E+02 | | | | 1.1E+04 | | |
| Plutonium Alpha | | | | | 3.1E+03 | | |
| $^{241}$Am | 3.8E+06 | | | | 5.7E+03 | | |
| $^{242}$Cm | | | | | 7.0E+00 | | |
| Total Alpha | 9.9E+06 | | 1.3E+11 | 1.1E+09 | 6.8E+10 | | 2.0E+10 |
| Total Beta/Gamma (Excl Tritium) | 6.8E+11 | | 5.6E+13 | | 3.1E+12 | | 1.4E+10 |
| Other Alpha particulate | 6.1E+06 | | 8.5E+09 | | 1.4E+08 | | |
| Other Beta/Gamma[b] | 1.3E+10 | | 3.9E+12 | 1.2E+06 | 9.4E+10 | | |
| Other Beta/Gamma particulate | 9.0E+07 | | | | 1.9E+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 2016*

[b] *Excluding specific radionuclides*

## Table 7.9 Discharges of gaseous radioactive wastes from non-nuclear establishments in Scotland by OSPAR region, 2017[a]

| | Discharges during 2017, 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 | Nil | Nil | Nil | Nil |
| $^{14}C$ | Nil | Nil | Nil | Nil | 4.31E+07 | Nil |
| $^{18}F$ | Nil | Nil | Nil | Nil | 4.87E+10 | Nil |
| Other Alpha | Nil | Nil | 1.85E+02 | Nil | Nil | 4.00E+00 |
| Other Beta/Gamma | 1.52E+11 | Nil | 1.74E+10 | 5.95E+05 | 6.27E+09 | 8.40E+05 |

[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, 2017[a]

| | Discharges during 2017, 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) |
| $^{3}H$ | 1.43E+09 | | 1.29E+09 | | 5.20E+08 | | 1.10E+08 |
| $^{14}C$ | 1.03E+07 | 1.32E+07 | 1.81E+10 | | 7.46E+07 | 2.37E+07 | 1.50E+08 |
| $^{18}F$ | | 1.16E+11 | 4.50E+06 | | | 3.01E+11 | |
| $^{22}Na$ | 5.90E+05 | | | | | | |
| $^{32}P$ | 6.78E+08 | 1.70E+08 | 3.74E+08 | | 4.66E+08 | 5.28E+08 | |
| $^{33}P$ | 3.72E+09 | | 1.29E+10 | | | | |
| $^{35}S$ | 2.82E+09 | | 1.60E+08 | | 2.09E+09 | | |
| $^{51}Cr$ | 6.70E+03 | 1.35E+09 | | | | 2.71E+08 | |
| $^{67}Ga$ | | | | | | 9.00E+07 | |
| $^{75}Se$ | | 6.84E+07 | | | | 1.11E+06 | |
| $^{90}Y$ | | 4.21E+08 | | | | 5.42E+08 | |
| $^{99m}Tc$ | 5.00E+07 | 2.45E+12 | | | | 1.95E+12 | |
| $^{111}In$ | | 9.77E+09 | | | | 3.31E+10 | |
| $^{123}I$ | | 4.13E+10 | | | | 2.86E+10 | |
| $^{125}I$ | 5.60E+05 | 7.00E+06 | 3.13E+07 | | 3.20E+06 | 1.88E+07 | 1.63E+06 |
| $^{131}I$ | 2.76E+09 | 3.97E+11 | | | 4.57E+02 | 2.99E+11 | |
| $^{201}Tl$ | | | | | | 8.86E+09 | |
| $^{210}Pb$ | | | 2.70E+04 | 3.74E+08 | | | |
| $^{210}Po$ | | | 2.70E+04 | 3.74E+08 | | | |
| $^{226}Ra$ | | | 2.40E+04 | 7.47E+08 | | | |
| $^{228}Ra$ | | | 1.70E+04 | 1.06E+09 | | | |
| $^{232}Th$ | | | 1.61E+05 | | | | 1.15E+06 |
| Uranium Alpha | | | | | 1.44E+02 | | |
| Plutonium Alpha | | | | | 3.68E+00 | | |
| Other Alpha | | 4.52E+08 | | | | | 1.10E+05 |
| Other Beta/Gamma[b] | 1.41E+11 | 8.98E+09 | 1.84E+07 | | 3.83E+08 | 8.83E+10 | 2.55E+06 |

[a] *Excludes nuclear power and defence industries. Excludes discharges which are exempt from reporting*
[b] *Excluding specific radionuclides*

## Table 7.11 Concentrations of naturally occuring radionuclides in the environment near Longannet, 2017[a]

| Site reference | Radioactivity concentration, Bq kg$^{-1}$ | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | $^{40}$K | $^{129}$I | $^{210}$Pb | $^{226}$Ra | $^{228}$Ac | $^{228}$Th | $^{230}$Th | $^{235}$U |
| Sample 1[b] | 230 | <1.8 | 47 | 48 | 36 | <6.6 | <27 | 1.8 |
| Sample 1[c] | 380 | 8.2 | 58 | 74 | 59 | 38 | <38 | 2.7 |
| Sample 1[d] | 370 | 7.0 | 54 | 78 | 58 | 61 | <41 | 2.7 |
| Sample 2[b] | 260 | <1.5 | 38 | 50 | 30 | <6.4 | 82 | 1.1 |
| Sample 2[c] | 370 | <1.9 | 49 | 78 | 44 | 45 | <32 | 1.5 |
| Sample 2[d] | 380 | 5.6 | 45 | 81 | 43 | 48 | 96 | 1.5 |
| Sample 3[b] | 310 | 6.9 | 65 | 61 | 43 | <19 | <25 | 3.2 |
| Sample 3[c] | 440 | 6.8 | 87 | 79 | 63 | <17 | 140 | 5.8 |
| Sample 3[d] | 440 | 7.2 | 85 | 87 | 61 | <17 | 120 | 5.2 |

[a] *Results are available for other radionuclides detected by gamma-ray spectrometry, all such results are less than the limit of detection*
[b] *Sample as received*
[c] *Dried Sample*
[d] *Sample in secular equilibrium*

## Table 7.12 Monitoring in the Firth of Forth, River Clyde and near Glasgow, 2017[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 | | 21 | <4.0 | <0.10 | | <0.10 | 0.95 |
| Between Finlaystone and Woodhall | *Fucus vesiculosus* | 1 | | | 1.9 | <0.10 | | <0.10 | 37 |
| Dalmuir Clydebank | Sediment | 1 | | <15 | <7.3 | <0.10 | | <0.10 | |
| Downstream of Dalmuir | Freshwater | 4 | | | <0.18 | <0.10 | | <0.10 | |
| River Clyde | Freshwater | 4 | <1.0 | | | | <0.0050 | | |
| Firth of Forth | Freshwater | 4 | <1.1 | | | | <0.0060 | | |
| Daldowie | Sludge pellets | 4 | | | <37 | <0.10 | | <0.10 | |

| 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 beta |
| Between Finlaystone and Woodhall | Mussels | 1 | <0.26 | 0.10 | 0.24 | <0.23 | <0.14 | |
| Between Finlaystone and Woodhall | *Fucus vesiculosus* | 1 | <0.19 | 3.9 | 0.36 | <0.24 | <0.25 | |
| Dalmuir Clydebank | Sediment | 1 | <0.17 | <0.13 | 4.4 | <0.18 | <0.22 | |
| Downstream of Dalmuir | Freshwater | 4 | <0.12 | <0.10 | <0.10 | <0.16 | <0.14 | |
| River Clyde | Freshwater | 4 | | | <0.01 | | | 0.70 |
| Firth of Forth | Freshwater | 4 | | | <0.01 | | | 0.43 |
| Daldowie | Sludge pellets | 4 | <0.23 | 180 | 2.6 | <0.76 | <0.60 | |

[a] *Results are available for other radionuclides detected by gamma-ray 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 2017:

(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 1 per cent (or less) of the public 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 2017 are given in Table 8.1. There was evidence of routine releases from the nuclear industry in some food and environmental samples (e.g. 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 2017, 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 (e.g. Environment Agency, FSA, NIEA and SEPA, 2013) 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 provides an indication of the far-field effects of current and historical discharges from Sellafield and other UK nuclear sites. These are reported annually: **https://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 given in Tables 8.2(a) and (b).

In 2017, the main effect of discharges from Sellafield was observed in concentrations of technetium-99 in shellfish and seaweed samples. These were similar to values reported in recent years, reflecting the considerably

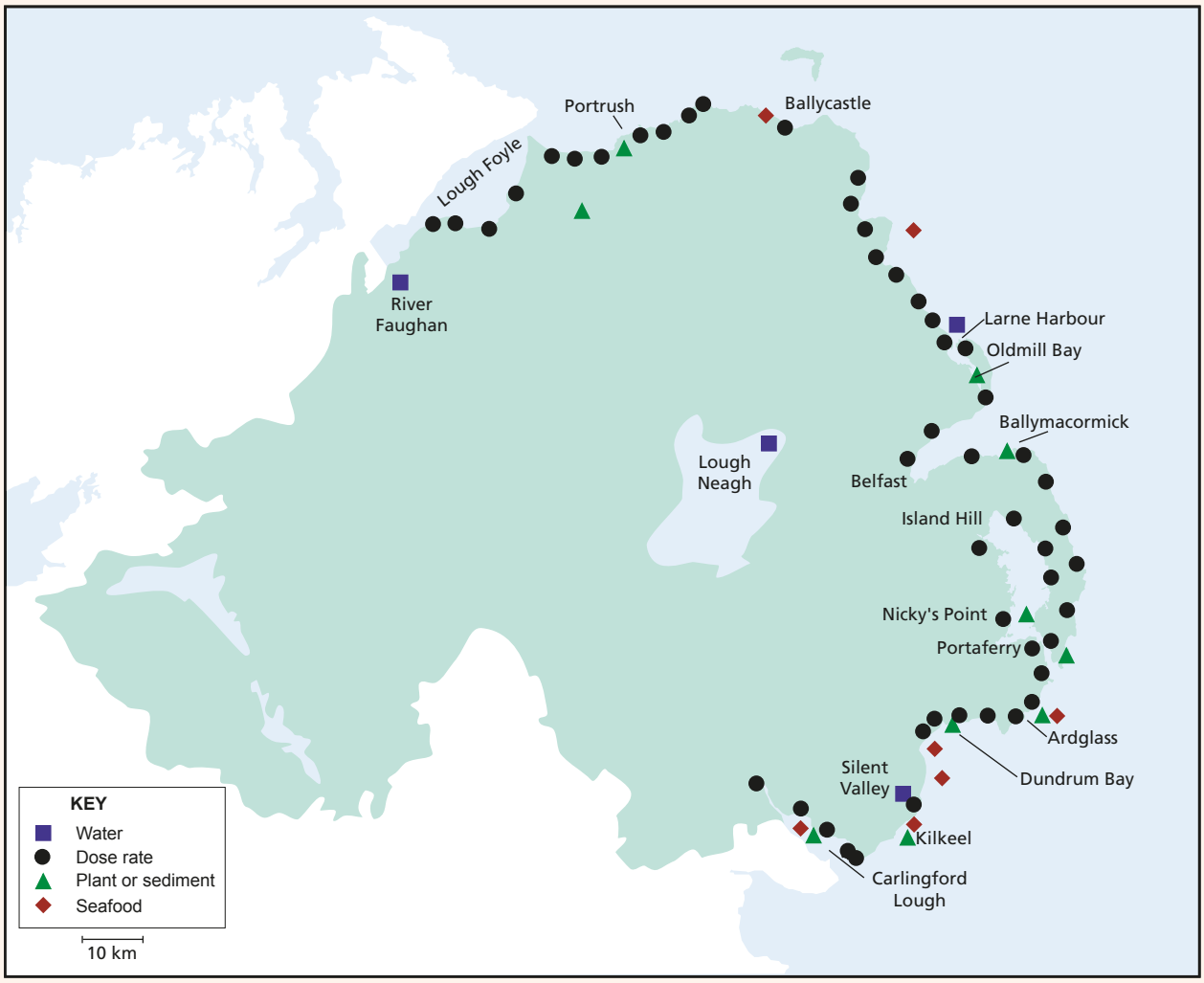



**Figure 8.1.** Monitoring locations in Northern Ireland, 2017

decreased inputs to the Irish Sea (see also Section 2.3.3). Caesium-137 concentrations were low and generally similar to those in 2016. The reported caesium-137 concentration in lobsters (Kilkeel) was higher (by a small amount) in comparison to those in recent years. As expected, trace amounts of transuranic nuclides were also detected in 2017. Reported concentrations are less than those found nearer to Sellafield and continued at the low levels, as 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 2017, the dose from the consumption of seafood and exposure over intertidal areas was 0.010 mSv (Table 2.16), which is 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.

In 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).

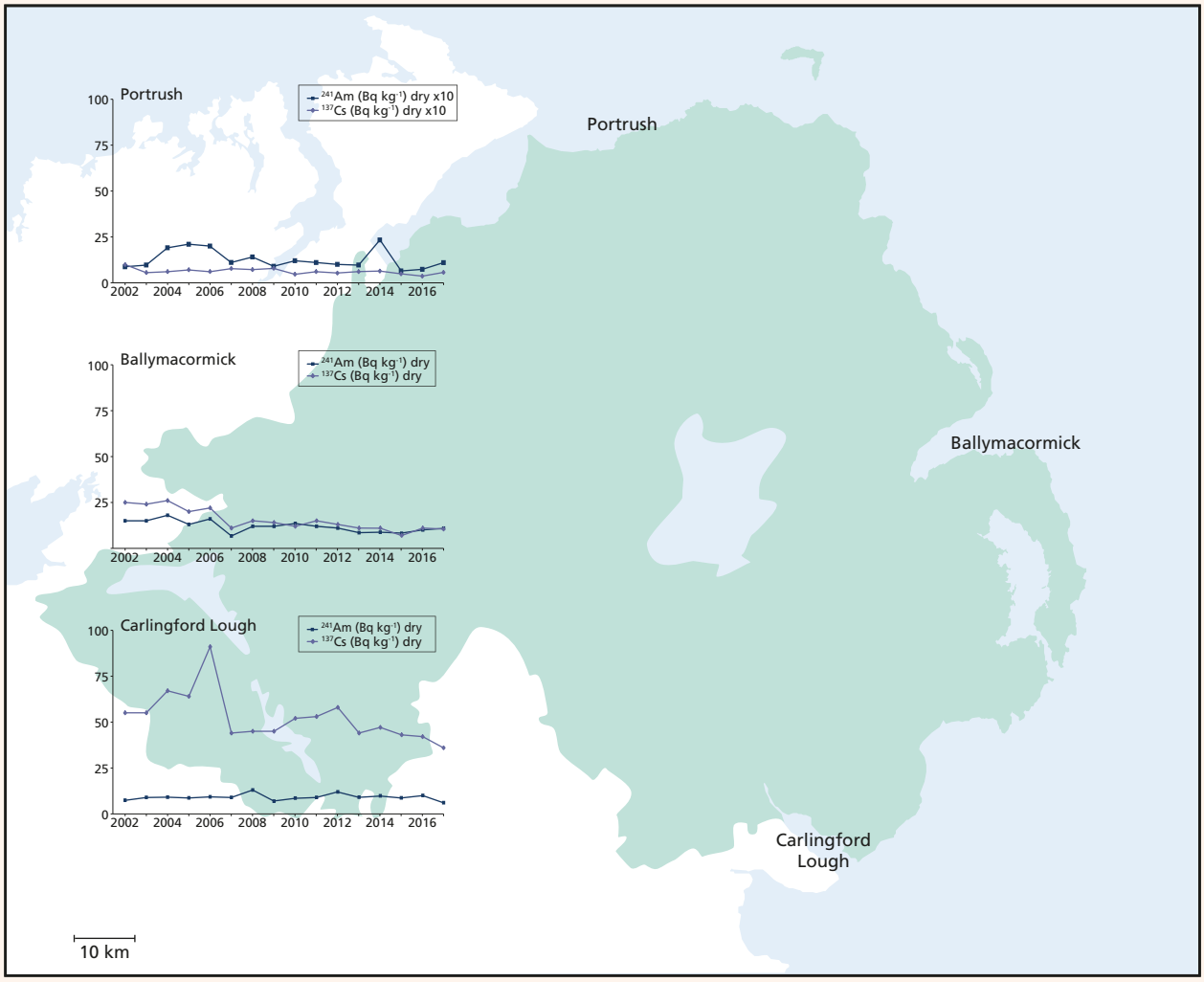



**Figure 8.2.** Concentrations of americium-241 and caesium-137 in coastal sediments in Northern Ireland, 2002-2017

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 through Border Inspection Posts (BIPs) and products of non-animal origin can only enter through Designated Points of Entry (DPE).

The legislation was 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 to 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: **https://www.food.gov.uk/business-guidance/importing-high-risk-foods**.

A percentage of Japanese imports into the EU are monitored in the UK and this work continued in 2017. Monitoring is carried out by local Port Health Authorities (or Local Authorities in Scotland). 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 2017, 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 2017, the concentrations found in a survey of radioactivity in canteen meals collected across the UK, and mixed diets in Scotland, were very low or typical of natural sources (Table 8.3). Activity concentrations were generally similar, in comparison to those in previous years.

## 8.6 Milk

The programme of milk sampling across dairies in the UK continued in 2017. The 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 results (where comparisons can be made) were similar to those in previous years. The mean carbon-14 concentrations in England, Northern Ireland and Scotland were close to the expected background concentration in milk (see Appendix 1, Annex 4). Alternatively, the mean carbon-14 concentration in Wales was enhanced above the expected background for milk. The maximum concentrations of carbon-14 in milk for England, Northern Ireland, Wales and Scotland were 24 Bq $l^{-1}$, 17 Bq $l^{-1}$, 25 Bq $l^{-1}$ and < 16 Bq $l^{-1}$, respectively. As in previous years, tritium concentrations were reported as less than values at all remote sites. In 2017, strontium-90 concentrations were also reported as less than values. The mean concentration of strontium-90 detected in the UK was < 0.036 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 2017, infants (1 year-old) was the most exposed age group. 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. Tritium and caesium-137 concentrations in air and rainwater are reported as less than values in 2017. Caesium-137 concentrations in air, as in 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). 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 2017 (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 are given in Tables 8.6, 8.7 and 8.8. Tritium concentrations were all substantially below the investigation level for drinking water of 100 Bq $l^{-1}$ in the European Directive 2013/51 and most are reported as less than values. The highest tritium concentration was found at Gullielands Burn, which is near to the Chapelcross nuclear licensed site. Concentrations of gross alpha and gross beta were 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 0.008 mSv in 2017 (Table 8.9). The highest annual dose was estimated to be 0.015 mSv for drinking water from Silent Valley, County Down. 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, SEPA took a series of groundwater samples from across Scotland in 2017, 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.

## 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

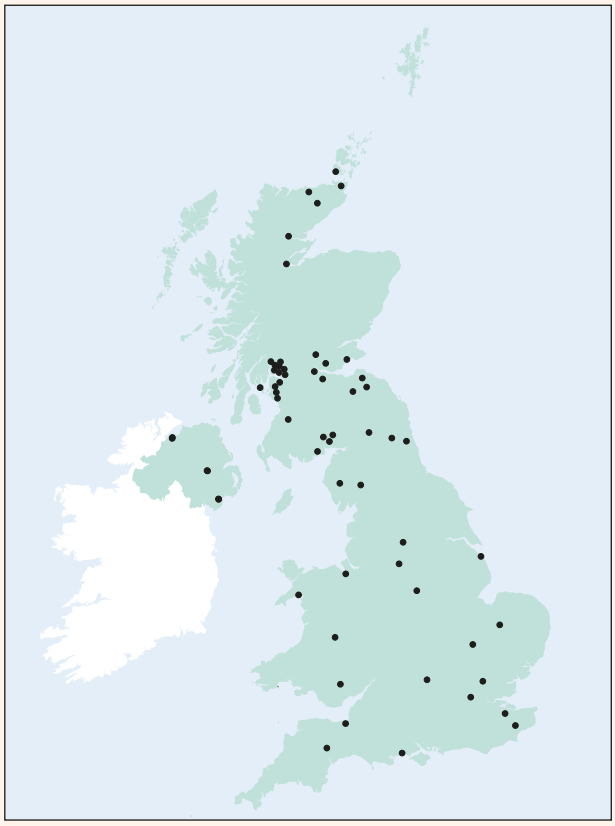


**Figure 8.3.** Drinking water sampling locations, 2017

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 (e.g., Kershaw and Baxter, 1995) and to derive dispersion factors for nuclear licensed sites (e.g., 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 2017 are given in Figures 8.4 – 8.8.

A seawater survey of the Irish Sea was carried out in 2017 (Figure 8.4). As in previous surveys, a band of slightly higher concentrations of caesium-137 was observed along the coast to the north and south of Sellafield, with levels generally decreasing with distance from the coast. The

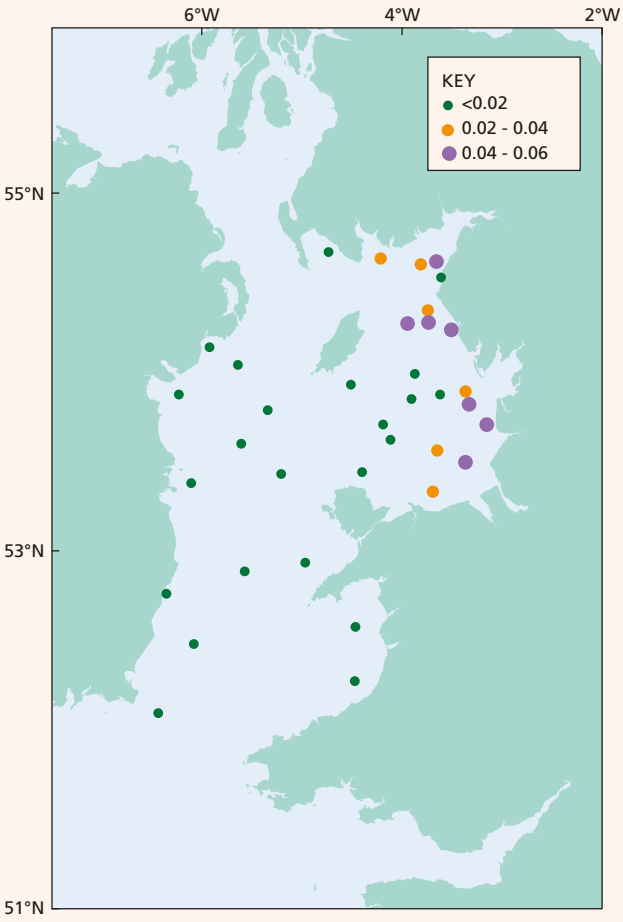



**Figure 8.4.** Concentrations (Bq $l^{-1}$) of caesium-137 in filtered surface water from the Irish Sea, August–September 2017

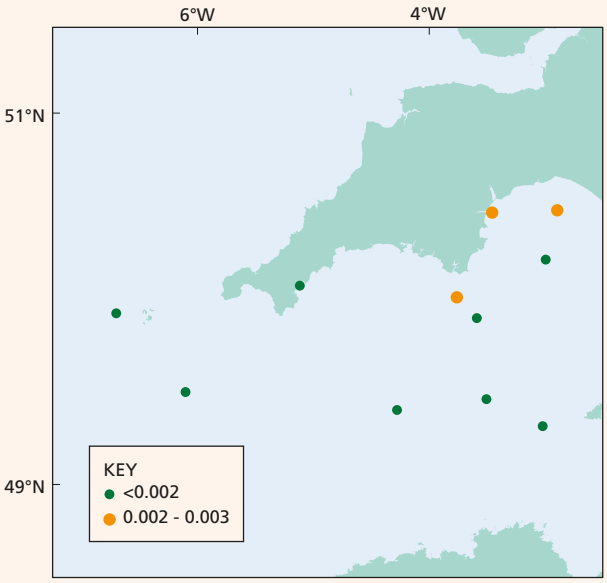



**Figure 8.5.** Concentrations (Bq $l^{-1}$) of caesium-137 in filtered surface water from the English Channel, February-March 2017

2017 survey recorded concentrations of up to 0.06 Bq $l^{-1}$ in the eastern Irish Sea (0.06 Bq $l^{-1}$ in 2015). Elsewhere, caesium-137 concentrations were uniform, and reported as less than values (0.02 Bq $l^{-1}$), for the remainder of the Irish Sea. Overall, concentrations were similar to those reported in the previous Irish Sea survey in 2015 (Environment Agency, FSA, FSS, NIEA, NRW and SEPA, 2016). Caesium-137 concentrations in the Irish Sea were only a very 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 predominant source of caesium-137 to the Irish Sea is now considered to be remobilisation into the water column from activity associated with seabed sediment. This was re-confirmed in a recent study (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.

In 2016, very low concentrations of caesium-137 (up to 0.006 Bq $l^{-1}$) were found throughout most of the North Sea survey area (Environment Agency, FSA, FSS, NIEA, NRW and SEPA, 2017). 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). 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).

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 2017. Activity concentrations near the Channel Islands were similar in 2017 (compared to those in 2016), and lower than the 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 Irish Sea seawater in 2017 are shown in Figure 8.6. As expected, these are higher (by small amounts) than those observed in the North Sea in 2016 (Environment Agency, FSA, FSS, NIEA, NRW and SEPA, 2017) due to the influence of discharges from Sellafield and other nuclear licensed sites. Tritium concentrations to the south and west of the Isle of Man, including along the coastline of Ireland, were as mostly reported as below (or close to) a less than value.

In the Bristol Channel, the combined effect of historical tritium discharges from Cardiff, and those from Berkeley, Oldbury and Hinkley Point, is shown in Figure 8.7. Fewer water samples were collected (in comparison to those in previous years) due to prevailing poor weather conditions

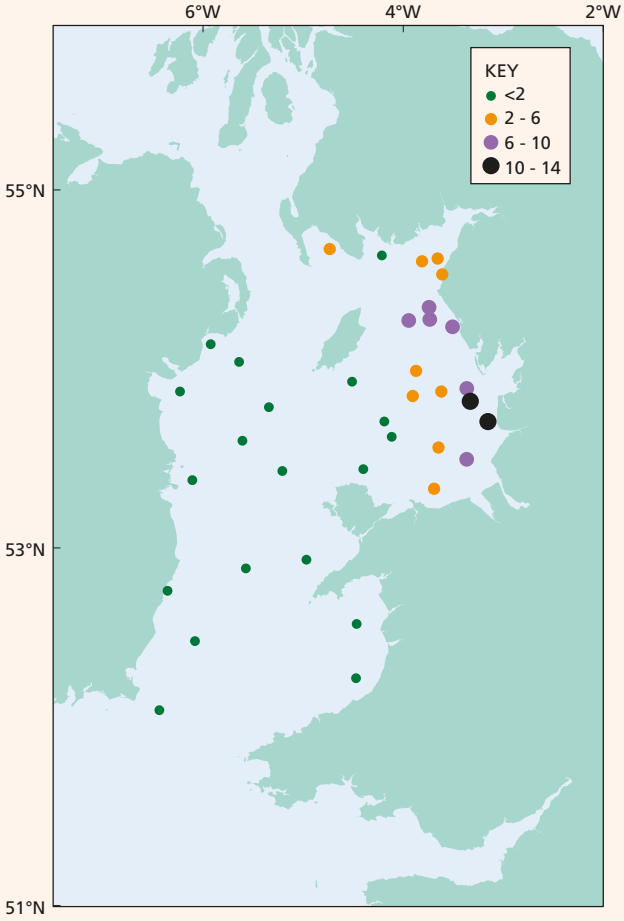



**Figure 8.6.** Concentrations (Bq $l^{-1}$) of tritium in surface water from the Irish Sea, August–September 2017

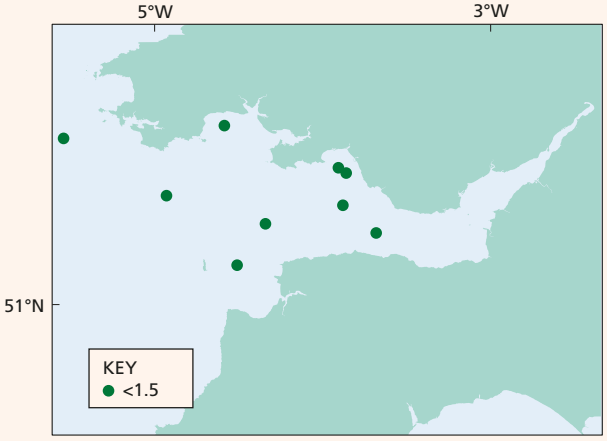



**Figure 8.7.** Concentrations (Bq $l^{-1}$) of tritium in surface water from the Bristol Channel, September 2017

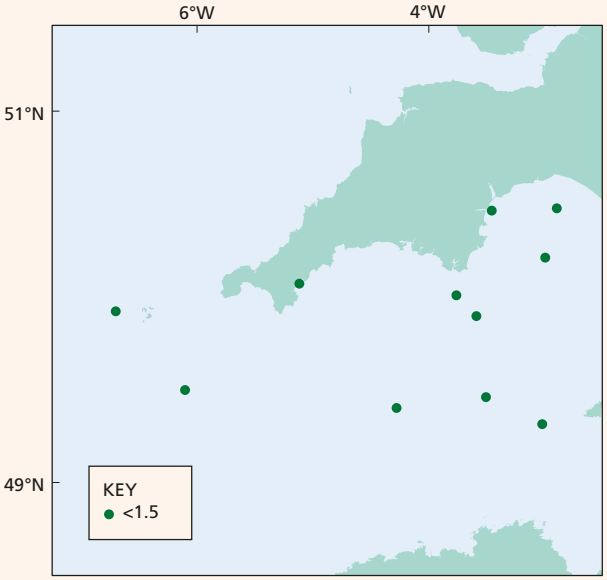



**Figure 8.8.** Concentrations (Bq $l^{-1}$) of tritium in surface water from the English Channel, February–March 2017

during the seawater survey in 2017. From the available samples, the tritium concentrations in the Bristol Channel were very low (reported as less than values) in 2017. Overall (and where comparisons can be made), tritium concentrations were lower in comparison to those reported in 2016. There is no evidence of tritium entering the Irish Sea from the combined effect of discharges from Cardiff, Berkeley, Oldbury and Hinkley Point. Tritium concentrations in the western English Channel were all reported as below the less than value (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 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.

SEPA took a series of marine sediment and seawater samples from across Scotland, in 2016. All radionuclides were reported as less than values in seawater (or close to the less than value). Results and further information for this background survey is available in RIFE 22 (Environment Agency, FSA, FSS, NIEA, NRW and SEPA, 2017).

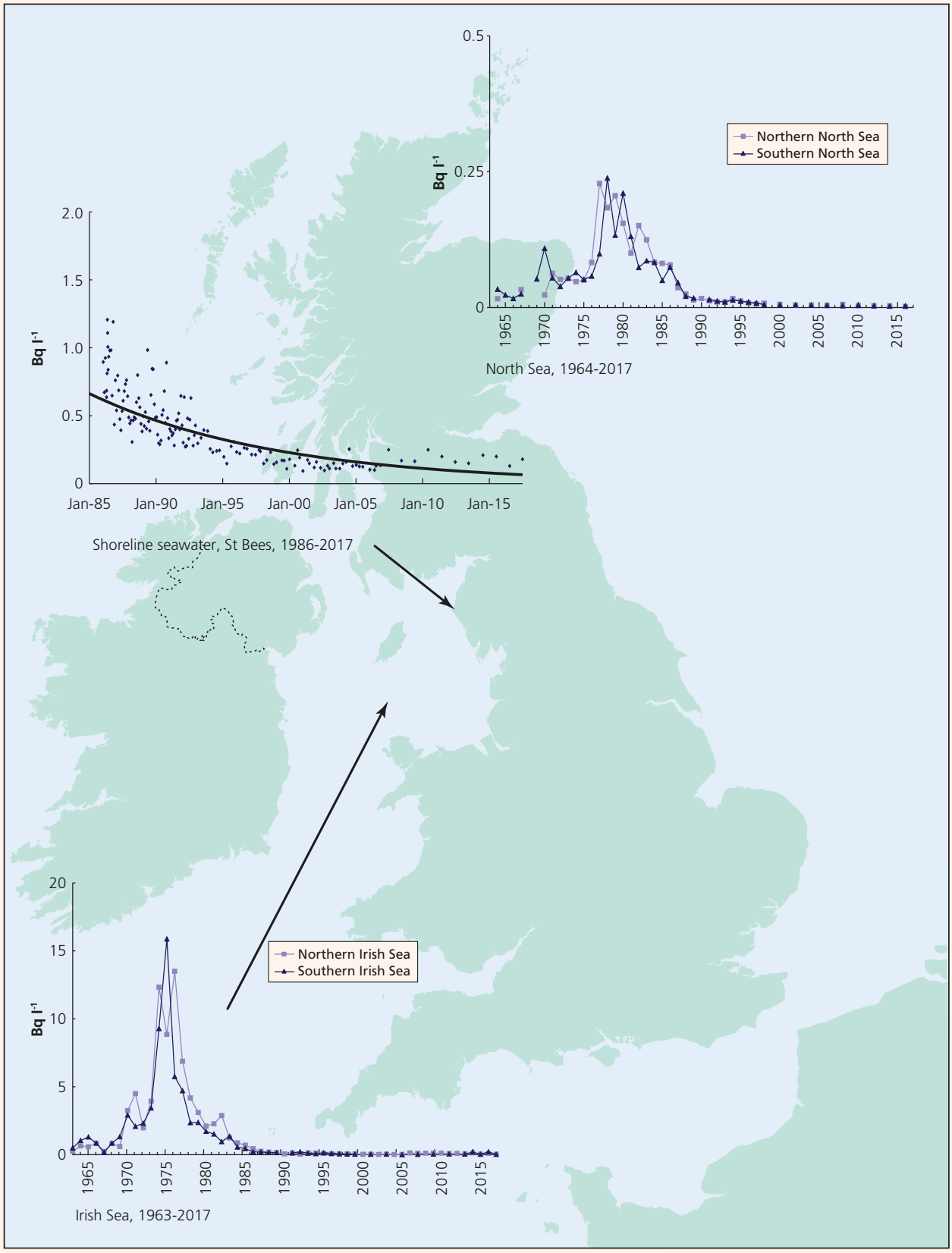



**Figure 8.9.** Concentration of caesium-137 in the Irish Sea, North Sea and in shoreline seawater close to Sellafield at St. Bees
(Note different scales used for activity concentrations)

**Table 8.1 Concentrations of radionuclides in seafood and the environment near the Channel Islands, 2017**

| 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** | | | | | | | | | | |
| | Mackerel | 1 | | | | <0.10 | | | <0.75 | <0.10 |
| | Bass | 1 | | | | <0.08 | | | <0.56 | 0.22 |
| | Crabs | 1 | | | | <0.07 | | | <0.55 | <0.06 |
| | Lobsters | 1 | | | | <0.07 | | | <0.52 | <0.06 |
| | Limpets | 1 | | | | <0.12 | | | <0.97 | <0.10 |
| | Pacific Oysters | 1 | | | | <0.12 | | | <1.0 | <0.11 |
| | Scallops | 1 | | | | <0.05 | | | <0.39 | <0.04 |
| St. Sampson's Harbour | Sand | 1 | | | | <0.20 | | | <1.8 | 0.57 |
| | Seawater | 4 | | | | | | | | 0.002 |
| **Jersey** | | | | | | | | | | |
| | Crabs | 1 | | | | <0.08 | | | <0.66 | <0.08 |
| | Spiny spider crabs | 1 | | | | <0.09 | | | <0.69 | <0.07 |
| | Lobsters | 1 | | | | <0.13 | | 0.30 | <1.1 | <0.12 |
| La Rocque | Oysters | 1 | | | | <0.03 | | | <0.28 | <0.03 |
| Plemont Bay | *Porphyra* | 2 | | | | <0.07 | | | <0.53 | <0.05 |
| La Rozel | *Fucus vesiculosus* | 4 | | | | <0.06 | <0.047 | 2.2 | <0.46 | <0.05 |
| Gorey | *Ascophyllum nodosum* | 4 | | | | <0.06 | | | <0.44 | <0.05 |
| **Alderney** | | | | | | | | | | |
| | Crabs | 2 | <25 | <25 | 40 | <0.07 | | <0.26 | <0.62 | <0.07 |
| | Spiny spider crabs | 1 | | | | <0.11 | | | <0.81 | <0.08 |
| | Lobsters | 1 | | | | <0.06 | | | <0.53 | <0.06 |
| | Toothed winkles | 1 | <25 | <25 | 30 | <0.15 | 0.28 | | <1.2 | <0.13 |
| | *Fucus vesiculosus*[b] | 2 | | | | | | | | |
| Quenard Point | *Fucus serratus* | 4 | | | | <0.09 | <0.028 | 0.89 | <0.67 | <0.07 |
| Quenard Point | *Laminaria digitata* | 4 | | | | <0.08 | | | <0.67 | <0.07 |
| Little Crabbe Harbour | Sand | 1 | | | | <0.14 | | | <1.4 | 1.5 |
| | Seawater | 4 | | <4.4 | | | | | | 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** | | | | | | | | | |
| | Mackerel | 1 | <0.22 | <0.000048 | 0.000035 | 0.000052 | * | * | 120 |
| | Bass | 1 | <0.12 | <0.000063 | 0.000053 | 0.00019 | * | * | 130 |
| | Crabs | 1 | <0.15 | 0.00029 | 0.0010 | 0.0021 | * | 0.00017 | 100 |
| | Lobsters | 1 | <0.11 | | | <0.07 | | | 100 |
| | Limpets | 1 | <0.16 | | | <0.09 | | | 65 |
| | Pacific Oysters | 1 | <0.26 | | | <0.23 | | | 40 |
| | Scallops | 1 | <0.08 | 0.00068 | 0.0024 | 0.00078 | * | 0.000057 | 68 |
| St. Sampson's Harbour | Sand | 1 | <0.72 | 0.020 | 0.084 | 0.087 | * | 0.0045 | 660 |
| **Jersey** | | | | | | | | | |
| | Crabs | 1 | <0.14 | 0.00050 | 0.0021 | 0.0024 | * | 0.00015 | 110 |
| | Spiny spider crabs | 1 | <0.14 | | | <0.08 | | | 110 |
| | Lobsters | 1 | <0.18 | 0.00045 | 0.0015 | 0.016 | * | 0.0011 | 63 |
| La Rocque | Oysters | 1 | <0.06 | 0.0015 | 0.0048 | 0.0058 | * | 0.00044 | 120 |
| Plemont Bay | *Porphyra* | 2 | <0.12 | | | <0.11 | | | 130 |
| La Rozel | *Fucus vesiculosus* | 4 | <0.14 | 0.0062 | 0.020 | 0.0053 | * | 0.00041 | 270 |
| Gorey | *Ascophyllum nodosum* | 4 | <0.12 | | | <0.11 | | | 220 |
| **Alderney** | | | | | | | | | |
| | Crabs | 2 | <0.15 | 0.00035 | 0.00090 | 0.0031 | 0.000047 | 0.00031 | 130 |
| | Spiny spider crabs | 1 | <0.14 | 0.0014 | 0.0039 | 0.0036 | * | 0.00035 | 130 |
| | Lobsters | 1 | <0.16 | 0.00019 | 0.00056 | 0.0054 | * | 0.00061 | 100 |
| | Toothed winkles | 1 | <0.22 | 0.0084 | 0.028 | 0.047 | * | 0.0037 | 56 |
| | *Fucus vesiculosus*[b] | 2 | | | | | | | |
| Quenard Point | *Fucus serratus* | 4 | <0.15 | 0.0031 | 0.010 | 0.0045 | 0.000047 | 0.00047 | 180 |
| Quenard Point | *Laminaria digitata* | 4 | <0.14 | | | <0.08 | | | 240 |
| Little Crabbe Harbour | Sand | 1 | <0.50 | | | 0.65 | | | 650 |

* *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 1.3 Bq kg$^{-1}$*

**Table 8.2(a) Concentrations of radionuclides in seafood and the environment in Northern Ireland, 2017[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 | 25 | <0.07 | | <0.14 | <0.07 | 0.98 |
| Plaice | Kilkeel | 4 | | <0.05 | | <0.13 | <0.06 | 0.40 |
| Haddock | Kilkeel | 4 | | <0.08 | | <0.16 | <0.08 | 0.35 |
| Herring | Ardglass | 2 | | <0.09 | | <0.25 | <0.10 | 0.62 |
| Lesser spotted dogfish | North coast | 4 | | <0.16 | | <0.39 | <0.16 | 0.79 |
| Skates / rays | Kilkeel | 4 | | <0.17 | | <0.36 | <0.18 | 0.67 |
| Crabs | Kilkeel | 4 | | <0.07 | | <0.16 | <0.07 | 0.15 |
| Lobsters | Ballycastle | 2 | | <0.13 | 6.7 | <0.30 | <0.13 | 0.18 |
| Lobsters | Kilkeel | 4 | | <0.13 | 9.6 | <0.22 | <0.12 | 4.9 |
| *Nephrops* | Kilkeel | 4 | | <0.08 | 3.4 | <0.19 | <0.09 | 0.39 |
| Winkles | Minerstown | 4 | | <0.07 | | <0.17 | <0.08 | 0.16 |
| Mussels | Carlingford Lough | 2 | | <0.11 | 1.4 | <0.25 | <0.10 | 0.28 |
| Scallops | Co. Down | 2 | | <0.07 | | <0.11 | <0.06 | 0.18 |
| *Ascophyllum nodosum* | Carlingford Lough | 1 | | <0.05 | | <0.13 | <0.06 | 0.20 |
| *Fucus* spp. | Carlingford Lough | 3 | | <0.05 | 50 | <0.14 | <0.07 | 0.19 |
| *Fucus* spp. | Portrush | 4 | | <0.07 | | <0.12 | <0.06 | <0.06 |
| *Fucus vesiculosus* | Ardglass | 4 | | <0.07 | 26 | <0.13 | <0.08 | 0.57 |
| *Rhodymenia* spp. | Portaferry | 1 | | <0.04 | 0.25 | <0.15 | <0.08 | 0.61 |
| Mixed *Rhodymenia spp./ Pseudopalamata* & *Palmaria palmata* | Portaferry | 3 | | <0.05 | 0.49 | <0.10 | <0.05 | 0.59 |
| Mud | Carlingford Lough | 2 | | <0.32 | | <1.1 | <0.46 | 36 |
| Sandy mud | Ballymacormick | 1 | | <0.35 | | <0.87 | <0.44 | 11 |
| Mud | Ballymacormick | 1 | | <0.12 | | <0.89 | <0.40 | 10 |
| Mud | Dundrum Bay | 2 | | <0.34 | | <1.1 | <0.54 | 28 |
| Mud | Strangford Lough - (Nicky's Point) | 2 | | <0.24 | | <0.72 | <0.41 | 15 |
| Mud | Oldmill Bay | 2 | | <0.54 | | <1.3 | <0.68 | 39 |
| Sand | Portrush | 2 | | <0.25 | | <0.71 | <0.34 | 0.56 |
| Sandy mud | Carrichue | 1 | | <0.24 | | <0.74 | <0.34 | 1.6 |
| Mud | Carrichue | 1 | | <0.38 | | <0.88 | <0.35 | 1.4 |
| Seawater | North of Larne | 12 | | | 0.0013 | | * | 0.0069 |

**Table 8.2(a) continued**

| Material | Location | No. of sampling observations | 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 | <0.14 | | | <0.15 | | |
| Plaice | Kilkeel | 4 | <0.11 | | | <0.08 | | |
| Haddock | Kilkeel | 4 | <0.14 | | | <0.09 | | |
| Herring | Ardglass | 2 | <0.25 | | | <0.27 | | |
| Lesser spotted dogfish | North coast | 4 | <0.27 | | | <0.13 | | |
| Skates / rays | Kilkeel | 4 | <0.29 | | | <0.26 | | |
| Crabs | Kilkeel | 4 | <0.12 | | | <0.13 | | |
| Lobsters | Ballycastle | 2 | <0.25 | | | <0.29 | | |
| Lobsters | Kilkeel | 4 | <0.18 | | | <0.17 | | |
| *Nephrops* | Kilkeel | 4 | <0.18 | 0.0017 | 0.012 | 0.028 | * | * |
| Winkles | Minerstown | 4 | <0.16 | 0.026 | 0.17 | 0.12 | * | * |
| Mussels | Carlingford Lough | 2 | <0.16 | | | <0.11 | | |
| Scallops | Co. Down | 2 | <0.11 | | | <0.10 | | |
| *Ascophyllum nodosum* | Carlingford Lough | 1 | <0.14 | | | <0.15 | | |
| *Fucus* spp. | Carlingford Lough | 3 | <0.17 | | | <0.10 | | |
| *Fucus* spp. | Portrush | 4 | <0.11 | | | <0.10 | | |
| *Fucus vesiculosus* | Ardglass | 4 | <0.17 | | | 0.35 | | |
| *Rhodymenia* spp. | Portaferry | 1 | <0.13 | 0.088 | 0.51 | 0.96 | * | * |
| Mixed *Rhodymenia spp./ Pseudopalamata* & *Palmaria palmata* | Portaferry | 3 | <0.09 | | | 1.0 | | |
| Mud | Carlingford Lough | 2 | <1.2 | 1.8 | 12 | 9.0 | * | * |
| Sandy mud | Ballymacormick | 1 | <0.83 | | | 11 | | |
| Mud | Ballymacormick | 1 | <1.0 | | | 11 | | |
| Mud | Dundrum Bay | 2 | <1.1 | | | 9.1 | | |
| Mud | Strangford Lough - (Nicky's Point) | 2 | <0.96 | | | 5.7 | | |
| Mud | Oldmill Bay | 2 | <1.1 | | | 8.9 | | |
| Sand | Portrush | 2 | <0.73 | | | <1.1 | | |
| Sandy mud | Carrichue | 1 | <0.95 | | | 2.7 | | |
| Mud | Carrichue | 1 | <0.95 | 0.18 | 0.89 | 1.5 | * | * |

* *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, 2017[a]**

| Location | Ground type | No. of sampling observations | Mean gamma dose rate in air at 1m, μGy $h^{-1}$ |
|---|---|---|---|
| Lisahally | Mud | 1 | 0.062 |
| Donnybrewer | Shingle | 1 | 0.053 |
| Carrichue | Mud | 1 | 0.056 |
| Bellerena | Mud | 1 | 0.058 |
| Benone | Sand | 1 | 0.056 |
| Castlerock | Sand | 1 | 0.052 |
| Portstewart | Sand | 1 | 0.057 |
| Portrush, Blue Pool | Sand | 1 | 0.059 |
| Portrush, White Rocks | Sand | 1 | 0.057 |
| Portballintrae | Sand | 1 | 0.058 |
| Giant's Causeway | Sand | 1 | 0.058 |
| Ballycastle | Sand | 1 | 0.054 |
| Cushendun | Sand | 1 | 0.058 |
| Cushendall | Sand and stones | 1 | 0.062 |
| Red Bay | Sand | 1 | 0.064 |
| Carnlough | Sand | 1 | 0.055 |
| Glenarm | Sand | 1 | 0.056 |
| Half Way House | Sand | 1 | 0.055 |
| Ballygally | Sand | 1 | 0.060 |
| Drains Bay | Sand | 1 | 0.057 |
| Larne | Sand | 1 | 0.058 |
| Whitehead | Sand | 1 | 0.059 |
| Carrickfergus | Sand | 1 | 0.060 |
| Jordanstown | Sand | 1 | 0.061 |
| Helen's Bay | Sand | 1 | 0.064 |
| Groomsport | Sand | 1 | 0.067 |
| Millisle | Sand | 1 | 0.066 |
| Ballywalter | Sand | 1 | 0.062 |
| Ballyhalbert | Sand | 1 | 0.063 |
| Cloghy | Sand | 1 | 0.072 |
| Portaferry | Shingle and stones | 1 | 0.082 |
| Kircubbin | Sand | 1 | 0.077 |
| Greyabbey | Sand | 1 | 0.076 |
| Ards Maltings | Mud | 1 | 0.072 |
| Island Hill | Mud | 1 | 0.072 |
| Nicky's Point | Mud | 1 | 0.077 |
| Strangford | Shingle and stones | 1 | 0.097 |
| Kilclief | Sand | 1 | 0.071 |
| Ardglass | Mud | 1 | 0.081 |
| Killough | Mud | 1 | 0.084 |
| Ringmore Point | Sand | 1 | 0.074 |
| Tyrella | Sand | 1 | 0.075 |
| Dundrum | Sand | 1 | 0.096 |
| Newcastle | Sand | 1 | 0.102 |
| Annalong | Sand | 1 | 0.11 |
| Cranfield Bay | Sand | 1 | 0.084 |
| Mill Bay | Sand | 1 | 0.11 |
| Greencastle | Sand | 1 | 0.079 |
| Rostrevor | Sand | 1 | 0.11 |
| Narrow Water | Mud | 1 | 0.089 |

[a] *All measurements are made on behalf of the Northern Ireland Environment Agency*

## Table 8.3 Concentrations of radionuclides in diet, 2017[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 | | 110 | <0.037 | <0.06 |
| Northern Ireland | 5 | | 100 | <0.026 | <0.06 |
| Scotland | 12 | 39 | 110 | 0.026 | <0.02 |
| Wales | 5 | | 90 | <0.021 | <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 | | 71 | <0.10 | <0.05 |
| **East Lothian** North Berwick | 4 | | 84 | <0.10 | <0.05 |
| **Renfrewshire** Paisley | 4 | | 78 | <0.10 | <0.05 |
| **Ross-shire** Dingwall | 4 | | 85 | <0.10 | <0.06 |

[a] *Results are available for other artificial nuclides detected by gamma-ray spectrometry All such results were less than the limit of detection*

## Table 8.4 Concentrations of radionuclides in milk remote from nuclear sites, 2017

| 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 | | 17 | <0.023 | <0.07 |
| Co. Armagh | | 1 | | | <0.027 | <0.05 |
| Ceredigion | | 1 | | | <0.027 | <0.05 |
| Cheshire | | 1 | | 24 | <0.023 | <0.05 |
| Clwyd | | 1 | | 25 | <0.022 | <0.05 |
| Cornwall | | 1 | | 12 | <0.025 | <0.05 |
| Devon | | 1 | | 13 | <0.024 | <0.04 |
| Dorset | | 1 | | 11 | <0.027 | <0.05 |
| Co. Down | | 1 | | | <0.024 | <0.04 |
| Dumfriesshire | | 1 | <5.0 | <15 | <0.10 | <0.05 |
| Co. Fermanagh | | 1 | | | <0.025 | <0.05 |
| Gloucestershire | | 1 | | 11 | <0.026 | <0.05 |
| Gwynedd | | 1 | | 16 | <0.025 | <0.05 |
| Hampshire | | 1 | | 14 | <0.025 | <0.05 |
| Humberside | | 1 | | 22 | <0.029 | <0.05 |
| Kent | | 1 | | 18 | <0.023 | <0.05 |
| Lanarkshire | | 1 | <5.0 | <15 | <0.017 | <0.02 |
| Lancashire | | 1 | | 18 | <0.024 | <0.05 |
| Leicestershire | | 1 | | 17 | <0.024 | <0.05 |
| Middlesex | | 1 | | 18 | <0.034 | <0.04 |
| Midlothian | | 1 | <5.0 | <16 | <0.10 | <0.06 |
| Nairnshire | | 1 | <5.0 | <15 | <0.10 | <0.05 |
| Norfolk | | 1 | | 15 | <0.025 | <0.04 |
| North Yorkshire | | 1 | | 17 | <0.023 | <0.05 |
| Renfrewshire | | 1 | <5.0 | <15 | <0.10 | <0.05 |
| Suffolk | | 1 | | 9.4 | <0.024 | <0.04 |
| Co. Tyrone | | 2 | | 15 | <0.024 | <0.05 |
| | max | | | | | |
| | | | | | | |
| **Mean Values** | | | | | | |
| England | | | | 16 | <0.025 | <0.05 |
| Northern Ireland | | | | 16 | <0.025 | <0.05 |
| Wales | | | | 21 | <0.025 | <0.05 |
| Scotland | | | <5.0 | <15 | <0.083 | <0.05 |
| United Kingdom | | | <5.0 | <16 | <0.036 | <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, 2017

| Location | Sample | Number 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 | 1.8 | | | <0.0074 | |
| | Air | 4 | | 0.0031 | | | $<6.1\ 10^{-7}$ | |
| **Co. Down** | | | | | | | | |
| Conlig | Rainwater | 4 | | 1.2 | | | <0.011 | |
| | Air | 4 | | 0.0039 | | | $<5.3\ 10^{-7}$ | |
| **Dumfries and Galloway** | | | | | | | | |
| Eskdalemuir | Rainwater | 12 | <1.0 | 1.1 | | <0.0052 | <0.010 | |
| | Air | 12 | | 0.0014 | | | $<1.0\ 10^{-5}$ | |
| **City of Edinburgh** | | | | | | | | |
| Edinburgh Silvan | Air | 5 | | 0.0015 | | | $<1.0\ 10^{-5}$ | |
| **North Lanarkshire** | | | | | | | | |
| Holytown | Rainwater | 12 | <1.0 | <0.34 | | <0.013 | <0.011 | |
| | Air | 12 | | 0.0011 | | | $<1.0\ 10^{-5}$ | |
| **North Yorkshire** | | | | | | | | |
| Dishforth/Leeming | Rainwater | 4 | | 1.6 | | | <0.015 | |
| | Air | 4 | | 0.0026 | | | $<7.5\ 10^{-7}$ | |
| **Oxfordshire** | | | | | | | | |
| Chilton | Rainwater | 4 | | 0.95 | 1.4 | <0.00056[b] | <0.016 | <0.00043 |
| | Air | 12 | | | 0.00031 | | | $<2.3\ 10^{-7}$ |
| **Shetland** | | | | | | | | |
| Lerwick | Rainwater | 12 | <1.0 | 1.7 | | <0.0053 | <0.010 | |
| | Air | 12 | | 0.0015 | | | $<1.0\ 10^{-5}$ | |
| **Suffolk** | | | | | | | | |
| Orfordness | Rainwater | 4 | <1.3 | 1.7 | | | <0.017 | |
| | Air | 4 | | 0.0041 | | | $<6.7\ 10^{-7}$ | |

| Location | Sample | Number 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 | $<2.4\ 10^{-6}$ | $8.2\ 10^{-6}$ | $<9.0\ 10^{-6}$ | | |
| | Air | 4 | $<2.3\ 10^{-9}$ | $2.5\ 10^{-9}$ | $2.0\ 10^{-9}$ | | |
| **Dumfries and Galloway** | | | | | | | |
| Eskdalemuir | Air | 12 | | | | | <0.00020 |
| **City of Edinburgh** | | | | | | | |
| Edinburgh Silvan | Air | 5 | | | | | <0.00020 |
| **North Lanarkshire** | | | | | | | |
| Holytown | Air | 12 | | | | | <0.00020 |
| **Oxfordshire** | | | | | | | |
| Chilton | Rainwater | 4 | | | | 0.034[d] | 0.28[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, 2017**

| 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 | <0.010 | 0.025 |
| Argyll and Bute | Auchengaich | 1 | <1.1 | | <0.01 | <0.010 | 0.023 |
| Argyll and Bute | Helensburgh Reservoir | 1 | <1.1 | | <0.01 | <0.010 | 0.028 |
| Argyll and Bute | Loch Ascog | 1 | <1.0 | | <0.01 | <0.010 | 0.11 |
| Argyll and Bute | Loch Eck | 1 | <1.0 | | <0.01 | <0.010 | 0.046 |
| Argyll and Bute | Lochan Ghlas Laoigh | 1 | <1.0 | | <0.01 | <0.010 | 0.048 |
| Argyll and Bute | Loch Finlas | 1 | <1.1 | | <0.01 | <0.010 | 0.027 |
| Clackmannanshire | Gartmorn Dam | 1 | <1.0 | | <0.01 | <0.010 | 0.11 |
| Dumfries and Galloway | Black Esk | 1 | <1.1 | | <0.01 | <0.010 | 0.017 |
| Dumfries and Galloway | Gullielands Burn | 1 | 9.4 | | <0.01 | 0.012 | 0.20 |
| Dumfries and Galloway | Purdomstone | 1 | <1.1 | | <0.01 | <0.010 | 0.062 |
| Dumfries and Galloway | Winterhope | 1 | <1.1 | | <0.01 | <0.010 | 0.056 |
| East Lothian | Hopes Reservoir | 1 | <1.0 | | <0.01 | <0.010 | 0.042 |
| East Lothian | Thorters Reservoir | 1 | <1.0 | | <0.01 | <0.010 | 0.052 |
| East Lothian | Whiteadder | 1 | <1.0 | | <0.01 | <0.010 | 0.050 |
| East Lothian | Thornton Loch Burn | 1 | <1.0 | | <0.01 | <0.010 | 0.093 |
| Fife | Holl Reservoir | 1 | <1.1 | | <0.01 | <0.010 | 0.037 |
| Highland | Loch Baligill | 1 | <1.0 | | 0.01 | 0.021 | 0.071 |
| Highland | Loch Calder | 1 | <1.0 | | <0.01 | 0.014 | 0.048 |
| Highland | Loch Glass | 4 | <1.1 | <0.0050 | <0.01 | <0.011 | 0.038 |
| Highland | Loch Shurrerey | 1 | <1.0 | | <0.01 | 0.010 | 0.050 |
| North Ayrshire | Camphill | 1 | <1.0 | | <0.01 | <0.010 | 0.12 |
| North Ayrshire | Knockendon Reservoir | 1 | <1.0 | | <0.01 | <0.010 | 0.023 |
| North Ayrshire | Munnoch Reservoir | 1 | <1.0 | | <0.01 | <0.010 | 0.039 |
| North Ayrshire | Outerwards | 1 | <1.0 | | <0.01 | <0.010 | 0.013 |
| Orkney Islands | Heldale Water | 1 | <1.0 | | <0.01 | <0.010 | 0.081 |
| Perth and Kinross | Castlehill Reservoir | 1 | <1.0 | | <0.01 | <0.010 | 0.025 |
| Scottish Borders | Knowesdean | 4 | <1.0 | <0.0050 | <0.01 | <0.010 | 0.029 |
| Stirling | Loch Katrine | 12 | <1.0 | <0.0021 | <0.001 | <0.0083 | 0.025 |
| West Dunbartonshire | Loch Lomond (Ross Priory) | 1 | <1.0 | | <0.01 | <0.010 | 0.028 |
| West Lothian | Morton No 2 Reservoir | 1 | <1.0 | | <0.01 | <0.010 | 0.046 |

## Table 8.7 Concentrations of radionuclides in sources of drinking water in England and Wales, 2017

| 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 | 0.34 | 0.0027 | | <0.0010 | 0.025 | 0.48 | 0.32 |
| Cheshire | River Dee, Chester | 1 | <4.0 | <0.050 | <0.0073 | | <0.0015 | | | |
| Cornwall | River Fowey | 4 | <4.0 | <0.039 | <0.0015 | <0.0026 | <0.0010 | 0.026 | 0.089 | 0.060 |
| County Durham | Honey Hill Water Treatment Works, Consett | 4 | <4.0 | <0.034 | 0.0042 | | <0.0015 | 0.069 | 0.16 | 0.11 |
| County Durham | River Tees, Darlington | 4 | <4.0 | <0.034 | 0.0033 | <0.0025 | <0.0010 | <0.020 | 0.062 | <0.050 |
| Cumbria | Ennerdale Lake | 4 | <4.0 | <0.013 | 0.0029 | | <0.0010 | <0.019 | <0.053 | <0.050 |
| Cumbria | Haweswater Reservoir | 4 | <4.0 | <0.018 | <0.0017 | | <0.0010 | <0.020 | <0.050 | <0.050 |
| Derbyshire | Arnfield Water Treatment Plant | 4 | <4.0 | <0.026 | <0.0017 | | <0.0010 | <0.020 | <0.048 | <0.050 |
| Derbyshire | Matlock, Groundwater[a] | 4 | <4.0 | <0.018 | <0.0018 | | <0.0010 | 0.087 | 0.10 | 0.068 |
| Devon | River Exe, Exeter | 3 | <4.0 | 0.083 | <0.0017 | <0.0058 | <0.0013 | <0.019 | 0.12 | 0.075 |
| Devon | Roadford Reservoir, Broadwoodwidger | 4 | <4.0 | 0.083 | 0.0032 | | <0.0010 | <0.020 | 0.087 | 0.058 |
| Greater London | River Lee, Chingford | 4 | <4.0 | 0.37 | <0.0019 | <0.0029 | <0.0010 | <0.023 | 0.45 | 0.29 |
| Hampshire | River Avon, Christchurch | 4 | <4.0 | 0.098 | <0.0011 | <0.0027 | <0.0010 | <0.020 | 0.12 | 0.078 |
| Humberside | Littlecoates, Groundwater | 4 | <4.0 | 0.095 | <0.0010 | | <0.0011 | <0.024 | 0.13 | 0.082 |
| Kent | Chatham, Deep Groundwater | 1 | <4.0 | <0.020 | <0.0010 | | <0.0010 | 0.021 | 0.067 | 0.043 |
| Kent | Denge, Shallow Groundwater | 4 | <4.0 | 0.12 | 0.0040 | | <0.0010 | <0.020 | 0.15 | 0.10 |
| Lancashire | Corn Close, Groundwater | 2 | <4.0 | <0.065 | <0.0010 | | <0.0012 | <0.021 | 0.096 | 0.064 |
| Norfolk | River Drove, Stoke Ferry | 4 | <4.0 | 0.098 | <0.0017 | <0.0034 | <0.0010 | <0.027 | 0.16 | 0.10 |
| Northumberland | Kielder Reservoir | 4 | <4.0 | <0.023 | 0.0033 | | <0.0011 | 0.018 | <0.049 | <0.050 |
| Oxfordshire | River Thames, Oxford | 4 | <4.0 | 0.17 | <0.0013 | <0.0029 | <0.0010 | <0.025 | 0.24 | 0.16 |
| Somerset | Ashford Reservoir, Bridgwater | 4 | <4.0 | <0.076 | <0.0015 | | <0.0012 | 0.022 | 0.12 | 0.075 |
| Somerset | Chew Valley Lake Reservoir, Bristol | 4 | <4.0 | 0.13 | <0.0028 | | <0.0010 | 0.026 | 0.17 | 0.11 |
| Surrey | River Thames, Walton | 4 | <4.0 | 0.23 | <0.0015 | <0.0031 | <0.0010 | <0.021 | 0.32 | 0.22 |
| **Wales** | | | | | | | | | | |
| Gwynedd | Cwm Ystradllyn Treatment Works | 4 | <4.0 | <0.014 | <0.0033 | | <0.0010 | <0.020 | <0.050 | <0.050 |
| Mid-Glamorgan | Llwyn-on Reservoir | 4 | <4.0 | <0.011 | <0.0019 | | <0.0010 | <0.025 | <0.050 | <0.050 |
| Powys | Elan Valley Reservoir | 4 | <4.0 | <0.014 | 0.0030 | | <0.0010 | <0.019 | <0.050 | <0.050 |

[1] *Using $^{137}Cs$ standard*
[2] *Using $^{40}K$ standard*
[a] *The concentrations of $^{234}U$, $^{235}U$ and $^{238}U$ were <0.040, <0.0010 and <0.022 Bq $kg^{-1}$ respectively*

## Table 8.8 Concentrations of radionuclides in sources of drinking water in Northern Ireland, 2017

| 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 | 0.0042 | <0.015 | 0.0030 | <0.01 | 0.0040 | <0.00030 | 0.0030 | <0.020 | <0.050 |
| Co. Antrim | Lough Neagh | 4 | <1.3 | <0.0050 | <0.015 | 0.0010 | <0.01 | 0.0060 | <0.00020 | 0.0030 | <0.020 | <0.050 |
| Co. Down | Silent Valley | 4 | <1.3 | 0.0027 | <0.016 | 0.0050 | <0.01 | 0.011 | 0.0010 | 0.0070 | 0.020 | <0.050 |

## Table 8.9 Doses from radionuclides in drinking water, 2017[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 | <0.001 | 0.002 | 0.002 | Matlock, Groundwater, Derbyshire | 0.002 |
| Wales[d] | <0.001 | | | Cwm Ystradllyn Treatment Works, Gwynedd | <0.001[d] |
| Northern Ireland | <0.001 | 0.010 | 0.010 | Silent Valley, Co. Down | 0.015 |
| Scotland[d] | <0.001 | | | Gullielands Burn, Dumfries and Galloway | <0.001[d] |
| UK | <0.001 | 0.008 | 0.008 | Silent Valley, Co. Down | 0.015 |

[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, 2017

| 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 | <1.0 | <0.10 | 0.10 | <0.10 |
| West Lothian | Livingston | 1 | <1.0 | <0.10 | 0.10 | 0.42 |
| Fife | St Andrews | 1 | <1.0 | <0.10 | 0.10 | 0.26 |
| Fife | Falkland | 1 | <1.0 | <0.10 | 0.10 | <0.10 |
| Angus | Arbroath | 1 | <1.0 | <0.10 | 0.10 | 0.11 |
| Angus | Montrose | 1 | <1.0 | <0.10 | 0.10 | <0.10 |
| Angus | Brechin | 1 | <1.0 | <0.10 | 0.10 | <0.10 |
| Angus | Forfar | 1 | <1.0 | <0.10 | 0.10 | 0.13 |
| Aberdeenshire | Huntly | 1 | <1.0 | <0.10 | 0.10 | <0.10 |
| Aberdeenshire | Mintlaw | 1 | <1.0 | <0.10 | 0.10 | 0.12 |
| Aberdeenshire | Delgaty | 1 | <1.0 | <0.10 | 0.10 | <0.10 |
| Highland | Cromarty | 1 | <1.0 | <0.10 | 0.10 | <0.10 |
| Highland | Annat | 1 | <1.0 | <0.10 | 0.10 | <0.10 |
| Ayr | Girvan | 1 | <1.0 | <0.10 | 0.10 | <0.10 |
| Dumfries & Galloway | Stranraer | 1 | <1.0 | <0.10 | 0.10 | 0.12 |
| Dumfries & Galloway | Dumfries | 1 | <1.0 | <0.10 | 0.10 | <0.10 |
| Dumfries & Galloway | Annan | 1 | <1.0 | <0.10 | 0.10 | <0.10 |

## Table 8.11 Concentrations of radionuclides in seawater, 2017

| 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] | <1.1 | | <0.10 | | | <0.33 | <0.10 | |
| Dounreay (Brims Ness) | 2[S] | <1.1 | | <0.10 | | | <0.29 | <0.10 | |
| Rosyth | 2[S] | <1.1 | | <0.10 | | | <0.30 | <0.10 | |
| Torness[a] | 2[S] | 2600 | | <0.10 | | | <0.29 | <0.10 | |
| Hartlepool (North Gare)[b] | 2 | <5.2 | | <0.26 | | | <2.2 | <0.38 | |
| Sizewell | 2 | <5.2 | <5.3 | <0.29 | | | <2.2 | <0.37 | |
| Bradwell (Beach pipeline) | 2 | <3.8 | | <0.30 | | | <2.3 | <0.41 | |
| Bradwell (Marina) | 2 | | | <0.24 | | | <2.1 | <0.34 | |
| Bradwell (Steeple) | 2 | | | <0.30 | | | <2.5 | <0.40 | |
| Bradwell (Maylandsea Bay) | 2 | | | <0.34 | | | <2.6 | <0.45 | |
| Bradwell (Blackwater) | 2 | | | <0.33 | | | <2.5 | <0.40 | |
| Bradwell (Osea Causeway) | 2 | | | <0.28 | | | <2.1 | <0.37 | |
| Bradwell (Maldon) | 2 | <3.7 | | <0.35 | | | <2.5 | <0.43 | |
| Bradwell (Heybridge) | 2 | | | <0.32 | | | <2.4 | <0.40 | |
| Bradwell (Strood Channel) | 2 | <4.0 | | <0.33 | | | <2.4 | <0.42 | |
| Bradwell (Tollesbury boatyard) | 2 | | | <0.28 | | | <2.2 | <0.37 | |
| Bradwell (Tollesbury saltwater pool) | 2 | | | <0.32 | | | <2.3 | <0.42 | |
| Bradwell (Pyefleet) | 2 | <3.9 | | <0.26 | | | <2.3 | <0.36 | |
| Bradwell (Rowhedge) | 2 | | | <0.28 | | | <2.3 | <0.40 | |
| Bradwell (Alresford Creek) | 2 | | | <0.29 | | | <2.4 | <0.39 | |
| Bradwell (Brightlingsea Bateman's Tower) | 2 | | | <0.27 | | | <2.4 | <0.40 | |
| Bradwell (Brightlingsea saltwater pool) | 2 | | | <0.29 | | | <2.3 | <0.39 | |
| Bradwell (St Osyth) | 2 | | | <0.31 | | | <2.6 | <0.44 | |
| Dungeness south | 2 | <3.7 | | <0.30 | | | <2.4 | <0.41 | |
| Winfrith (Lulworth Cove) | 1 | | | <0.32 | | | <2.2 | <0.39 | |
| Alderney | 4[F] | <4.4 | | | | | | | |
| Guernsey | 4[F] | | | | | | | | |
| Devonport (Millbrook Lake) | 1 | <3.9 | <1.7 | <0.29 | | | | | |
| Devonport (Tor Point South) | 1 | <3.9 | <2.1 | <0.29 | | | | | |
| Hinkley | 1 | <6.2 | | <0.25 | <0.016 | | <2.2 | <0.35 | |
| Berkeley and Oldbury | 2 | <3.3 | | <0.28 | | | <2.1 | <0.35 | |
| Cardiff (West of sewage outfall)[c] | 1 | <2.7 | <1.7 | | | | | | |
| Wylfa (Cemaes Bay) | 2 | <4.3 | | <0.24 | | | <2.0 | <0.31 | |
| Seascale (Particulate)[d] | 2 | | | <0.03 | <0.0099 | | <0.20 | <0.03 | <0.021 |
| Seascale (Filtrate) | 3 | 16 | <2.1 | <0.20 | <0.030 | <0.33 | <1.7 | <0.28 | <0.41 |
| St. Bees (Particulate)[e] | 2 | | | <0.03 | <0.0097 | | <0.20 | <0.03 | <0.024 |
| St. Bees (Filtrate) | 3 | 9.5 | <2.1 | <0.23 | <0.028 | <0.32 | <1.8 | <0.30 | <0.25 |
| Seafield | 2[S] | 3.0 | | <0.10 | | | <0.43 | <0.10 | |
| Southerness | 2[S] | 4.3 | | <0.10 | | | <0.33 | <0.10 | |
| Auchencairn | 2[S] | 4.0 | | <0.10 | | | <0.31 | <0.10 | |
| Port Patrick | 2[S] | <1.8 | | <0.10 | | | <0.40 | <0.10 | |
| Hunterston[f] | 2[S] | 3.0 | | <0.10 | | | <0.35 | <0.10 | |
| North of Larne | 12[N] | | | | | 0.0013 | | | |
| Faslane (Carnban) | 2[S] | <1.1 | | <0.10 | | | <0.15 | <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 | <0.17 | | <0.10 | | |
| Rosyth | 2[S] | <0.10 | <0.10 | <0.18 | | <0.10 | | |
| Torness[a] | 2[S] | <0.10 | <0.10 | <0.18 | | <0.10 | | |
| Hartlepool (North Gare)[b] | 2 | <0.28 | <0.22 | <1.3 | | <0.31 | <3.4 | 13 |
| Sizewell | 2 | <0.29 | <0.23 | <1.1 | | <0.29 | <4.4 | 13 |
| Bradwell (Beach pipeline) | 2 | <0.29 | <0.23 | <1.2 | | <0.30 | <3.9 | 13 |
| Bradwell (Marina) | 2 | <0.27 | <0.20 | <1.2 | | <0.31 | <3.8 | <8.9 |
| Bradwell (Steeple) | 2 | <0.31 | <0.23 | <1.2 | | <0.31 | <3.4 | 17 |
| Bradwell (Maylandsea Bay) | 2 | <0.35 | <0.26 | <1.2 | | <0.29 | <3.5 | 21 |
| Bradwell (Blackwater) | 2 | <0.32 | <0.25 | <1.1 | | <0.30 | <3.2 | 15 |
| Bradwell (Osea Causeway) | 2 | <0.29 | <0.23 | <1.1 | | <0.30 | <2.9 | 12 |
| Bradwell (Maldon) | 2 | <0.35 | <0.28 | <1.2 | | <0.30 | <2.4 | 10 |
| Bradwell (Heybridge) | 2 | <0.30 | <0.26 | <1.1 | | <0.29 | <2.6 | 8.9 |
| Bradwell (Strood Channel) | 2 | <0.32 | <0.27 | <1.2 | | <0.30 | <3.1 | 18 |
| Bradwell (Tollesbury boatyard) | 2 | <0.29 | <0.23 | <1.1 | | <0.30 | <3.4 | 13 |
| Bradwell (Tollesbury saltwater pool) | 2 | <0.34 | <0.27 | <1.1 | | <0.30 | <3.4 | 13 |
| Bradwell (Pyefleet) | 2 | <0.28 | <0.23 | <1.2 | | <0.30 | <3.7 | 17 |
| Bradwell (Rowhedge) | 2 | <0.30 | <0.23 | <1.1 | | <0.30 | <3.0 | 12 |
| Bradwell (Alresford Creek) | 2 | <0.30 | <0.23 | <1.1 | | <0.30 | <2.9 | 11 |
| Bradwell (Brightlingsea Bateman's Tower) | 2 | <0.31 | <0.23 | <1.1 | | <0.29 | <3.9 | 14 |
| Bradwell (Brightlingsea saltwater pool) | 2 | <0.30 | <0.24 | <1.1 | | <0.30 | <4.1 | 14 |
| Bradwell (St Osyth) | 2 | <0.30 | <0.26 | <1.1 | | <0.30 | <2.2 | 12 |
| Dungeness south | 2 | <0.30 | <0.24 | <1.2 | | <0.29 | <3.9 | 14 |
| Winfrith (Lulworth Cove) | 1 | <0.30 | <0.24 | <0.92 | | <0.25 | <4.3 | 13 |
| Alderney | 4[F] | * | 0.0020 | | | | | |
| Guernsey | 4[F] | * | 0.0016 | | | | | |
| Devonport (Millbrook Lake) | 1 | | | | | | | |
| Devonport (Tor Point South) | 1 | | | | | | | |
| Hinkley | 1 | <0.27 | <0.21 | <1.3 | | <0.31 | <2.3 | 11 |
| Berkeley and Oldbury | 2 | <0.29 | <0.23 | <1.1 | | <0.30 | <2.1 | 7.0 |
| Cardiff (West of sewage outfall)[c] | 1 | | | | | | | |
| Wylfa (Cemaes Bay) | 2 | <0.26 | <0.21 | <1.1 | | <0.30 | <3.4 | 14 |
| Seascale (Particulate)[d] | 2 | <0.03 | <0.02 | <0.08 | <0.0011 | 0.062 | 0.17 | 0.12 |
| Seascale (Filtrate) | 3 | <0.22 | <0.18 | <0.98 | <0.053 | <0.25 | <3.8 | 9.4 |
| St. Bees (Particulate)[e] | 2 | <0.03 | <0.02 | <0.09 | <0.00066 | <0.025 | <0.074 | 0.083 |
| St. Bees (Filtrate) | 3 | <0.24 | <0.18 | <0.97 | <0.053 | <0.24 | <3.8 | 13 |
| Seafield | 2[S] | <0.10 | <0.10 | <0.24 | | <0.10 | | |
| Southerness | 2[S] | <0.10 | <0.10 | <0.21 | | <0.10 | | |
| Auchencairn | 2[S] | <0.10 | <0.10 | <0.18 | | <0.10 | | |
| Port Patrick | 2[S] | <0.10 | <0.10 | <0.25 | | <0.10 | | |
| Hunterston[f] | 2[S] | <0.10 | <0.10 | <0.23 | | <0.10 | | |
| North of Larne | 12[N] | * | 0.0070 | | | | | |
| Faslane (Carnban) | 2[S] | <0.10 | <0.10 | <0.12 | | <0.10 | | |

* *Not detected by the method used*

[a] *The concentration of $^{35}$S was <11 Bq $l^{-1}$*

[b] *The concentration of $^{35}$S was 1.3 Bq $l^{-1}$*

[c] *The concentration of $^{3}$H as tritiated water was <14 Bq $l^{-1}$*

[d] *The concentrations of $^{238}$Pu, $^{239/40}$Pu and $^{241}$Pu were 0.0053, 0.029 and <0.16 Bq $l^{-1}$ respectively*

[e] *The concentrations of $^{238}$Pu, $^{239/40}$Pu and $^{241}$Pu were <0.0017, 0.0075 and <0.16 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*

# 9. References


(Includes references from Appendix 1: CD supplement; sorted in order of first author and then date)

Allott, R., 2005. Assessment of compliance with the public dose limit. Principles for the assessment of total retrospective public doses. NDAWG/2/2005. Environment Agency, FSA, HPA, NII, Chilton.

Baxter, A.J., Camplin, W.C. and Steele, A.K., 1992. Radiocaesium in the seas of northern Europe: 1975 – 79. Fish. Res. Data Rep., MAFF Direct. Fish. Res., Lowestoft, (28): 1 – 166.

Baxter, A.J. and Camplin, W.C., 1994. The use of caesium-137 to measure dispersion from discharge pipelines at nuclear sites in the UK. Proc. Instn. Civ. Engrs. Wat., Marit. And Energy, (106): 281 – 288.

Baxter, J.M., Boyd, I.L., Cox, M., Donald, A.E., Malcolm, S.J., Miles, H., Miller, B. and Moffat, C.F., (Editors), 2011. Scotland's Marine Atlas: Information for the national marine plan. Marine Scotland, Edinburgh. pp. 191 **http://www.scotland.gov.uk/Topics/marine/science/atlas**

BEIS, 2017. The United Kingdom's sixth national report on compliance with the obligations of the Joint Convention on the safety of spent fuel management and on the safety of radioactive waste management. BEIS, London.

BEIS, 2018. UK Strategy for Radioactive Discharges - 2018 Review of the 2009 Strategy. BEIS, London.

BNFL, 2002. Discharges and monitoring of the environment in the UK. Annual Report 2001. BNFL, Warrington.

Boyd, C, 2018. Personal communication. ONR, Bootle.

Brenk, H.D., Onishi, Y., Simmonds, J.R. and Subbaratnam, T., (unpublished). A practical methodology for the assessment of individual and collective radiation doses from radionuclides in the environment. International Atomic Energy Authority draft working document no. 1987–05–06, Vienna.

Brown, J. and Etherington, G., 2011. Health Risks from Radioactive Objects on Beaches in the Vicinity of the Sellafield Site. HPA-CRCE-018, April 2011, HPA, Chilton.

Byrom, J., Robinson, C.A., Simmonds, J.R., Walters, C.B. and Taylor, R.R., 1995. Food consumption rates for use in generalised radiological dose assessments. J. Rad. Prot., 15(4): 335 – 342.

Camplin, W.C., Grzechnik, m. and Smedley, C.A., 2005. Methods for assessment of *total dose* in the Radioactivity in Food and the Environment report. NDAWG/3/2005. Environment Agency, FSA, HPA, NII, Chilton.

Camplin, W.C. and Jenkinson, S., 2007. Use of measurements in determining retrospective dose assessments in RIFE. (NDAWG/11/03) 2007. Environment Agency, FSA, HPA, NII, Chilton.

CEC, 1989. Council regulation (Euratom) No 3954/87 laying down the maximum permitted levels of radioactive contamination of foodstuffs and feeding stuffs following a nuclear accident or any other case of radiological emergency. OJ 11(L371), amended by Council Regulation 2218/89 OJ 1(L211).

CEC, 1992. Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora. OJ L206: 7 – 50.

CEC, 2000a. Commission recommendation on the application of Article 36 of the Euratom Treaty concerning the monitoring of the concentrations of radioactivity in the environment for the purpose of assessing the exposure of the population as a whole. OJ 27th July 2000. 2000/473/Euratom.

CEC, 2008. Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008 establishing a framework for Community action in the field of marine environmental policy (Marine Strategy Framework Directive). OJ L164.

CEC, 2009. Directive 2009/147/EC of the European Parliament and of the Council of 130 November 2009 on the conservation of wild birds. OJ L 20, 26.1.2010, 7 – 25.

Clyne, F.J., Gough, C., Edgar, A. and Smedley, C.A., 2008. Radiological Habits Survey: Sellafield Beach Occupancy, 2007. Project C3015. RL 02/08. Cefas, Lowestoft

Clyne, F.J., Gough, C., Edgar, A., Garrod, C.J. and Elliott, J., 2010. Radiological Habits Survey: Sellafield Beach Occupancy, 2009. Project C3635. RL 01/10. Cefas, Lowestoft

Clyne, F.J., Garrod, C.J., Ly, V.E. and Rumney, P., 2011. Radiological Habits Survey:

Dungeness, 2010. Project C2848. RL 11/11. Cefas, Lowestoft.

Clyne, F.J., Garrod, C.J., Ly, V.E., Dewar, A. and Papworth, G.P., 2013. Radiological Habits Survey: Low Level Waste Repository, 2012. RL 02a/13. Cefas, Lowestoft.

Clyne, F.J., Garrod, C.J. and Papworth, G.P., 2014. Radiological Habits Survey: Sellafield, 2013. RL 02/14. Cefas, Lowestoft.

Clyne, F.J., Garrod, C.J. and Papworth, G.P., 2015. Radiological Habits Survey: Berkeley and Oldbury, 2014. RL 02/15. Cefas, Lowestoft.

Clyne, F.J., Garrod, C.J. and Ly, V.E. 2016a. Radiological Habits Survey: Bradwell, 2015. RL 02/16. Cefas, Lowestoft.

Clyne, F.J., Garrod, C.J. and Dewar, A. 2016b. Radiological Habits Survey: Harwell, 2015. RL 03/16. Cefas, Lowestoft.

Clyne, F.J., Garrod, C.J., Dewar, A, Greenhill, B. and Ly, V.E. 2017. Radiological Habits Survey: Amersham, 2016. RL 02/17. Cefas, Lowestoft.

Codex Alimentarius Commission, 2006. Codex Alimentarius Commission Report, Twenty-ninth session 3-7 July 2006. AL INORM 06/29/41. Codex, Rome.

CoRWM, 2017a. Thirteenth annual report 2016-17. CoRWM, London.

CoRWM, 2017b. Proposed programme of work 2107-2020, CoRWM, London.

Cooper, J. R., 2008. Review of risks from tritium – report of the AGIR – November 2007. Letter dated 17 April 2008. HPA, Chilton.

Corbett, J.O., 1983. The Radiation Dose from Coal Burning: A Review of Pathways and Data. Radiat. Prot. Dosimetry 4 (1): 5-19.

Dale, P., Robertson, I and Toner, M., 2008. Radioactive particles in dose assessments. J. Environ. Rad., 99: 1589-1595.

DECC, Department of the Environment Northern Ireland, the Scottish Government and Welsh Assembly Government, 2009. UK Strategy for Radioactive Discharges. DECC, London. **https://www.gov.uk/government/publications/implementing-geological-disposal**

DECC and Welsh Assembly Government, 2009. Statutory Guidance to the Environment Agency concerning the regulation of radioactive discharges into the environment. DECC and Welsh Assembly Government, London and Cardiff.

DECC, 2012. Environmental Protection Act 1990: Part iiA. Contaminated Land. Statutory Guidance. DECC, London.

DECC, Scottish Government, Welsh Government and the Northern Ireland Department of the Environment, 2012. Strategy for the Management of Solid Low Level Radioactive Waste from the Non-Nuclear Industry; Part 1 – Anthropogenic Radionuclides, DECC, London.

DECC, 2014a. Implementing Geological Disposal. DECC, London.

DECC, 2014b. The United Kingdom's fifth national report on compliance with the obligations of the Joint Convention on the safety of spent fuel management and the safety of radioactive waste management. DECC, London.

DECC, 2015. The United Kingdom's national report on compliance with European Council Directive (2011/70/EURATOM). DECC, London.

DECC, 2016. Geological Disposal Facility (GDF) for higher-activity radioactive waste. 4 March 2016. DECC, London.

DECC, Scottish Government, Welsh Government and the Northern Ireland Department of the Environment, 2014. Strategy for the management of naturally occurring radioactive material (NORM) waste in the United Kingdom. The Scottish Government, Edinburgh.

DECC, Scottish Government, Welsh Government and the Department of the Environment Northern Ireland, 2016. UK Strategy for the management of solid low level waste for the nuclear industry. February 2016, DECC, London.

Defra, 2002. UK strategy for radioactive discharges 2001 – 2020. Defra, London.

Defra, 2004. Contribution of aerial radioactive discharges to radionuclide concentrations in the marine environment. DEFRA/RAS/04.002. Defra, London.

Defra, 2005a. 1: Marine Environment Quality. Report 1 of 5 contributing to Charting Progress: an Integrated Assessment of the State of UK Seas. Defra, London.

Defra, 2005b. 5: Integrated Regional Assessment. Report 5 of 5 contributing to Charting Progress: an Integrated Assessment of the State of UK Seas. Defra, London.

Defra, 2006. Industry profile. Industrial activities which have used materials containing radioactivity. Defra, London.

Defra, 2010. Charting Progress 2. Defra, London.

Defra, Department for Business, Enterprise and Regulatory Reform, National Assembly for Wales and Northern Ireland Assembly, 2008. Managing Radioactive Waste Safely: A framework for Implementing Geological Disposal, 2008. Cm7386. The Stationery Office, London.

Defra, Department of the Environment Northern Ireland, Scottish Executive, Welsh Assembly Government, 2005. Charting Progress. An Integrated Assessment of the State of UK Seas. Defra, London.

Defra, Department of the Environment Northern Ireland, Scottish Government, Welsh Government, 2014. Marine Strategy Part Two: UK Marine Monitoring Programmes. Defra, London.

Defra, Department of the Environment Northern Ireland, Scottish Government, Welsh Government, 2015. Marine Strategy Part Three: UK programme of measures. Defra, London

Defra, DTI and the Devolved Administrations, 2007. Policy for the Long Term Management of Solid Low Level Radioactive Waste in the United Kingdom. Defra, London.

Defra, Scottish Executive and Welsh Assembly Government, 2002. Safeguarding our seas. A strategy for the conservation and sustainable development of our marine environment. Defra, London.

Department for Business, Enterprise and Regulatory Reform, 2008. Meeting the energy challenge. A White Paper on Nuclear Power. Cmnd.7296. HMSO, London.
Department of the Environment Northern Ireland, 2011. The State of the Seas Report. DoENI, Belfast. https://www.daera-ni.gov.uk/publications/state-seas-report

DETR, 2000. Radioactive Substances (Basic Safety Standards) (England and Wales) Direction 2000. DETR, London.

Dewar, A., Camplin, W., Barry, J. and Kennedy, P., 2014. A statistical approach to investigating enhancement of polonium-210 in the Eastern Irish Sea arising from discharges from a former phosphate processing plant. Journal of Environmental Radioactivity, 138: 289-301.

Dick, R., 2012. Personal communication. Thames Water Utilities Limited, Reading.

DPAG, 2008. 4th Report, November 2008. SEPA, Stirling.

DSTL Radiological Protection Services, 2016. Marine environmental radioactivity surveys at nuclear submarine berths 2014. The Stationery Office, London.

EC, 2011a. Council Directive 2011/70/EURATOM of 19 July 2011 establishing a Community framework for the responsible and safe management of spent fuel and radioactive waste. OJ L 199/48. EC, Brussels.

EC, 2011b. Council implementing regulation (EU) No 297/2011 of 25 March 2011 imposing special conditions governing the import of feed and food originating in or consigned from Japan following the accident at the Fukushima nuclear power station. EC, Brussels.

EC, 2013. Council Directive 2013/51/EURATOM of 22 October 2013 laying down requirements for the protection of the health of the general public with regard to radioactive substances in water intended for human consumption. OJ L 296/2. EC, Brussels.

EC, 2014. Council Directive 2013/59/EURATOM laying down basic safety standards for protection against the dangers arising from exposure to ionising radiation. OJ L 13, 17.1.2014:1-73. EC, Brussels.

EC, 2016. Council implementing regulation (EU) 2016/6 of 5 January 2016 imposing special conditions governing the import of feed and food originating in or consigned from Japan following the accident at the Fukushima nuclear power station and repealing Implementation Regulation (EU) No. 322/2014. EC, Brussels.

Elliott, J., Clyne F.J. and Garrod C.J. 2010. Radiological Habits Survey: Derby 2009. Project C2848. RL 05/10. Cefas, Lowestoft.

Environment Agency, 2002a. Radioactivity in the environment. Report for 2001. Environment Agency, Lancaster.

Environment Agency, 2002b. Radioactive Waste Regulation. Summary of Research 1996 – 2001. R&D Publication 129. Environment Agency, Bristol and London.

Environment Agency, 2006a. Initial radiological assessment methodology – part 1 user report. SC030162/SR1. Environment Agency, Bristol and London.

Environment Agency, 2006b. Initial radiological assessment methodology – part 2 methods and input data. SC030162/SR2. Environment Agency, Bristol and London.

Environment Agency, 2008. Sellafield Radioactive Particles in the Environment – Programme of Work, February 2008. Environment Agency, Bristol and London.

Environment Agency, 2009a. Habitats assessment for Radioactive Substances. Science report: SC060083/SR1, May 2009. Environment Agency, Bristol.

Environment Agency, 2009b. Impact of radioactive substances on Ribble and Alt estuarine habitats. Science report: SC060083/SR2. May 2009. Environment Agency, Bristol.

Environment Agency, 2009c. Dealing with contaminated land in England and Wales. Environment Agency, Bristol.

Environment Agency, 2010. Radioactive substances regulation - Environmental Principles. Regulatory Guidance Series, No. RSR 1, v2 April 2010. Environment Agency, Bristol.

Environment Agency, 2012. Radioactive Contaminated Land. Environment Agency, Bristol and London.

Environment Agency, 2013a. Guidance Note for Developers and Operators of Radioactive Waste Disposal Facilities in England and Wales. Environment Agency, Bristol and London.

Environment Agency, 2013b. An environmental risk assessment for shale gas exploratory operations in England. Environment Agency, Bristol and London.

Environment Agency, Environment and Heritage Service, FSA and SEPA, 2007. Radioactivity in Food and the Environment, 2006. RIFE-12. Environment Agency, Environment and Heritage Service, FSA and SEPA. Bristol, Belfast, London and Stirling.

Environment Agency and SEPA, 2004. Guidance for the Environment Agencies' Assessment of Best Practicable Environmental Option Studies at Nuclear Sites. Environment Agency, Bristol and London.

Environment Agency and NIEA, 2009. Geological disposal facilities on land for solid radioactive wastes: guidance on requirements for authorisation. Environment Agency and NIEA, Bristol, London and Belfast.

Environment Agency, NIEA and SEPA, 2009. Near-surface disposal facilities on land for solid radioactive wastes: guidance on requirements for authorisation. Environment Agency, NIEA and SEPA, Bristol, London, Belfast and Stirling.

Environment Agency, FSA and SEPA, 2010. Environmental Radiological Monitoring. Radiological Monitoring Technical Guidance Note 2. Environment Agency, FSA and SEPA, Bristol, London and Stirling.

Environment Agency, FSA, NIEA and SEPA, 2010. Radioactivity in Food and the Environment, 2009. RIFE 15. Environment Agency, FSA, NIEA and SEPA, Bristol, London, Belfast and Stirling.

Environment Agency, SEPA, NIEA, HPA and FSA, 2012. Principles for the assessment of prospective public doses arising from authorised discharges of radioactive waste to the environment. Environment Agency, SEPA, NIEA, HPA and FSA. Bristol, Stirling, Belfast, Chilton and London.

Environment Agency, FSA, NIEA and SEPA, 2013. Radioactivity in Food and the Environment, 2012. RIFE 18. Environment Agency, FSA, NIEA and SEPA, Bristol, London, Belfast and Stirling.

Environment Agency, FSA, NIEA, NRW and SEPA, 2014. Radioactivity in Food and the Environment, 2013. RIFE 19. Environment Agency, FSA, NIEA, NRW and SEPA, Bristol, London, Belfast, Cardiff and Stirling.

Environment Agency, FSA, FSS, NIEA, NRW and SEPA, 2015. Radioactivity in Food and the Environment, 2014. RIFE 20. Environment Agency, FSA, FSS, NIEA, NRW and SEPA, Bristol, London, Aberdeen, Belfast, Cardiff and Stirling.

Environment Agency, FSA, FSS, NIEA, NRW and SEPA, 2016. Radioactivity in Food and the Environment, 2015. RIFE 21. Environment Agency, FSA, FSS, NIEA, NRW and SEPA, Bristol, London, Aberdeen, Belfast, Cardiff and Stirling.

Environment Agency, FSA, FSS, NIEA, NRW and SEPA, 2017. Radioactivity in Food and the Environment, 2016. RIFE 22. Environment Agency, FSA, FSS, NIEA, NRW and SEPA, Bristol, London, Aberdeen, Belfast, Cardiff and Stirling.

Etherington, G., Youngman, M.J., Brown, J. and Oatway, W., 2012. Evaluation of the Groundhog Synergy Beach Monitoring System for Detection of Alpha-rich Objects and Implications for the Health Risks to Beach Users. HPA-CRCE-038, August 2012, HPA, Chilton.

FSA, 2001a. Consultative Exercise on Dose Assessment, 3 and 4 October 2000. FSA/0022/0501.500. FSA, London.

FSA, 2001b. Radiological survey of foodstuffs from the Cardiff area. Food Survey Information Sheet 18/01.

FSA and SEPA, 2002. Radioactivity in Food and the Environment, 2001. RIFE-7. FSA and SEPA, London and Stirling.

FSA, 2003. Analysis of farmed salmon for technetium-99 and other radionuclides. Food Survey Information Sheet Number 39/03. FSA, London.

FSA, 2004. Review of FSA research programmes on radiological protection. Research review report for the period 1998 – 2003. FSA, London.

FSA, 2009. Estimate of the Food Chain Risks to Inform an Assessment of the Need for and Extent of the Food and Environment Protection Act Area at Dounreay. FSA, Aberdeen.
**http://www.food.gov.uk/multimedia/pdfs/dounreayfepariskassessment.pdf**

Garrod, C.J., Clyne, F.J., Ly, V.E., Rumney, P. and Papworth, G.P., 2013. Radiological Habits Survey: Barrow and the south-west Cumbrian coast, 2012. RL 01/13. Cefas, Lowestoft.

Garrod, C.J., Clyne, F.J. and Papworth, G.P., 2014. Radiological Habits Survey: Wylfa, 2013. RL 03/14. Cefas, Lowestoft.

Garrod, C.J., Clyne, F.J. and Papworth, G.P., 2015. Radiological Habits Survey: Hartlepool, 2014. RL 01/15. Cefas, Lowestoft.

Garrod, C.J., Clyne, F.J. and Rumney, P. 2016. Radiological Habits Survey: Sizewell, 2015. RL 01/16. Cefas, Lowestoft.

Garrod, C.J., Clyne, F.J., Greenhill, B. and Moran, C. 2017. Radiological Habits Survey: Heysham, 2016. RL 01/17. Cefas, Lowestoft.

Graven, H.D. and Gruber, N., 2011. Continental-scale enrichment of atmospheric $^{14}CO_2$ from the nuclear power industry: potential impact on the estimation of fossil fuel derived $CO_2$. Atmos. Chem. Phys., 11, 12339-12346.

Greenhill, B. J., Clyne, F. J., Milligan, A., and Neish, A., 2018. Radiological Habits Survey: Hinkley Point, 2017. RL 09/18. Cefas, Lowestoft.

Harrison, J.D. and Phipps, A., 2001. Invited editorial: gut transfer and doses from environmental technetium. J. Radiol. Prot., 21: (9 – 11).

Harrison, J.D., Khursheed, A and Lambert, B.E., 2002. Uncertainties in dose coefficients for intakes of tritiated water and organically bound forms of tritium by members of the public. Radiation Protection Dosimetry, 98, 299 – 311.

Harvey, M., Smith, J. and Cabianca, T., 2010. Assessment of collective and per caput doses due to discharges of radionuclides from the oil and gas industry into the marine environment. RPD-EA-4-2010. HPA, Chilton.

HM Government, 2012. UK Initial Assessment and Good Environmental Status. December 2012, London.

HMIP, 1995. Routine measurement of gamma ray air kerma rate in the environment. Technical Guidance Note (Monitoring) M5. HMSO, London.

Hodgson, A., Scott, J.E., Fell, T.P., and Harrison, J.D., 2005. Doses from the consumption of Cardiff Bay flounder containing organically bound tritium. Project SC020042/SR. Environment Agency, Bristol.

HPA, 2007. Review of the risks from tritium. Report of the Independent Advisory Group on Ionising Radiation. RCE-4. HPA, London.

HPA, 2009. Application of the 2007 Recommendations of the ICRP to the UK. Advice from the HPA. HPA, London.

HSE, 2017. Consultation on the implementation of Directive 2013/59/EURATOM laying down basic safety standards for protection against the dangers arising from exposure to ionising radiation – Occupational health and safety. February 2017. HSE, Bootle.

HSE, 2018. Work with ionising radiation. Ionising Radiations Regulations 2017. Approved Code of Practice and guidance. L121 (Second edition), Published 2018. ISBN 978 0 7176 6662 1. Available from: The Stationery Office, PO Box 29, Norwich NR3 1GN.

Hughes, L.M., Runacres, S.M. and Leonard, K.S., 2011. Marine Radioactivity in the Channel Islands, 1990 – 2009. Environmental Radiochemical Analysis IV, 170-180.

Hunt, G.J., Hewitt, C.J. and Shepherd, J.G., 1982. The identification of critical groups and its application to fish and shellfish consumers in the coastal area of the north-east Irish Sea. Health Physics 43 (6) 875 – 889.

Hunt, G.J., 1984. Simple models for prediction of external radiation exposure from aquatic pathways. Radiat. Prot. Dosim., 8: 215 – 224.

Hunt, G.J., Leonard, D.R.P. and Lovett, M.B., 1986. Transfer of environmental plutonium and americium across the human gut. Sci. Total Environ., 53: 89 – 109.

Hunt, G.J., 1998. Transfer across the human gut of environmental plutonium, americium, cobalt, caesium and technetium: studies with cockles (*Cerostoderma edule*) from the Irish Sea. J. Radiol. Prot., 18(2): 101 – 109.

Hunt, G.J., Leonard, D.R.P. and Lovett, M.B., 1990. Transfer of environmental plutonium and americium across the human gut. Sci. Total Environ., 90: 273 – 282.

Hunt, G.J. and Allington, D.J., 1993. Absorption of environmental polonium-210 by the human gut. J. Radiol. Prot., 13(2):119 – 126.

Hunt, G.J., Young, A.K. and Bonfield, R.A., 2001. Transfer across the human gut of environmental technetium in lobsters (*Homarus gammarus L.)* from the Irish Sea. J. Radiol. Prot., 21: 21 – 29.

Hunt, G.J. and Rumney, H.S., 2004. The human gut transfer of environmental polonium-210. Proc. Int. Conf. on widening the radiation protection world, 23 – 28 May 2004, Madrid. IRPA, Fontenay-aux-Roses.

Hunt, G.J and Rumney, H.S., 2005. The human alimentary tract transfer of environmental polonium-210. Proceedings of the Seventh International Symposium of the Society for Radiological Protection, 12th-17th June 2005, Cardiff. SRP, London.

Hunt, G.J. and Rumney, H.S., 2007. The human alimentary tract transfer and body retention of environmental polonium-210. J. Radiol. Prot., 27(4):405-26.

Hunt, G.J., Leonard, K.S., Gitzinger, C., Janssens, A., Godeanu-Metz, A. and Henrich, E., 2007. Article-35 of the Euratom Treaty: Overview of national radioactive discharge and environmental monitoring requirements in the European Union. Extended Synopsis in International Conference on Environmental Radioactivity, "From Measurement and Assessments in Regulations", 23-27 April 2007, Vienna.

Hunt, J., Bailey, T. and Reese, A., 2009. The human body retention time of environmental organically bound tritium. J. Radiol. Prot., 29(1):23-36.

Hunt, G.J., Bailey, T.A., Jenkinson, S.B. and Leonard, K.S., 2010. Enhancement of tritium on uptake by marine biota: experience from UK coastal waters. J. Radiol. Prot., 30(1):73.

Hunt, G.J., Leonard, K.S. and Hughes, L.M., 2013. Artificial radionuclides in the Irish Sea from Sellafield: remobilisation revisited. J. Radiol. Prot., 33(2):261.

IAEA, 1996. International basic safety standards for protection against ionising radiation and for the safety of radiation sources. Saf. Ser. No. 115. IAEA Vienna.

IAEA, 1997. Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management. INF CIRC/546. IAEA, Vienna.

IAEA, 1999. Application of radiological exclusion and exemption principles to sea disposal. IAEA-TECDOC-1068. IAEA, Vienna.

IAEA, 2003. Determining the suitability of materials for disposal at sea under the London Convention 1972: a radiological assessment procedure. IAEA-TECDOC-1375. IAEA, Vienna.

IAEA, 2015. Determining the suitability of materials for disposal at sea under the London Convention 1972 and London Protocol 1996: a radiological assessment procedure. IAEA-TECDOC-1759. IAEA, Vienna.

ICRP, 1994. Age-dependent doses to members of the public from intake of radionuclides: Part 2 Ingestion dose coefficients. Annal ICRP 23(3/4). Pergamon Press, Oxford, 167pp. (ICRP Publ. (67)).

ICRP, 2001. Doses to the embryo and fetus from intakes of radionuclides by the mother. Annal ICRP 31(1 – 3). Elsevier Science, Oxford. (ICRP Publ. (88)).

ICRP, 2007. The 2007 recommendations of the International Commission on Radiological Protection. Annal ICRP 37 (2-4). Elsevier Science, Oxford (ICRP Publ (103)).

ICRP, 2008. Environmental protection: the concept and use of reference animals and plants. Annal ICRP 38(4-6). Elsevier Science, Oxford, 242pp. (ICRP Publ (108)).

ICRP, 2012. Compendium of Dose Coefficients based on ICRP Publication 60. Annal ICRP 41(Supp.). Elsevier Science, Oxford, 130pp. (ICRP Publ (119)).

ICRP, 2014. Protection of the environment under different exposure situations. Annal ICRP 43(1). SAGE, Stanford, 58pp. (ICRP Publ (124)).

International Organisation for Standardisation, 2005. General requirements for the competence of testing and calibration laboratories. ISO 17025.

Jenkinson, S.B., McCubbin, D., Kennedy, P.H.W., Dewar, A., Bonfield, R and Leonard, K.S., 2014. An estimate of the inventory of technetium-99 in the sub-tidal sediments in the Irish Sea. J. Environ. Rad., 133, 40-47.

Jobling, S., Williams, R., Johnson, A., Taylor, A., Gross-Sorokin, M., Nolan, M., Tyler, C., van Aerle, R., Santos, E., and Brighty, G., 2006. Predicted exposures to steroid estrogens in UK rivers correlate with widespread sexual disruption in wild fish populations. Environmental Health Perspective, 114 (S-1), 32 – 39.

Joint Research Centre of the European Commission, 2009. Environmental Radioactivity in the European Community 2004 – 2006. Radiation Protection No. 161. CEC, Luxembourg.

Jones, K.A., Smith, J.G., Anderson, T., Harvey, M.P., Brown, I., Field, S.J. and Jones, A.L., 2013a. Implied doses to the population of the EU arising from reported discharges from EU nuclear power stations and reprocessing sites in the years 2004 to 2008, EC RP 176 **http://ec.europa.eu/energy/nuclear/radiation_protection/doc/publication/176.pdf**

Jones, A., Jones, K., Holmes, S., Ewers, L. and Cabianca T., 2013b. Assessing the possible radiological impact of routine radiological discharges from proposed nuclear power stations in England and Wales. J. Rad. Prot., 33: 163 – 174.

Jones, A.L. and Harvey, M.P., 2014. Radiological consequences resulting from accidents and incidents involving the transport of radioactive materials in the UK – 2012 review. PHE-CRCE-0147, Public Health England, Chilton.

Kershaw, P.J. and Baxter, A.J., 1995. The transfer of reprocessing wastes from north-west Europe to the Arctic. Deep-Sea Res. II, 43(6): 1413 – 1448.

Kibble, A., Cabianca, T., Daraktchieva, Z., Gooding, T., Smithard, J., Kowalczyk, G., McColl, N.P., Singh, m. Mitchem, L., Lamb, P., Vardoulakis S. and Kamanyire, R., 2014. Review of the potential public health impacts of exposure to chemical and radioactive pollutants as a result of shale gas extraction process. PHE-CRCE-009. Public Health England, Chilton.

Knowles, J.F., Smith, D.L. and Winpenny K., 1998. A comparative study of the uptake, clearance and metabolism of technetium in lobster (*Homarus gammarus*) and edible crab (*Cancer pagurus*). Radiat. Prot. Dosim., 75: 125 – 129.

Kocher, D.C. and Eckerman, K.F., 1987. Electron dose-rate conversion factors for external exposure of the skin from uniformly deposited activity on the body surface. Hlth. Phys., 53: 135 – 141.

Leonard, K.S., McCubbin, D., Brown, J., Bonfield, R. and Brooks, T., 1997a. A summary report of the distribution of Technetium-99 in UK Coastal Waters. Radioprotection, 32: 109 – 114.

Leonard, K.S., McCubbin, D., Brown, J., Bonfield, R. and Brooks, T., 1997b. Distribution of technetium-99 in UK coastal waters. Mar. Pollut. Bull., 34(8): 628 – 636.

Leonard, K.S., McCubbin, D., Blowers, P. and Taylor, B.R., 1999. Dissolved plutonium and americium in surface waters of the Irish Sea, 1973 – 96. J. Environ. Rad., 44: 129 – 158.

Leonard, K.S., McCubbin, D. and Bailey, T.A., 2001. Organic forms of tritium in food chains. Project R01023/ C0814. RL 6/01. Cefas, Lowestoft.

Leonard, K.S., McCubbin, D., McDonald, P., Service, M., Bonfield, R. and Conney, S., 2004. Accumulation of technetium-99 in the Irish Sea. Sci. Tot. Env., 322: 255 – 270.

Leonard, K.S., Donaszi-Ivanov, A., Dewar, A. and Ly, V., 2016. Monitoring of caesium-137 in surface seawater and seafood in both the Irish and North Seas: Trends and observations. J. Radioanal. Nucl. Chem., 311: 1117 –1125

Leonard, K. S., Smedley, P. A. and Cogan, S.M., 2017. Radiological assessment of dredging application for Hinkley Point C Power Station, Somerset (2017). RL 05/17. Cefas, Lowestoft.

LLWR Limited, 2015. Launch of the LLWR Plan. News and Updates 3rd July 2014. LLW Repository Limited, Holmrook.

LLWR Limited, 2017. Very Low Level Waste Service Guidance. LLW Repository Limited, Holmrook.

Ly, V.E., Garrod, C.J., Clyne, F.J. and Rumney, P., 2012. Radiological Habits Survey: Aldermaston and Burghfield, 2011. RL 03/12. Cefas, Lowestoft.

Ly, V.E., Clyne, F.J., Garrod, C.J. and Dewar, A., 2013. Radiological Habits Survey: Springfields, 2012. Project C2848. RL 03/13. Cefas, Lowestoft.

Ly V.E., Cogan S.M., Camplin W.C., Peake L. and Leonard, K.S., 2015. Long Term Trends in far-field effects of marine radioactivity measured around Northern Ireland. ERA12: Proceedings of the International Symposium on Nuclear and Environmental Radiochemical Analysis (17-19 September 2014, Bath, UK), 134 – 143, Royal Society of Chemistry, Cambridge

MAFF, 1995. Terrestrial radioactivity monitoring programme (TRAMP) report for 1994. Radioactivity in food and agricultural products in England and Wales. MAFF, London, TRAMP/9, 223pp.

MAFF, 1996. Pesticides Safety Directorate's Handbook. Appendix IC. MAFF, London.

MAFF and SEPA, 1998. Radioactivity in Food and the Environment, 1997. RIFE-3. MAFF and SEPA, London and Stirling.

McCubbin, D., Leonard, K.S., Bailey, T.A., Williams, J. and Tossell, P., 2001. Incorporation of organic tritium ($^{3}H$) by marine organisms and sediment in the Severn Estuary/ Bristol Channel (UK). Mar. Pollut. Bull., 42 (10): 852 – 863.

McCubbin, D., Leonard, K.S., Brown, J., Kershaw, P.J., Bonfield, R.A. and Peak, T., 2002. Further studies of the distribution of $^{99}Tc$ and $^{137}Cs$ in UK and European coastal waters. Cont. Shelf. Res. 22/10: 1417 – 1445.

McCubbin, D. and Vivian, C., 2006. Dose assessments in relation to disposal at sea under the London Convention 1972: judging *de minimis* radioactivity. FSA Project R01062. RL5/06. Cefas, Lowestoft.

McCubbin, D., Jenkinson, S.B., Leonard, K.S., Bonfield, R.A. and McMeekan, I.T., 2008. An assessment of the availability of Tc-99 to marine foodstuffs from contaminated sediments. Project R01062. RL09/08. Cefas, Lowestoft.

McKay, W.A., Barr H.M., Halliwell C.M., Spencer D., Adsley I. and Perks C.A., 1995. Site specific background dose rates in coastal areas. DoE/HMIP/RR/94/037. HMIP, London.

McTaggart, K.A., Tipple, J.R., Clyne, F.J. and McMeekan, I.T., 2004a. Radiological habits survey: Cardiff, 2003. RL 03/04. Cefas, Lowestoft.

McTaggart, K.A., Tipple, J.R., Sherlock, M., Cogan, S.M., Joyce, A.E. and Clyne, F.J., 2004b. Radiological Habits Survey: Winfrith, 2003. Projects C1659, RB103 and C1666. RL02/04. Cefas, Lowestoft.

Mobbs, S., Barraclough, I., Napier, I., Casey, A., Poynter, R. and Harvey, M., 1998. A review of the use and disposal of gaseous tritium light devices. Environment Agency, Lancaster.

Moore, K.J., Greenhill, B.J, and Clyne, F.J., 2018a. Radiological Habits Survey: Sellafield Review, 2017. RL 08/18. Cefas, Lowestoft.

Moore, K.J., Clyne, F.J., Greenhill, B.J., and Clarke, K., 2018b. Radiological Habits Survey: Devonport, 2017. RL 10/18. Cefas, Lowestoft.

National Dose Assessment Working Group, 2004. Radiological Assessment Exposure Pathways Checklist (Common and Unusual). NDAWG/2/2004. Environment Agency, FSA, NRPB, NII, Chilton.

Natural Scotland and SEPA, 2016. Alienated Land Former RAF Kinloss: Part IIA Inspection and Risk Assessment report. Scottish Government, Edinburgh.

NDA, 2010. UK Strategy for the Management of Solid Low Level Radioactive Waste from the Nuclear Industry. NDA, Moor Row, Cumbria.

NDA, 2016a. Strategy effective from April 2016. NDA, Moor Row, Cumbria.

NDA, 2016b. NDA Strategy. Integrated Impact Assessment Report. NDA, Moor Row, Cumbria.

NDA, 2016c. Industry Guidance. Interim Storage of Higher Activity Waste Packages – Integrated Approach. NDA, Moor Row, Cumbria.

NDA, 2018. NDA Business Plan 2018/2021. SG/2018/36, NDA, Moor Row, Cumbria.

NDA and BEIS, 2017. Radioactive Wastes in the UK: A Summary of the 2016 Inventory. NDA, Moor Row, Cumbria.

NIEA, 2013. Shale gas regulators forum. Minutes of 2nd meeting, March 2013. NIEA, Belfast.

Northern Ireland - Parliament, 2013. Marine Act (Northern Ireland) 2013. HMSO, Belfast.

Northern Ireland Assembly, 2003. Radioactive Substances (Basic Safety Standards) Regulations (Northern Ireland).

NRPB, 1990. Gut transfer factors. Docs. NRPB 1(2). NRPB, Chilton, 26pp.

NRPB, 2005. Guidance on the application of dose coefficients for the embryo and fetus from intakes of radionuclides by the mother. Docs NRPB 16(2). NRPB, Chilton, 41pp.

NRW, SEPA and Environment Agency, 2016. Summary brief of consultation and new Guidance on Requirements for Release of Nuclear Sites from Radioactive Substances Regulation. NRW, Cardiff.

Oatway, W. and Brown, J., 2015. Health Risk to Seafood Consumers from Radioactive Particles in the marine environment in the vicinity of the Sellafield site. PHE-CRCE-021. Public Health England, Chilton.

Oatway, W.B., Jones, A.L., Holmes, S., Watson, S.J. and Cabianca, T., 2016. Ionising radiation exposure of the UK population: 2010 Review. PHE-CRCE-026. PHE, Chilton.

OECD, Nuclear Energy Agency, 1985. Review of the continued suitability of the dumping site for radioactive waste in the North-East Atlantic. OECD, Paris, 448pp.

ONR, 2015. Decommissioning, Fuel and Waste Programme Imperial College Reactor Centre CONSORT Reactor Decommissioning Safety Case. Report ONR-DFW-PAR-15-010, November 2015. ONR, Bootle.

ONR, Environment Agency and NRW, 2017. Assessing new nuclear reactor designs Generic design assessment. Progress report. Nov. 2016 – Jan. 2017. ONR, Environment Agency and NRW, Bootle and Cardiff.

ONR and SEPA, 2017. Inspection of RWM's disposability assessment process for the management of HAW in Scotland. ONR and SEPA, Bootle, Bristol and Stirling.

OSPAR, 1998. SINTRA Statement. Summary Record OSPAR 98/14/1, Annex 45. OSPAR, London.

OSPAR, 2000a. Convention for the protection of the marine environment of the North-East Atlantic. OSPAR, London.

OSPAR, 2000b. Quality Status Report 2000. OSPAR, London.

OSPAR, 2003. 2003 Strategies of the OSPAR Commission for the Protection of the Marine Environment of the North-East Atlantic. 2003-21. OSPAR, London.

OSPAR, 2009. Towards the Radioactive Substances Strategy Objectives. Third Periodic Evaluation, OSPAR, London.

OSPAR, 2010a. The North-East Atlantic Environment Strategy. Strategy of the OSPAR Commission for the Protection of the Marine Environment of the North-East Atlantic 2010-2020. OSPAR Agreement 2010-3. OSPAR, London.

OSPAR, 2010b. Quality Status Report 2010. OSPAR, London.

OSPAR, 2015a. Liquid discharges from nuclear installations in 2015. OSPAR, London.

OSPAR, 2015b. Annual report on discharges of radioactive substances from the non-nuclear sectors in 2015. OSPAR, London.

OSPAR, 2016. Towards the Radioactive Substances Strategy Objectives. Forth Periodic Evaluation, OSPAR, London.

OSPAR, 2017. OSPAR Coordinated Environmental Monitoring Programme (CEMP)

(OSPAR Agreement 2016-01). CEMP Appendix R1 and R2. OSPAR, London.

OSPAR, 2018a. Part 1. UK Report on application of Best Available Techniques (BAT) in civil nuclear facilities (2012-2016) Implementation of PARCOM Recommendation 91/4 on radioactive discharges. Part 2. Summary of Radioactivity in Food and the Environment in the UK (2004-2016). OSPAR, London.

OSPAR, 2018b. Summary Record. Meeting of the Radioactive Substances Committee (RSC), Stockholm: 27 February - 1 March 2018. OSPAR, London.

Ould-Dada, Z., 2000. Sea-to-Land transfer of radionuclides. How much do we know. Proceedings of the second RADREM-TESC Workshop held in London on 21 January 1999. DETR/RADREM/00.001 DETR, London.

Papworth, G.P., Garrod, C.J. and Clyne, F.J., 2014. Radiological Habits Survey: Dounreay, 2013. RL 06/14. Cefas, Lowestoft.

PRAG (D), 2010. Annual report to SEPA and DSRL, March 2010. SEPA, Stirling.

PRAG (D), 2011. Annual report to SEPA and DSRL, March 2011. SEPA, Stirling.

PRAG (D), (2016). Annual report to SEPA and DSRL, SEPA, Stirling. March 2016. SEPA, Stirling.

Povinec, P.P., Bailly Du Bois, P., Kershaw, P.J., Nies, H. and Scotto, P., 2003. Temporal and spatial trends in the distribution of $^{137}$Cs in surface waters of Northern European Seas - a record of 40 years of investigations. Deep Sea Res. II, 50: 2785 – 2801.

Povinec, P.P., Aarkrog, A., Buesseler, K.O., Delfanti, R., Hirose, K., Hong, G.H., Ito, T., Livingston, H.D., Nies, H., Noshkin, V. E., Shima, S. and Togawa, O., 2005. $^{90}$Sr, $^{137}$Cs and $^{239,240}$Pu concentration surface water time series in the Pacific and Indian Oceans - WOMARS results. J. Environ. Rad, 81: 63 - 87.

Preston, A., Mitchell, N.T. and Jefferies, D.F., 1974. Experience gained in applying the ICRP Critical Group concept to the assessment of public radiation exposure in control of liquid waste disposal. Proc. Symp. IAEA Portoroz, IAEA-SM-184/10, 131 – 146.

Rollo, S.F.N., Camplin, W.C., Allington, D.J. and Young, A.K., 1992. Natural radionuclides in the UK marine environment. In: 'Proceedings of the Fifth International Symposium on Natural Radiation Environment, Salzburg, September 22 – 28, 1991'. Radiat. Prot. Dosim., 45(1/4): 203 – 210.

Rollo, S.F.N., Camplin, W.C., Duckett, L., Lovett, M.B. and Young, A.K., 1994. Airborne radioactivity in the Ribble Estuary. pp277 – 280. In: 'Proc. IRPA Regional Congress on Radiological Protection, 6 – 10 June 1994, Portsmouth, UK'. Nuclear Technology Publishing.

Scotland - Parliament, 2010. Marine (Scotland) Act, 2010. OQPS, Edinburgh.

Scotland - Parliament, 2015. Food (Scotland) Act 2015. HMSO, London.

Scottish Executive, 2000. Radioactive Substances (Basic Safety Standards) (Scotland) Direction 2000. Scottish Executive, Edinburgh.

Scottish Executive, 2006. Environmental Protection Act 1990: Part IIA Contaminated Land. Statutory Guidance: Edition 2. Scottish Executive, Edinburgh. SE/2006/44.

Scottish Government, 2008. Environment Act 1995. The UK Strategy for Radioactive Discharges. Statutory Guidance. Scottish Government, Edinburgh.

Scottish Government 2009. Environmental Protection Act 1990: Part IIA Contaminated Land. The Radioactive Contaminated Land (Scotland) Regulations 2007 Statutory Guidance. Scottish Government, Edinburgh. SG/2009/87.

Scottish Government, 2011. Scotland's Higher Activity Radioactive Waste Policy, 2011, Scottish Government, Edinburgh.

Scottish Government, 2016. Implementation strategy for Scotland's policy on higher activity radioactive waste, December 2016. Scottish Government, Edinburgh.

Sellafield Limited, 2018. Particles in the Environment. Annual Report for 2017 and Forward programme. NDA, June 2018, Seascale.

SEPA, 2007. Strategy for the Assessment of the potential impact of Sellafield Radioactive Particles on Southwest Scotland, December 2007. SEPA, Stirling.

SEPA and Environment Agency, 2010. Radiological Monitoring Technical Guidance Note 1. Standardised Reporting of Radioactive Discharges from Nuclear Sites. SEPA and Environment Agency, Stirling and Bristol.

SEPA, 2012a. Satisfying the ALARA requirement and the role of Best Practicable Means. SEPA, Stirling.

SEPA, 2012b. SEPA Policy on the Regulation of Disposal of Radioactive Low Level Waste from Nuclear Sites. SEPA, Stirling.

SEPA, 2013. Regulatory guidance: coal bed methane and shale gas. SEPA, Stirling.

SEPA, 2014. Interim Guidance on the Regulation of In-situ Disposals of Radioactive Waste and Residual Radioactive Contamination on Nuclear Authorised Premises. SEPA, Stirling.

SEPA, 2016. Radioactive Substances Unit Part IIA Inspection and Risk Assessment Report. Site: Alienated Land Former RAF Kinloss. SEPA, Stirling.

SEPA, 2017a. Guidance on monitoring for heterogeneous Radium-226 sources resulting from historic luminising or waste disposal sites. SEPA, Stirling.

SEPA, 2017b. Guidance on the Shipment of Wastes which contain Naturally Occurring Radioactive Material (NORM). SEPA, Stirling.

SEPA, *in press*/a. Radiological Habits Survey: Dumfries and Galloway. SEPA, Stirling.

SEPA, *in press*/b. Radiological Habits Survey: Hunterston. SEPA, Stirling.

SEPA, *in press*/c. Radiological Habits Survey: Torness. SEPA, Stirling.

SEPA, *in press*/d. Radiological Habits Survey: Faslane and Coulport. SEPA, Stirling.

SEPA and Scottish Government, 2017. Proposals for an Integrated Authorisation Framework SEPA, Edinburgh.

SEPA, Environment Agency and NRW, 2018. Management of radioactive waste from decommissioning of nuclear sites: Guidance on Requirements for Release from Radioactive Substance Regulation. Version 1.0: July 2018. SEPA, Environment Agency and NRW, Stirling, Bristol and Cardiff.

Simmonds, J.R., Lawson, G. and Mayall, A., 1995. Radiation Protection 72; Methodology for assessing the radiological consequences of routine releases of radionuclides to the environment. Report EUR 15760 EN. Office for Official Publications of the European Community, Luxembourg.

Smith, B.D. and Jeffs, T.M., 1999. Transfer of radioactivity from fishmeal in animal feeding stuffs to man. RL 8/99. Cefas, Lowestoft.

Smith, K.R. and Jones, A.L. 2003. Generalised habits data for radiological assessments. NRPB-W41. NRPB, Chilton.

Smith, J., Oatway, W., Brown, I. and Sherwood, J., 2009. PC Cream 08 User Guide. RPD-EA-9-2009. HPA, Chilton.

Smith, D.L., Smith, B.D., Joyce, A.E. and McMeekan, I.T., 2002. An assessment of aquatic radiation exposure pathways in Northern Ireland. SR(02)14. RL 20/02. Scotland and Northern Ireland Forum for Environmental Research, Edinburgh.

Smith, K.R., Mobbs, S.F. and Cooper, J.R., 2006. Dose criteria for the designation of radioactivity contaminated land. RCE-2. HPA, Chilton.

Statutory Instruments, 2007. SI 2007 No 3236. The Radioactive Contaminated Land (Amendment) Regulations (Northern Ireland) 2007.HMSO, London.

Statutory Instruments, 2010. SI 2010 No 2145. The Radioactive Contaminated Land (Amendment) Regulations (Northern Ireland) 2010. HMSO, London.

Statutory Instruments, 2016. SI 2016 No 614. The Water Supply (Water Quality) Regulations 2016. HMSO, London.

Swift, D.J., 2001. Cardiff radiological survey of selected foodstuffs. Project C1003. RL 11/01. Cefas, Lowestoft.

Swift, D.J. and Nicholson, M.D., 2001. Variability in the edible fraction content of $^{60}$Co, $^{99}$Tc, $^{110m}$Ag, $^{137}$Cs and $^{241}$Am between individual crabs and lobsters from Sellafield (north eastern Irish Sea). J. Environ. Radioact., 54, 311 – 326.

Tipple, J.R., McTaggart, K., Clyne, F.J. and Sherlock, M., 2006. Radiological Habits Survey: Trawsfynydd, 2005. Projects C1659, RB103 and C1666. RL 02/06. Cefas, Lowestoft.

Tipple, J.R., Jeffs, T.M., Clyne, F.J., Garrod, C.J. and Earl, T.J., 2009. Radiological Habits Survey: Capenhurst, 2008. Project C2848. RL 03/09. Cefas, Lowestoft.

Tyler, A., Watterson, A., Dale, I., Evans, L., Varley, A., Peredo-Alverez, V., Copplestone, D., Bradley, S., Shaw, B., Smith, P., Clarke P., Bartie, P. and Hunter, P., 2016. Radiological Habits Survey: Rosyth. SEPA, Stirling.

Tyler, A., Watterson, A., Dale, I., Smith, P., Evans, L., Copplestone, D., Varley, A., Peredo-Alverez, V., Bradley, S., Shaw, B., Bartie, P. and Hunter, P., 2017. Radiological Habits Survey: Chapelcross. SEPA, Stirling.

UKAEA, 2017. Mission and Goals. 2017/18. United Kingdom Atomic Energy Authority, Culham Science Centre, Abingdon, Oxfordshire.

United Kingdom - Parliament, 1965. Nuclear Installations Act, 1965. HMSO, London.

United Kingdom - Parliament, 1985. Food and Environment Protection Act, 1985. HMSO, London.

United Kingdom - Parliament, 1993. Radioactive Substances Act, 1993. HMSO, London.

United Kingdom - Parliament, 1995a. Environment Act, 1995. HMSO, London.

United Kingdom - Parliament, 1995b. Review of Radioactive Waste Management Policy. HMSO, London, 55pp. (Cm 2919).

United Kingdom - Parliament, 2004. Energy Act, 2004. HMSO, London.

United Kingdom - Parliament, 2009. Marine and Coastal Access Act 2009. HMSO, London

United Kingdom - Parliament, 2010. The Marine Strategy Regulations 2010. Stat. Inst. 2010 No 1627. HMSO, London.

United Kingdom - Parliament, 2016. Environmental Permitting (England and Wales) Regulations. Stat. Inst. 2016 No 1154. HMSO, London.

United Kingdom - Parliament, 2017. The Ionising Radiations Regulations 2017. Stat. Inst. 2017 No 1075. HMSO, London, 65pp.

United Kingdom - Parliament, 2018. Environmental Permitting (England and Wales) (Amendment) (No. 2) Regulations. Stat. Inst. 2018 No 428. HMSO, London.

Watson, S.J., Jones, A.L., Oatway, W.B. and Hughes, J.S., 2005. Ionising radiation exposure of the UK population: 2005 Review. HPA-RPD-001. HPA, Chilton.

Welsh Government, 2015. Welsh Government Policy on the Management and Disposal of Higher Activity Radioactive Waste, 2015, WG23160. Welsh Government, Cardiff.

Williams, J.L., Russ, R.M., McCubbin, D. and Knowles, J.F., 2001. An overview of tritium behaviour in the Severn estuary (UK). J. Rad. Prot., 21: 337 – 344.

Young, A.K., McCubbin, D. and Camplin, W.C., 2002. Natural radionuclides in seafood. Project R03010/C0808. RL 17/02. Cefas, Lowestoft.

Young, A.K., McCubbin, D., Thomas, K., Camplin, W.C., Leonard, K.S., and Wood, N., 2003. Po Concentrations in UK Seafood. 9th International Symposium on Environmental Radiochemical Analysis, 18-20 September 2002, Oxford. ERA III. Royal Society of Chemistry, London.

# 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-2017-rife-23**.

# APPENDIX 2. Disposals of radioactive waste*

**Table A2.1 Principal discharges of gaseous radioactive wastes from nuclear establishments in the United Kingdom, 2017**

| Establishment | Radioactivity | Discharge limit (annual equivalent)[a], Bq | Discharges during 2017 | |
|---|---|---|---|---|
| | | | Bq | % of annual limit[b] |
| **Nuclear fuel production and reprocessing** | | | | |
| Capenhurst (CNS Ltd)[1] | Alpha | BAT | 3.59E+05 | NA |
| Other authorised outlets | Beta | BAT | 1.20E+06 | NA |
| Capenhurst | Uranium | 7.50E+06 | 5.72E+05 | 7.6 |
| (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 | 7.85E+08 | 1.9 |
| | Tritium | 1.10E+15 | 9.95E+13 | 9.0 |
| | Carbon-14 | 3.30E+12 | 4.16E+11 | 13 |
| | Krypton-85 | 4.40E+17 | 4.33E+16 | 9.8 |
| | Strontium-90 | 7.10E+08 | 3.10E+07 | 4.4 |
| | Ruthenium-106 | 2.30E+10 | 6.51E+08 | 2.8 |
| | Antimony-125 | 3.00E+10 | 1.71E+09 | 5.7 |
| | Iodine-129 | 7.00E+10 | 6.52E+09 | 9.3 |
| | Iodine-131 | 3.70E+10 | 3.74E+08 | 1.0 |
| | Caesium-137 | 5.80E+09 | 4.16E+07 | <1 |
| | Radon-222 | 5.00E+11 | 3.91E+10 | 7.8 |
| | Plutonium alpha | 1.90E+08 | 3.47E+07 | 18 |
| | Plutonium-241 | 3.00E+09 | 3.32E+08 | 11 |
| | Americium-241 and Curium-242 | 1.20E+08 | 1.69E+07 | 14 |
| Springfields | Uranium | 5.30E+09 | 2.83E+07 | <1 |
| Springfields | Tritium | 1.00E+08 | 5.09E+05 | <1 |
| (National Nuclear Laboratory) | Carbon-14 | 1.00E+07 | 5.50E+04 | <1 |
| | Other alpha radionuclides | 1.00E+06 | Nil | Nil |
| | Other beta radionuclides | 1.00E+07 | 9.49E+02 | <1 |
| **Research establishments** | | | | |
| Dounreay[d] | | | | |
| | Alpha[e] | 3.10E+07 | 6.50E+06 | 21 |
| | Non-alpha[f] | 1.70E+09 | 8.20E+07 | 4.8 |
| | Tritium | 1.72E+13 | 6.30E+10 | <1 |
| | Krypton-85[g] | 5.69E+14 | 8.30E+09 | <1 |
| | Iodine-129 | 1.08E+08 | 1.70E+07 | 16 |

**Table A2.1 continued**

| Establishment | Radioactivity | Discharge limit (annual equivalent)[a], Bq | Discharges during 2017 | |
|---|---|---|---|---|
| | | | Bq | % of annual limit[b] |
| Harwell | Alpha | 8.00E+05 | 2.10E+04 | 2.6 |
| (Research Sites Restoration Ltd) | Beta | 2.00E+07 | 5.20E+05 | 2.6 |
| | Tritium | 1.50E+13 | 5.80E+11 | 3.9 |
| | Krypton-85 | 2.00E+12 | Nil | Nil |
| | Radon-220 | 1.00E+14 | 4.90E+12 | 4.9 |
| | Radon-222 | 3.00E+12 | 2.70E+11 | 9.0 |
| | 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 | 1.33E+11 | <1 |
| | Carbon-14 | 3.00E+10 | Nil | Nil |
| | Other | 1.00E+05 | Nil | Nil |
| Winfrith | Alpha | 2.00E+06 | 1.37E+03 | <1 |
| (Research Sites Restoration Ltd) | Tritium | 4.95E+13 | 1.64E+11 | <1 |
| | Carbon-14 | 5.90E+09 | 1.46E+08 | 2.5 |
| | Other | 5.00E+06 | 1.99E+04 | <1 |
| **Minor sites** | | | | |
| Imperial College Reactor Centre | Tritium | 3.00E+08 | 2.02E+06 | <1 |
| Ascot | Argon-41 | 1.70E+12 | Nil | Nil |
| **Nuclear power stations** | | | | |
| Berkeley[h] | Beta | 2.00E+07 | 1.60E+05 | <1 |
| | Tritium | 2.00E+10 | 8.15E+09 | 41 |
| | Carbon-14 | 5.00E+09 | 1.92E+09 | 38 |
| Bradwell | Beta | 6.00E+08 | 3.57E+05 | <1 |
| | Tritium | 6.00E+12 | 1.09E+12 | 18 |
| | Carbon-14 | 9.00E+11 | 2.13E+10 | 2.4 |
| Chapelcross | Tritium | 7.50E+14 | 3.05E+13 | 4.1 |
| | All other nuclides | 2.50E+09 | 1.49E+09 | 60 |
| Dungeness | Beta[i] | 5.00E+08 | 1.44E+06 | <1 |
| A Station | Tritium | 2.60E+12 | 1.74E+10 | <1 |
| | Carbon-14 | 5.00E+12 | 9.54E+08 | <1 |
| Dungeness | Tritium | 1.20E+13 | 2.19E+12 | 18 |
| B Station | Carbon-14 | 3.70E+12 | 1.27E+12 | 34 |
| | Sulphur-35 | 3.00E+11 | 4.89E+10 | 16 |
| | Argon-41 | 7.50E+13 | 1.07E+13 | 14 |
| | Cobalt-60[i] | 1.00E+08 | 3.03E+06 | 3.0 |
| | Iodine-131 | 1.50E+09 | 2.57E+07 | 1.7 |
| Hartlepool | Tritium | 1.00E+13 | 6.34E+11 | 6.3 |
| | Carbon-14 | 4.50E+12 | 2.60E+12 | 58 |
| | Sulphur-35 | 2.30E+11 | 3.56E+10 | 15 |
| | Argon-41 | 1.50E+14 | 9.32E+12 | 6.2 |
| | Cobalt-60[i] | 1.00E+08 | 1.89E+07 | 19 |
| | Iodine-131 | 1.50E+09 | 1.86E+08 | 12 |

**Table A2.1 continued**

| Establishment | Radioactivity | Discharge limit (annual equivalent)[a], Bq | Discharges during 2017 | |
|---|---|---|---|---|
| | | | Bq | % of annual limit[b] |
| Heysham | Tritium | 1.00E+13 | 8.34E+11 | 8.3 |
| Station 1 | Carbon-14 | 4.50E+12 | 1.53E+12 | 34 |
| | Sulphur-35 | 2.00E+11 | 4.02E+10 | 20 |
| | Argon-41 | 1.50E+14 | 9.32E+12 | 6.2 |
| | Cobalt-60[i] | 1.00E+08 | 6.52E+06 | 6.5 |
| | Iodine-131 | 1.50E+09 | 6.71E+07 | 4.5 |
| Heysham | Tritium | 1.00E+13 | 1.26E+12 | 13 |
| Station 2 | Carbon-14 | 3.70E+12 | 1.86E+12 | 50 |
| | Sulphur-35 | 2.30E+11 | 1.92E+10 | 8.3 |
| | Argon-41 | 7.50E+13 | 1.19E+13 | 16 |
| | Cobalt-60[i] | 1.00E+08 | 8.61E+06 | 8.6 |
| | Iodine-131 | 1.50E+09 | 7.40E+07 | 4.9 |
| Hinkley Point | Beta | 5.00E+07 | 2.00E+05 | <1 |
| A Station | Tritium | 7.50E+11 | 1.30E+10 | 1.7 |
| | Carbon-14 | 5.00E+10 | 4.50E+8 | <1 |
| Hinkley Point | Tritium | 1.20E+13 | 1.31E+12 | 11 |
| B Station | Carbon-14 | 3.70E+12 | 1.70E+12 | 46 |
| | Sulphur-35 | 3.50E+11 | 8.57E+10 | 24 |
| | Argon-41 | 1.00E+14 | 1.32E+13 | 13 |
| | Cobalt-60[i] | 1.00E+08 | 8.01E+06 | 8.0 |
| | Iodine-131 | 1.50E+09 | 4.55E+06 | <1 |
| Hunterston | Tritium | 2.00E+10 | 6.28E+08 | 3.1 |
| A Station | Carbon-14 | 2.00E+09 | 6.04E+07 | 3.0 |
| | All other radionuclides | 3.00E+06 | 1.04E+06 | 35 |
| Hunterston | Particulate beta | 5.00E+08 | 6.37E+07 | 13 |
| B Station[d] | Tritium | 1.50E+13 | 1.44E+12 | 9.6 |
| | Carbon-14 | 4.50E+12 | 1.97E+12 | 44 |
| | Sulphur-35 | 5.00E+11 | 5.14E+10 | 10 |
| | Argon-41 | 1.50E+14 | 8.94E+12 | 6.0 |
| | Iodine-131 | 2.00E+09 | 2.00E+03 | <1 |
| Oldbury | Beta | 1.00E+08 | 8.00E+04 | <1 |
| | Tritium | 9.00E+12 | 4.42E+10 | <1 |
| | Carbon-14 | 4.00E+12 | 4.79E+09 | <1 |
| Sizewell | Beta | 8.50E+08 | Nil | Nil |
| A Station | Tritium | 3.50E+12 | 1.55E+10 | <1 |
| | Carbon-14 | 1.00E+11 | 7.60E+08 | <1 |
| Sizewell | Noble gases | 3.00E+13 | 2.70E+12 | 9.0 |
| B Station | Particulate Beta | 1.00E+08 | 6.00E+06 | 6.0 |
| | Tritium | 3.00E+12 | 7.26E+11 | 24 |
| | Carbon-14 | 5.00E+11 | 2.24E+11 | 45 |
| | Iodine-131 | 5.00E+08 | 1.10E+07 | 2.2 |

**Table A2.1 continued**

| Establishment | Radioactivity | Discharge limit (annual equivalent)[a], Bq | Discharges during 2017 | |
|---|---|---|---|---|
| | | | Bq | % of annual limit[b] |
| Torness | Particulate beta | 4.00E+08 | 9.54E+06 | 2.4 |
| | Tritium | 1.10E+13 | 1.11E+12 | 10 |
| | Carbon-14 | 4.50E+12 | 1.13E+12 | 25 |
| | Sulphur-35 | 3.00E+11 | 4.30E+10 | 14 |
| | Argon-41 | 7.50E+13 | 5.39E+12 | 7.2 |
| | Iodine-131 | 2.00E+09 | 6.69E+06 | <1 |
| Trawsfynydd | Particulate Beta | 5.00E+07 | 8.70E+05 | 1.7 |
| | Tritium | 3.75E+11 | 3.12E+10 | 8.3 |
| | Carbon-14 | 1.00E+10 | 1.15E+09 | 12 |
| Wylfa | Particulate Beta | 7.00E+08 | 3.96E+06 | <1 |
| | Tritium | 1.80E+13 | 1.78E+11 | <1 |
| | Carbon-14 | 2.30E+12 | 1.51E+09 | <1 |
| | Sulphur-35 | 4.50E+11 | 8.94E+08 | <1 |
| | Argon-41 | 1.00E+14 | Nil | <1 |
| **Defence establishments** | | | | |
| Aldermaston[j] | Alpha | 1.65E+05 | 2.67E+04 | 16 |
| | Particulate Beta | 6.00E+05 | 2.02E+04 | 3.4 |
| | Tritium | 3.90E+13 | 7.26E+11 | 1.9 |
| | Carbon-14 | 6.00E+06 | Nil | Nil |
| | Activation products[k] | BAT | 5.81E+07 | NA |
| | Volatile beta | 4.40E+06 | 8.43E+04 | 1.9 |
| 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 | 1.79E+03 | 36 |
| Coulport | Tritium | 5.00E+10 | 1.78E+09 | 3.6 |
| Derby[m] | Alpha[n] | 3.00E+06 | 9.14E+05 | 30 |
| | Alpha[o,p] | 2.40E+04 | 4.30E+01 | <1 |
| | Beta[o,p] | 1.80E+06 | 4.07E+04 | 2.3 |
| Devonport[q,2] | Beta[i] | 3.00E+05 | 2.32E+04 | 7.7 |
| | Tritium | 4.00E+09 | 3.30E+08 | 8.3 |
| | Carbon-14 | 6.60E+10 | 1.69E+10 | 26 |
| | Argon-41 | 1.50E+10 | 5.59E+06 | <1 |
| Dounreay[d] | Beta[i] | 5.10E+06 | 1.20E+06 | 24 |
| (Vulcan) | Noble gases | 5.00E+09 | 1.20E+05 | <1 |
| Rosyth[r,3] | Tritium | 1.00E+07 | Nil | Nil |
| | Carbon-14 | 5.00E+07 | Nil | Nil |
| | Other radionuclides | 1.00E+05 | Nil | Nil |

**Table A2.1 continued**

| Establishment | Radioactivity | Discharge limit (annual equivalent)[a], Bq | Discharges during 2017 | |
|---|---|---|---|---|
| | | | Bq | % of annual limit[b] |
| **Radiochemical production** | | | | |
| Amersham | Alpha | 2.25E+06 | 3.22E+04 | 1.4 |
| (GE Healthcare) | Radionuclides T1/2<2hr | 7.50E+11 | 5.04E+09 | <1 |
| | Tritium | 2.00E+12 | 1.29E+09 | <1 |
| | Radon-222 | 1.00E+13 | 2.58E+12 | 26 |
| | Other including selenium-75 and iodine-131 | 1.60E+10 | 1.53E+07 | <1 |
| Cardiff | Tritium | 6.00E+12 | 5.30E+11 | 8.8 |
| (GE Healthcare) | Carbon-14 | 1.10E+12 | 1.21E+11 | 11 |
| **Industrial and landfill sites** | | | | |
| LLWR | Alpha | BAT | 4.77E+03 | NA |
| | Beta | BAT | 4.62E+04 | NA |
| Lillyhall | Alpha (particulate) | 5.00E+05 | 4.99E+03 | <1 |
| (Cyclife UK Limited)[4] | Beta (particulate) | 5.00E+05 | 1.72E+04 | 3.4 |

* *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 radionuclides, 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 Techniques*
[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] *On 30 October 2017 CNS Ltd was renamed URENCO Nuclear Stewardship (UNS) Ltd*
[2] *Discharge permit revised with effect September 2016. The limit for carbon-14 was revised*
[3] *Discharge authorisation revised with effect 1 December 2016*
[4] *Formerly Studsvik UK Limited*
*NA Not applicable under permit*
*BAT Best Available Techniques*

**Table A2.2 Principal discharges of liquid radioactive waste from nuclear establishments in the United Kingdom, 2017**

| Establishment | Radioactivity | Discharge limit (annual equivalent)[a], Bq | Discharges during 2017 | |
|---|---|---|---|---|
| | | | Bq | % of annual limit[b] |
| **Nuclear fuel production and reprocessing** | | | | |
| Capenhurst | Uranium | 7.50E+08 | 2.50E+06 | <1 |
| (Urenco UK Ltd) | Uranium daughters | 1.36E+09 | 5.67E+06 | <1 |
| | Non-uranic alpha | 2.20E+08 | 9.16E+06 | 4.2 |
| | Technetium-99 | 1.00E+09 | 2.99E+06 | <1 |
| Sellafield[c] | Alpha | 9.00E+11 | 1.84E+11 | 20 |
| | Beta[1] | 1.80E+14 | 1.21E+13 | 6.7 |
| | Tritium | 1.80E+16 | 1.30E+15 | 7.2 |
| | Carbon-14 | 2.10E+13 | 3.60E+12 | 17 |
| | Cobalt-60 | 3.60E+12 | 2.12E+10 | <1 |
| | Strontium-90 | 4.50E+13 | 2.12E+12 | 4.7 |
| | Zirconium-95 + Niobium-95 | 2.80E+12 | 6.36E+10 | 2.3 |
| | Technetium-99 | 1.00E+13 | 1.57E+12 | 16 |
| | Ruthenium-106 | 5.10E+13 | 1.03E+12 | 2.0 |
| | Iodine-129 | 2.00E+12 | 2.59E+11 | 13 |
| | Caesium-134 | 1.60E+12 | 4.24E+10 | 2.7 |
| | Caesium-137 | 3.40E+13 | 3.31E+12 | 9.7 |
| | Cerium-144 | 4.00E+12 | 1.24E+11 | 3.1 |
| | Neptunium-237 | 7.30E+11 | 3.63E+10 | 5.0 |
| | Plutonium alpha | 7.00E+11 | 1.50E+11 | 21 |
| | Plutonium-241 | 2.50E+13 | 2.09E+12 | 8.4 |
| | Americium-241 | 3.00E+11 | 2.02E+10 | 6.7 |
| | Curium-243+244 | 5.00E+10 | 1.92E+09 | 3.8 |
| | Uranium (in kg)[d] | 2.00E+03 | 3.48E+02 | 17 |
| Springfields | Alpha | 1.00E+11 | 1.81E+10 | 18 |
| | Beta | 2.00E+13 | 8.40E+11 | 4.2 |
| | Technetium-99 | 6.00E+11 | 8.06E+10 | 13 |
| | Thorium-230 | 2.00E+10 | 1.09E+09 | 5.5 |
| | Thorium-232[e] | 1.50E+10 | 1.48E+08 | <1 |
| | Neptunium-237 | 4.00E+10 | 2.44E+09 | 6.1 |
| | Other transuranic radionuclides | 2.00E+10 | 7.40E+09 | 37 |
| | Uranium | 4.00E+10 | 9.20E+09 | 23 |
| **Research establishments** | | | | |
| Dounreay[e] | Alpha[f] | 3.40E+09 | 2.80E+08 | 8.2 |
| | Non-alpha[g] | 4.80E+10 | 2.60E+09 | 5.4 |
| | Tritium | 6.90E+12 | 1.70E+10 | <1 |
| | Strontium-90 | 1.77E+11 | 2.90E+10 | 16 |
| | Caesium-137 | 6.29E+11 | 2.80E+09 | <1 |
| Harwell (Lydebank Brook) | Alpha | 3.00E+07 | 3.17E+06 | 11 |
| | Beta | 3.00E+08 | 8.15E+06 | 2.7 |
| | Tritium | 2.00E+10 | 8.92E+08 | 4.5 |
| Harwell (sewer) | Alpha | 1.00E+07 | 2.64E+05 | 2.6 |
| | Beta | 6.00E+08 | 1.40E+07 | 2.3 |
| | Tritium | 1.00E+11 | 2.04E+09 | 2.0 |
| | Cobalt-60 | 5.00E+06 | 2.91E+05 | 5.8 |
| | Caesium-137 | 2.00E+08 | 2.71E+06 | 1.4 |

**Table A2.2 continued**

| Establishment | Radioactivity | Discharge limit (annual equivalent)[a], Bq | Discharges during 2017 | |
|---|---|---|---|---|
| | | | Bq | % of annual limit[b] |
| Winfrith (inner pipeline)[h] | Alpha | 2.00E+10 | 1.29E+07 | <1 |
| | Tritium | 2.20E+14 | 2.08E+12 | <1 |
| | Caesium-137 | 2.00E+12 | 1.12E+09 | <1 |
| | Other radionuclides | 1.00E+12 | 2.97E+08 | <1 |
| Winfrith (outer pipeline) | Alpha | 2.00E+09 | 2.33E+06 | <1 |
| | Tritium | 1.50E+11 | 3.14E+08 | <1 |
| | Other radionuclides | 1.00E+09 | 6.74E+06 | <1 |
| Winfrith (River Frome) | Tritium | 7.50E+11 | Nil | Nil |
| **Minor sites** | | | | |
| Imperial College Reactor Centre | Tritium | 4.00E+07 | 6.24E+06 | 16 |
| Ascot | Other radioactivity | 1.00E+07 | 6.00E+03 | <1 |
| **Nuclear power stations** | | | | |
| Berkeley | Tritium | 1.00E+12 | 4.80E+07 | <1 |
| | Caesium-137 | 2.00E+11 | 9.20E+07 | <1 |
| | Other radionuclides | 2.00E+11 | 4.85E+07 | <1 |
| Bradwell | Tritium | 7.00E+12 | 2.57E+11 | 3.7 |
| | Caesium-137 | 7.00E+11 | 5.00E+08 | <1 |
| | Other radionuclides | 7.00E+11 | 1.49E+10 | 2.1 |
| Chapelcross | Alpha | 1.00E+09 | 5.86E+06 | <1 |
| | Non-alpha[i] | 1.00E+12 | 3.37E+09 | <1 |
| | Tritium | 6.50E+12 | 8.74E+09 | <1 |
| Dungeness A Station | Tritium | 8.00E+12 | 1.62E+10 | <1 |
| | Caesium-137 | 1.10E+12 | 1.56E+10 | 1.4 |
| | Other radionuclides | 8.00E+11 | 5.02E+09 | <1 |
| Dungeness B Station | Tritium | 6.50E+14 | 2.28E+14 | 35 |
| | Sulphur-35 | 2.00E+12 | 3.76E+11 | 19 |
| | Cobalt-60 | 1.00E+10 | 6.08E+08 | 6.1 |
| | Caesium-137 | 1.00E+11 | 2.01E+09 | 2.0 |
| | Other radionuclides | 8.00E+10 | 2.88E+09 | 3.6 |
| Hartlepool | Tritium | 6.50E+14 | 4.50E+14 | 69 |
| | Sulphur-35[2] | 3.60E+12 | 2.83E+12 | 79 |
| | Cobalt-60 | 1.00E+10 | 1.73E+08 | 1.7 |
| | Caesium-137 | 1.00E+11 | 2.00E+09 | 2.0 |
| | Other radionuclides | 8.00E+10 | 1.60E+09 | 2.0 |
| Heysham Station 1 | Tritium | 6.50E+14 | 2.57E+14 | 40 |
| | Sulphur-35 | 2.00E+12 | 3.63E+11 | 18 |
| | Cobalt-60 | 1.00E+10 | 2.80E+08 | 2.8 |
| | Caesium-137 | 1.00E+11 | 3.24E+09 | 3.2 |
| | Other radionuclides | 8.00E+10 | 4.84E+09 | 6.1 |

**Table A2.2 continued**

| Establishment | Radioactivity | Discharge limit (annual equivalent)[a], Bq | Discharges during 2017 | |
|---|---|---|---|---|
| | | | Bq | % of annual limit[b] |
| Heysham | Tritium | 6.50E+14 | 4.20E+14 | 65 |
| Station 2 | Sulphur-35 | 2.00E+12 | 1.53E+11 | 7.7 |
| | Cobalt-60 | 1.00E+10 | 6.28E+07 | <1 |
| | Caesium-137 | 1.00E+11 | 6.13E+08 | <1 |
| | Other radionuclides | 8.00E+10 | 1.25E+10 | 16 |
| | | | | |
| Hinkley Point | Tritium | 1.00E+12 | 9.90E+08 | <1 |
| A Station | Caesium-137 | 1.00E+12 | 3.99E+09 | <1 |
| | Other radionuclides | 7.00E+11 | 2.96E+10 | 4.2 |
| | | | | |
| Hinkley Point | Tritium | 6.50E+14 | 2.55E+14 | 39 |
| B Station | Sulphur-35 | 2.00E+12 | 2.68E+11 | 13 |
| | Cobalt-60 | 1.00E+10 | 7.94E+07 | <1 |
| | Caesium-137 | 1.00E+11 | 1.14E+09 | 1.1 |
| | Other radionuclides | 8.00E+10 | 3.43E+09 | 4.3 |
| | | | | |
| Hunterston | Alpha | 2.00E+09 | 1.70E+08 | 8.5 |
| A Station | All other non-alpha | 6.00E+10 | 4.92E+08 | <1 |
| | Tritium | 3.00E+10 | 3.21E+08 | 1.1 |
| | Caesium-137 | 1.60E+11 | 2.38E+08 | <1 |
| | Plutonium-241 | 2.00E+09 | 6.00E+07 | 3.0 |
| | | | | |
| Hunterston | Alpha | 1.00E+09 | 2.19E+07 | 2.2 |
| B Station | All other non-alpha | 1.50E+11 | 4.56E+09 | 3.0 |
| | Tritium | 7.00E+14 | 2.09E+14 | 30 |
| | Sulphur-35 | 6.00E+12 | 5.10E+11 | 8.5 |
| | Cobalt-60 | 1.00E+10 | 5.10E+08 | 5.1 |
| | | | | |
| Oldbury | Tritium | 1.00E+12 | 6.51E+10 | 6.5 |
| | Caesium-137 | 7.00E+11 | 3.85E+10 | 5.5 |
| | Other radionuclides | 7.00E+11 | 2.06E+10 | 2.9 |
| | | | | |
| Sizewell | Tritium | 5.00E+12 | 1.21E+10 | <1 |
| A Station | Caesium-137 | 1.00E+12 | 4.35E+10 | 4.4 |
| | Other radionuclides | 7.00E+11 | 4.68E+10 | 6.7 |
| | | | | |
| Sizewell | Tritium | 8.00E+13 | 3.01E+13 | 38 |
| B Station | Caesium-137 | 2.00E+10 | 1.00E+09 | 5.0 |
| | Other radionuclides | 1.30E+11 | 6.00E+09 | 4.6 |
| | | | | |
| Torness | Alpha | 5.00E+08 | 2.62E+06 | <1 |
| | All other non-alpha | 1.50E+11 | 3.16E+09 | 2.1 |
| | Tritium | 7.00E+14 | 3.32E+14 | 47 |
| | Sulphur-35 | 3.00E+12 | 8.69E+11 | 29 |
| | Cobalt-60 | 1.00E+10 | 4.70E+08 | 4.7 |
| | | | | |
| Trawsfynydd | Tritium | 3.00E+11 | 6.00E+08 | <1 |
| | Caesium-137 | 1.50E+10 | 2.00E+08 | 1.3 |
| | Other radionuclides[j] | 3.00E+10 | 4.00E+08 | 1.3 |
| | | | | |
| Wylfa | Tritium | 1.50E+13 | 7.58E+11 | 5.1 |
| | Other radionuclides | 1.10E+11 | 4.09E+09 | 3.7 |

**Table A2.2 continued**

| Establishment | Radioactivity | Discharge limit (annual equivalent)[a], Bq | Discharges during 2017 | |
|---|---|---|---|---|
| | | | Bq | % of annual limit[b] |
| **Defence establishments** | | | | |
| Aldermaston (to sewer)[k] | Alpha | 1.00E+07 | 1.40E+06 | 14 |
| | Other beta emitting radionuclides | 2.00E+07 | 1.80E+06 | 9.0 |
| | Tritium | 2.50E+10 | 1.50E+08 | <1 |
| Aldermaston (to Stream)[k, l] | Tritium | NA | 3.60E+08 | NA |
| Barrow[m,3] | Tritium | 1.20E+10 | 9.63E+05 | <1 |
| | Carbon-14 | 2.95E+08 | 2.58E+05 | <1 |
| | Cobalt-60 | 1.34E+07 | 2.95E+03 | <1 |
| | Other gamma emitting radionuclides | 3.50E+06 | 1.94E+03 | <1 |
| Derby[n] | Alpha[o] | 2.00E+09 | 8.59E+07 | 4.3 |
| | Alpha[p] | 3.00E+05 | 7.65E+03 | 2.6 |
| | Beta[p] | 3.00E+08 | 2.91E+05 | <1 |
| Devonport (sewer)[q] | Tritium | 2.00E+09 | 5.24E+07 | 2.6 |
| | Cobalt-60 | 3.50E+08 | 5.52E+06 | 1.6 |
| | Other radionuclides | 6.50E+08 | 8.21E+07 | 13 |
| Devonport (estuary)[q] | Tritium | 7.00E+11 | 2.86E+10 | 4.1 |
| | Carbon-14 | 1.70E+09 | 1.06E+08 | 6.2 |
| | Cobalt-60 | 8.00E+08 | 2.28E+07 | 2.9 |
| | Other radionuclides | 3.00E+08 | 1.70E+07 | 5.7 |
| Faslane | Alpha | 2.00E+08 | 1.30E+05 | <1 |
| | Beta[i,r] | 5.00E+08 | 1.36E+06 | <1 |
| | Tritium | 1.00E+12 | 3.54E+10 | 3.5 |
| | Cobalt-60 | 5.00E+08 | 6.80E+05 | <1 |
| Rosyth[s,4] | Tritium | 3.00E+08 | 1.21E+07 | 4.0 |
| | Cobalt-60 | 1.00E+08 | 4.42E+06 | 4.4 |
| | Other radionuclides | 1.00E+08 | 5.04E+06 | 5.0 |
| **Radiochemical production** | | | | |
| Amersham (GE Healthcare) | Alpha | 3.00E+08 | 2.38E+06 | <1 |
| | Tritium | 1.41E+11 | 1.00E+06 | <1 |
| | Other radionuclides | 6.50E+10 | 2.79E+08 | <1 |
| **Industrial and landfill sites** | | | | |
| LLWR | Alpha | BAT | 3.36E+07 | NA |
| | Beta | BAT | 8.56E+08 | NA |
| | Tritium | BAT | 4.49E+10 | NA |
| Lillyhall (Cyclife UK Limited)[5] | Alpha | 5.00E+05 | 1.37E+03 | <1 |
| | Beta | 5.00E+05 | 1.13E+04 | 2.3 |

**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 radionuclides, 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] *The discharge permit was revised with effect from 1 December 2016; limit for beta was revised*
[2] *The discharge permit was revised with effect from 9 October 2017; the limit for sulphur-35 was revised. The percentage of annual limit is based on the revised limit*
[3] *BAE were granted a minor variation to their discharge permit, effective June 2016, for the sampling and analysis of cobalt-60, with an annual discharge limit of 1.34E+07 Bq, to the sewer. The limit for carbon-14 was also revised*
[4] *Discharge authorisation revised with effect 1 December 2016*
[5] *Formerly Studsvik UK Limited*

*NA Not applicable under permit*
*BAT Best Available Techniques*

## Table A2.3 Disposals and receipt with the intention of disposal of solid radioactive waste at nuclear establishments in the United Kingdom, Financial Year 2017/18

| Radionuclide or group of radionuclides | Total vault disposed[a] waste FY17/18 (Bq) | Cumulative total vault disposed[a] waste (Bq) |
|---|---|---|
| Tritium | 2.86E+11 | 2.69E+13 |
| Carbon-14 | 1.18E+10 | 4.73E+11 |
| Chlorine-36 | 6.76E+09 | 7.07E+11 |
| Calcium-41 | Nil | 1.20E+10 |
| Selenium-79 | Nil | Nil |
| Molybdenum-93 | Nil | 1.40E+06 |
| Zironium-93 | Nil | 3.83E+10 |
| Niobium-94 | 6.42E+07 | 6.69E+09 |
| Technetium-99 | 1.34E+09 | 3.04E+12 |
| Silver-108m | 4.29E+07 | 5.73E+09 |
| Iodine-129 | 9.40E+06 | 3.32E+09 |
| Caesium-135 | 1.14E+07 | 5.25E+08 |
| Radium-226 | 8.42E+05 | 7.32E+10 |
| Thorium-229 | Nil | 5.29E+05 |
| Thorium-230 | 3.58E+06 | 7.05E+09 |
| Thorium-232 | 2.02E+06 | 3.57E+10 |
| Protactinium-231 | Nil | 2.44E+09 |
| Uranium-233 | 2.42E+05 | 5.69E+10 |
| Uranium-234 | 3.33E+09 | 4.63E+11 |
| Uranium-235 | 9.22E+07 | 3.18E+10 |
| Uranium-236 | 4.08E+08 | 2.72E+10 |
| Uranium-238 | 3.19E+09 | 5.25E+11 |
| Neptunium-237 | 3.84E+07 | 4.29E+10 |
| Plutonium-238 | 3.60E+09 | 1.95E+11 |
| Plutonium-239 | 5.00E+09 | 4.96E+11 |
| Plutonium-240 | 5.11E+09 | 3.16E+11 |
| Plutonium-241 | 1.04E+11 | 9.70E+12 |
| Plutonium-242 | 7.00E+04 | 9.85E+08 |
| Americium-241 | 1.90E+10 | 1.35E+12 |
| Americium-242m | Nil | 5.87E+10 |
| Americium-243 | 2.86E+06 | 5.55E+08 |
| Curium-243 | 4.73E+06 | 3.31E+09 |
| Curium-244 | 2.55E+08 | 2.02E+10 |
| Curium-245 | 8.20E+04 | 5.27E+06 |
| Curium-246 | Nil | 1.87E+06 |
| Curium-248 | Nil | 4.98E+07 |
| OTHRT** | Nil | 4.81E+06 |
| PUALD** | Nil | 1.01E+11 |
| UALD** | Nil | 1.13E+10 |
| URRM** | 2.86E+08 | 2.38E+10 |
| Others* | 3.69E+11 | 6.41E+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 |
| 2017/18 | 1.81E+03 | 2.49E+05 | 2.31E+04 | 4.11E+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, 2017*

| Establishment – transfer from | Volume $m^3$ | Total Activity Bq | Alpha Bq | Beta/Gamma Bq |
|---|---|---|---|---|
| **Research establishments** | | | | |
| Dounreay[a] | 3.90E+01 | | 7.99E+07 | 2.75E+09 |
| | | | | |
| **Nuclear Power Stations** | | | | |
| Chapelcross | 2.02E+01 | 2.33E+08[b] | N/A | N/A |
| Hunterston A | 2.84E+02 | | 8.54E+08 | 1.30E+10 |
| Hunterston B | 7.81E+01 | | 5.43E+06 | 1.74E+12 |
| Torness | 4.20E+01 | | 7.81E+07 | 8.76E+11 |
| | | | | |
| **Defence establishments** | | | | |
| Coulport | Nil | | Nil | Nil |
| Dounreay (Vulcan) | Nil | | Nil | Nil |
| Faslane | Nil | | Nil | Nil |
| Rosyth | Nil | | Nil | Nil |

* *As reported by site operators to SEPA*
[a] *Solid waste transfer to low level waste facility located adjacent to the site*
[b] *Reported as total activity only*

**Table A2.5 Summary of unintended leakages, spillages, emissions or unusual findings of radioactive substances from nuclear licensed sites in the UK in 2017**

| Site | Month/Year | Summary of incident | Consequences and action taken |
|---|---|---|---|
| Dounreay | April 2017 | DSRL notified SEPA that incorrect duct flowrate information had been used in the calculation of gaseous tritium discharges from the PFR facility. | This resulted in revisions being made to previously reported discharges of tritium from the PFR facility. Details of the revised reported discharges from the site are provided in the RIFE-23 errata document: **https://www.gov.uk/government/publications/radioactivity-in-food-and-the-environment-rife-reports-2004-to-2016**. |
| Dounreay | May 2017 | DSRL notified SEPA of elevated levels of caesium-137 within its non-active drainage system. | Investigations by DSRL isolated the source to an area round a single building in the Fuel Cycle Area. Discharges to the marine environment have returned to being below Limit of Detection and intervention taken by DSRL to direct discharges from the source area to the low active drainage network. |
| Dounreay | July 2017 | DSRL notified SEPA of the identification of a crack in a recently installed section of ventilation ductwork within the PFR Facility. | SEPA investigated the circumstances surrounding the occurrence of the crack and installation of this section of ductwork. As a result, SEPA sent a Final Warning Letter to DSRL in relation to the site's arrangements for controlling modifications to equipment. |
| Dounreay | September 2017 | Incidents of non-compliance relating to DSRL's reporting of its liquid and gaseous discharges from the site | SEPA issued a Notice of Variation to the site authorisation under RSA 93. The variation requires DSRL to undertake a range of specified improvements; to review and validate its arrangements for the sampling, calculation and reporting of liquid and gaseous discharges and to implement any improvements to its arrangements arising from the review work. |
| Hunterston B | 2017 | Discharges of carbon-14 increased from Hunterston B in 2017, in comparison to those releases in 2016. The increase in carbon-14 appears to be due to a higher loss rate from the Inlet Guide Vane Interspace on a Gas Circulator on Reactor 4 towards the end of 2017. | This interspace required to be vented for nuclear safety proposes to protect the outer seal. As the necessary repair to the inner seal requires reactor shutdown and depressurisation and did not challenge any authorised limit, the station carried out a Best Practicable Means assessment which concluded that the work could be delayed until the next scheduled outage. |
| 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. | A full account of this incident, together with a table of data from the radioactive analysis, is provided in Section 7.7 of this report (RIFE 23). |
| Sellafield | February 2017 | Holes in calandria tubes in the uranyl nitrate evaporator led to a release of uranyl nitrate solution into the Suspect Active Steam Condensate (SASC) System in Thorp Chemical Plants Uranium Finishing. This condensate was subsequently discharged to sea. | The event resulted in the discharge of ~13 kg of uranium into the sea. This is a failure to comply with specific permit conditions, although it is well within the site annual limit of 2000 kg and the Quarterly Notification Level of 500 kg.<br>The root cause of this event is the incomplete inspections performed in 2013 and 2014 on the uranyl nitrate evaporator calandria tubes. The results from these inspections were used as the basis for deferring future inspections. As a result, Sellafield Limited was not aware of the corrosion rate of the inner bundle of calandria tubes and did not expect them to be holed.<br>Sellafield has completed actions to ensure this event is not repeated, including:<br>• Capping of the calandria inner tubes and<br>• Improving the asset management arrangements regarding the analyser, to detect breakthrough of uranium into the Suspect Active Steam Condensate. |
| Sellafield | June 2017 | A container of waste dispatched from Sellafield Limited to the Low Level Waste Repository (LLWR) was found to be in breach of the LLWR Waste Acceptance Criteria (WAC). | The failure to meet the Waste Acceptance Criteria was a breach in permit conditions. The Environment Agency prepared a Radioactive Substances Compliance report which contained a number of actions to ensure that the event is not repeated. |
| Sellafield | November 2017 | Two items of waste sent by Sellafield Limited to Cyclife for metals recycling failed to meet the Cyclife Waste Acceptance Criteria (WAC) because they contained oil that had not been sufficiently drained. | This event was a breach of permit conditions. Sellafield Limited is completing actions raised in its Basic Cause Investigation, to ensure against repeat events. |

# 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 |
| 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 |
| EPR 18 | Environment Permitting (England and Wales) Regulations 2018 |
| 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 |
| HAW | Higher Activity radioactive Waste |
| 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 |

| | |
|---|---|
| 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 radiation | 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). |

| | |
|---|---|
| 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 habits 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 reviewed regularly 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 ongoing and recently completed extramural research is presented in Table A4.1. Those sponsored by the Environment Agency and FSA are also listed on their websites: **https://www.gov.uk/government/organisations/environment-agency**, and **www.food.gov.uk**, respectively. Copies of the final reports for each of the projects funded by the FSA are available from Clive House, 70 Petty France, London, SW1H 9EX. 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 | Further details | Target completion date |
|---|---|---|---|
| Soil and herbage survey | UKRSR01 and SCO00027 | E, S | *In press* |
| Offshore Dose Assessment Model | N/A | S | Q4, 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 |
| Background monitoring in urban environments | N/A | S | Q4, 2018 |
| FSS/SEPA Bottled Water Study | N/A | S | Q1, 2019 |
| Clyde Estuary Assessment | N/A | S | Q4, 2018 |
| Project to investigate polonium-210 legacy discharges to the Irish Sea | N/A | E, F | December 2018 |
| Sellafield and Trawsfynydd Habits Surveys | N/A | E, F, O | Q1, 2019 |
| Dounreay Habits Survey | N/A | S | 2019 |

*E Environment Agency*
*F Food Standards Agency*
*O Office for Nuclear Regulation*
*S Scotland and Northern Ireland Forum for Environmental Research or SEPA*

# APPENDIX 5. Radiological assessment of dredging application for Hinkley Point C Power Station, Somerset (2017)

In England, the Marine Management Organisation (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 (Defra), this includes under the Marine and Coastal Access Act (MCAA), 2009 (United Kingdom - Parliament, 2009) for the disposal of dredged material at sea. Licences for disposals made in Scottish waters and around the coast of Northern Ireland are the responsibility of the Scottish Government (Marine Scotland) and the Department of Environment (NIEA), respectively. As of 1 April 2013, licences for Welsh waters are the responsibility of NRW.

The protection of the marine environment is considered before a licence is issued. Since dredge material will contain radioactivity from natural and man-made sources at varying concentrations, assessments are undertaken when appropriate for assurance that there is no significant food chain or other risk from the disposal. Guidance on exemption criteria for radioactivity in relation to sea disposal is available from the International Atomic Energy Agency (IAEA) (International Atomic Energy Agency, 1999). IAEA has published a system of assessment that can be applied to dredge spoil disposal (IAEA, 2003). This has been adapted to reflect operational practices in England and Wales (McCubbin and Vivian, 2006).

In 2017, NNB GenCo lodged a licensing application to carry out a variety of dredging scenarios, within which dredging could occur at Hinkley Point C. A generic assessment of doses to workers and members of the public was conducted for the disposal of the dredge material (Leonard *et al*., 2017). Samples of the material were taken and analysed, and the results are given in Table A5.1. The contributions from individual radionuclides to the doses for individual crew members and individual members of the public are given in Figures A5.1-2.

Under the London Convention, only materials with *de minimis* levels of radioactivity may be considered for dumping. Using the conservative generic radiological assessment procedure developed by the IAEA (IAEA, 2003) to convert radionuclide concentrations in dumped material into radiation doses due to dumping, the total dose (from artificial and naturally-occurring radionuclides) to individual members of the crew and public were within the IAEA *de minimis* criteria of 0.010 mSv per year. Therefore, there was no objection to the licence being issued from radiological considerations.

**Table A5.1 Concentrations of radionuclides in sediment dredged from Hinkley Point C, Somerset, 2017**

| Sample number | Mean radioactivity concentration (dry), Bq kg$^{-1}$ | | | | | |
|---|---|---|---|---|---|---|
| | $^{60}$Co | $^{137}$Cs | $^{226}$Ra (via $^{214}$Pb)[1] | $^{232}$Th (via $^{228}$Ac)[1] | $^{238}$U (via $^{234}$Th)[1] | $^{241}$Am |
| HPCD06 | < 0.4 | 20 | 23 | 37 | 62 | < 1.5 |
| HPCD07 | < 0.4 | 20 | 22 | 38 | 58 | < 1.6 |
| HPCD08 | < 0.4 | 18 | 22 | 33 | 66 | < 1.4 |
| HPCD09 | < 0.4 | 18 | 23 | 32 | 54 | < 1.6 |
| HPCD10 | < 0.5 | 15 | 20 | 29 | 42 | < 1.7 |
| HPCD11 | < 0.3 | 15 | 21 | 30 | 49 | < 1.1 |
| HPCD12 | < 0.4 | 15 | 22 | 29 | 46 | < 1.4 |
| HPCD13 | < 0.4 | 15 | 22 | 29 | 52 | < 0.59 |
| HPCD14 | < 0.5 | 15 | 22 | 27 | 49 | < 0.62 |
| HPCD15 | < 0.4 | 15 | 23 | 28 | 49 | < 1.4 |
| HPCD16 | < 0.4 | 13 | 24 | 30 | 47 | < 1.5 |
| HPCD17 | < 0.4 | 14 | 22 | 30 | 47 | < 1.4 |
| **Mean**[2] | **0.4** | **16** | **22** | **31** | **52** | **1.3** |

[1] *Parent nuclides not directly detected by the method used. Instead, concentrations were estimated from levels of their daughter products*

[2] *Mean determinations use < results as positively measured values to produce a conservative estimate and are calculated from raw data (raw data are rounded in the table above)*

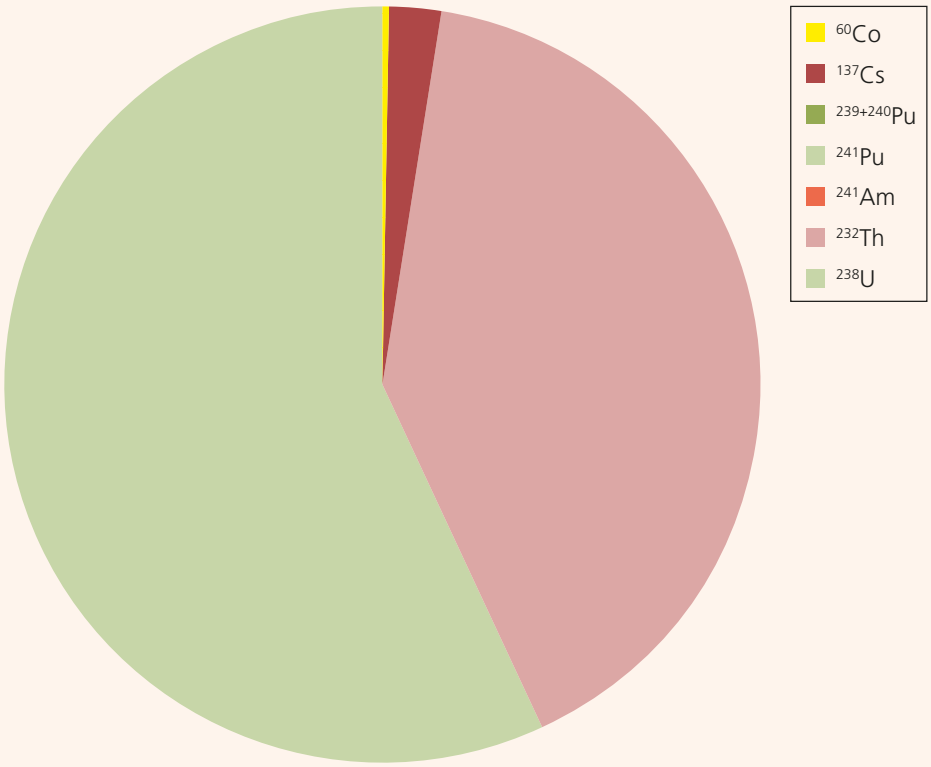



**Figure A5.1.** Radionuclide contribution to dose to individual crew members due to dredging at Hinkley Point C, Somerset, 2017

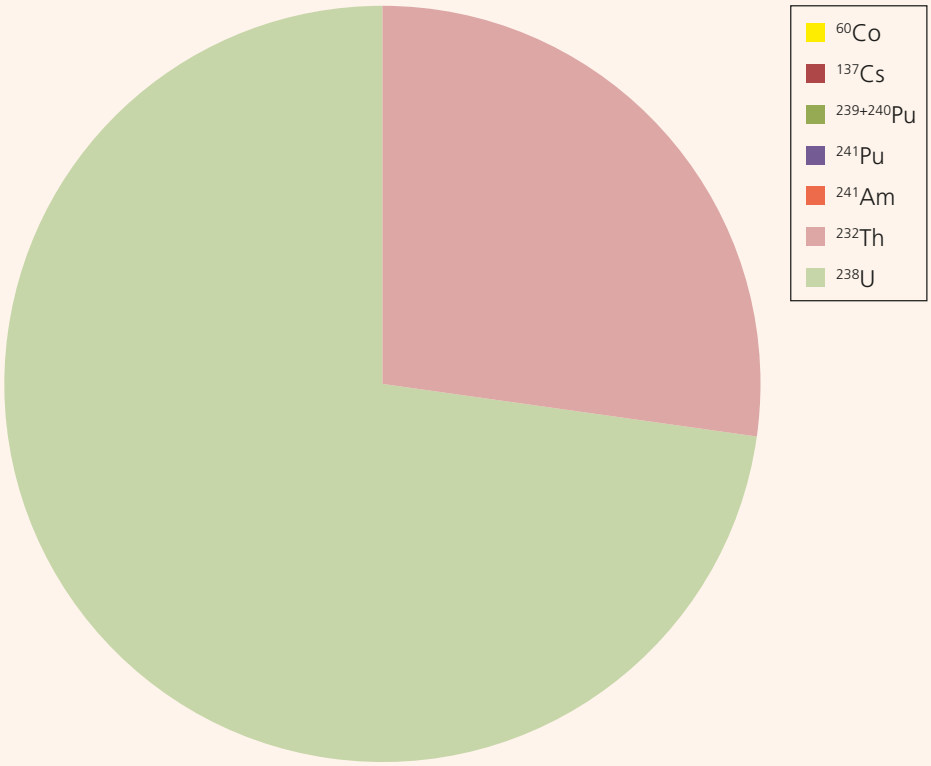



**Figure A5.2.** Radionuclide contribution to dose to individual members of the public due to dredging Hinkley Point C, Somerset, 2017

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
Clive House, 70 Petty France, London SW1H 9EX

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

ISSN 1365-6414