RIFE - 24

Radioactivity in Food and the Environment, 2018

Environment Agency

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Radioactivity in Food and the Environment, 2018

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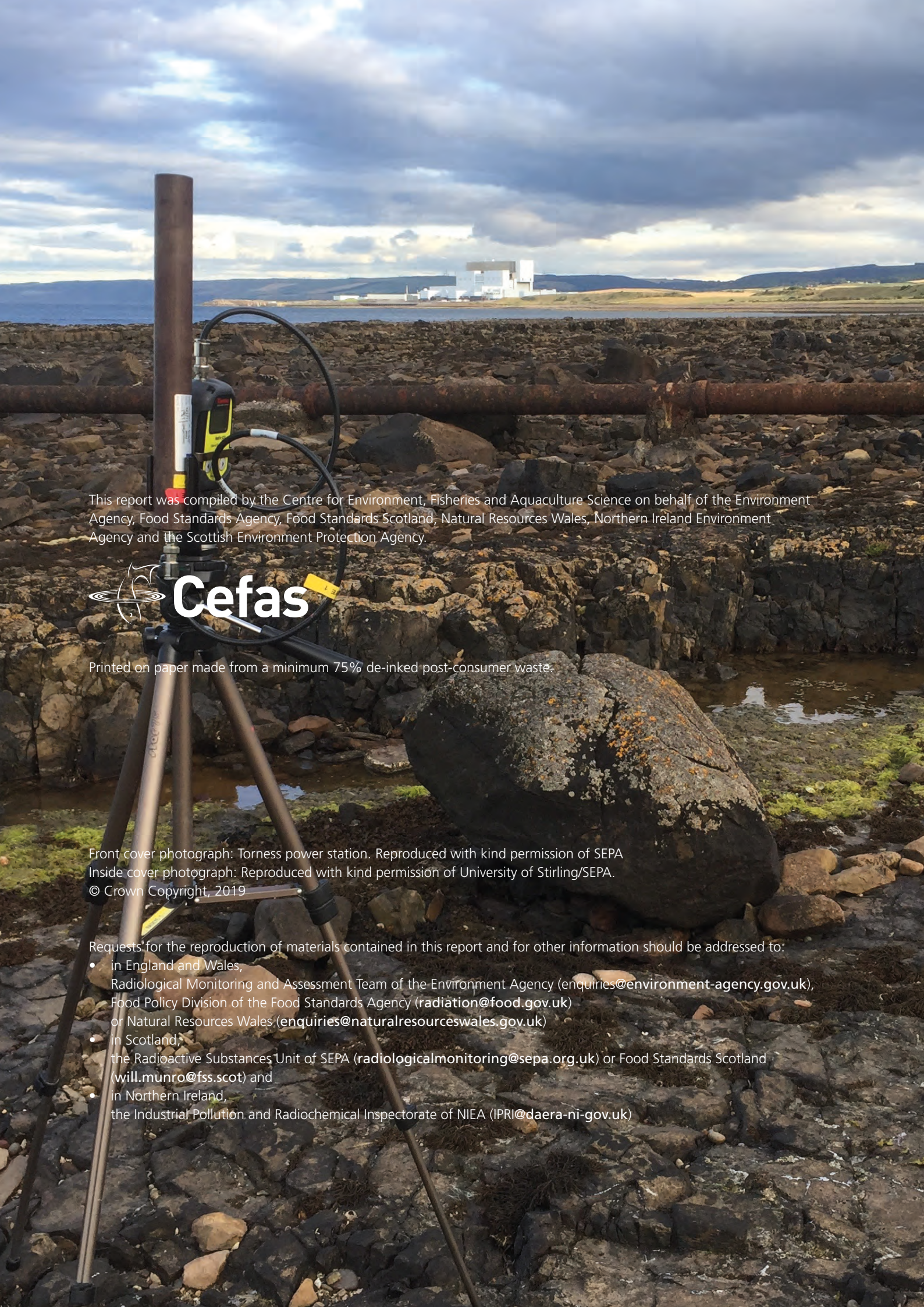
October 2019



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Preface

RIFE 24 sets out the findings of the UK-wide radiological monitoring programmes carried out in 2018. 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 across the UK. Results and subsequent assessments demonstrate that radioactivity in food and the environment is safe. Radiation exposures to members of the public resulting from authorised discharges and direct radiation near nuclear and non-nuclear sites are low and within dose limits.

As part of its withdrawal from the European Union, 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.

The UK continues to comply with other international commitments such as those under the OSPAR Convention. Last year we published a RIFE summary report (for the period 2004 – 2016) in support of the OSPAR requirement to demonstrate the application of the Best Available Techniques (BAT) for minimising radioactive discharges from civil nuclear facilities (2012 – 2016).

Technical summary

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

- Radiation exposures (doses) to people living around UK nuclear licensed sites
- Radioactivity concentrations in samples collected around UK nuclear licensed sites
- External dose rates measured 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 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.

Figure S and Table S show the assessed *total doses* in 2018 due to the combined effects of authorised/permitted waste discharges and direct exposure from the site ("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 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 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 for each habits profile are calculated and the 'representative person' is that profile which receives the highest dose.

In 2018, 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 2018 were the same as those in 2017. These were near Sellafield (0.37 mSv), Capenhurst (0.16 mSv) and Amersham (0.14 mSv). The doses received near Capenhurst and Amersham were dominated by direct radiation from sources on the sites.

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* *ICRP (2007) recommendations use the term 'representative person' for assessing doses to members of the public. It is defined as 'an individual receiving a dose that is representative of the more highly exposed individuals in the population'. Published RIFE reports published before 2013 referred to an average dose to individuals in a group of people 'the 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, the UK will 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. The Government has put in place all the necessary measures to ensure that the UK nuclear industry can continue to operate with certainty regardless of the outcome of negotiations with the European Union.*

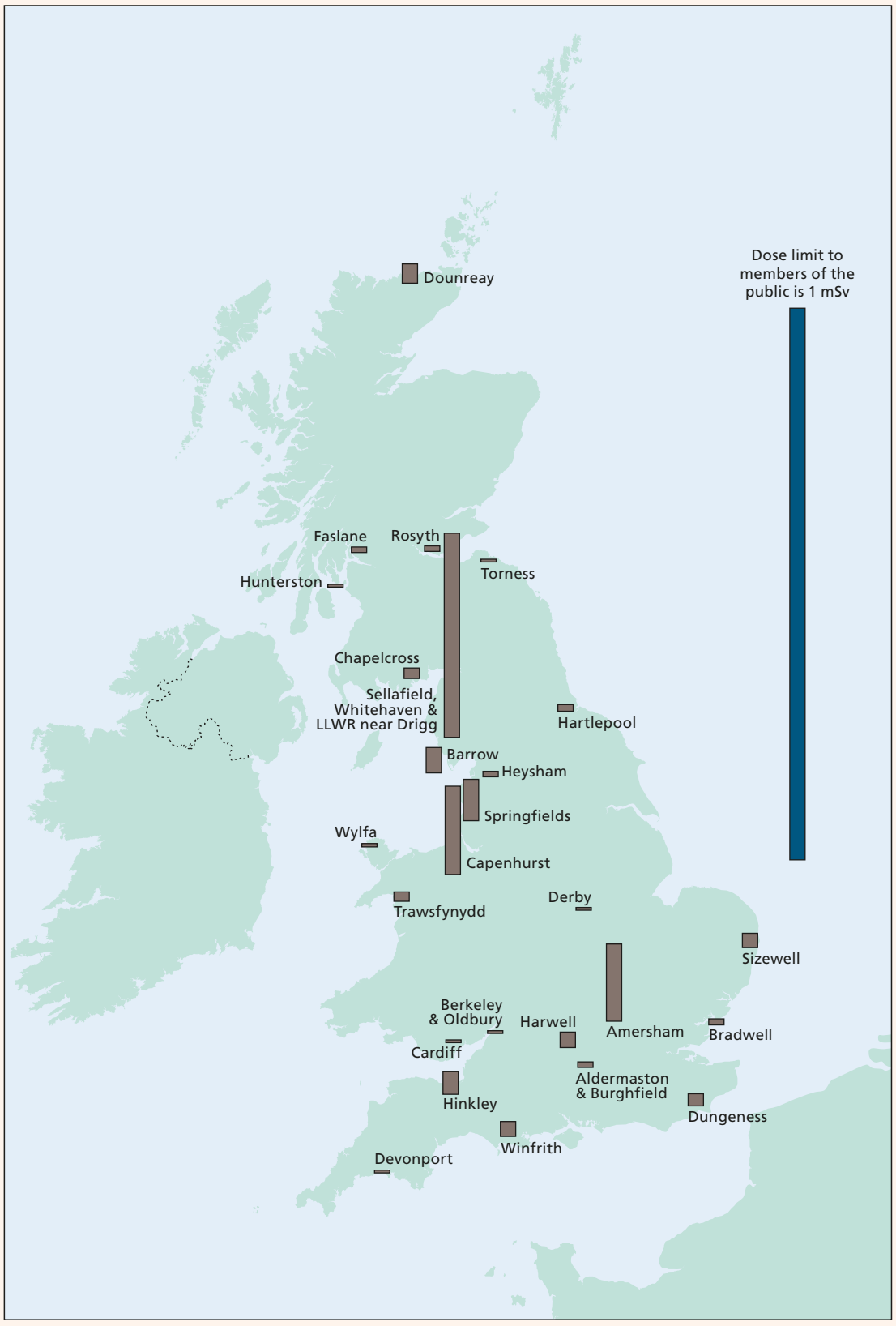


Figure S. *Total doses* in the UK due to radioactive waste discharges and direct radiation, 2018
(Exposures at Sellafield, Whitehaven and Drigg receive a significant contribution to the dose from technologically enhanced naturally occurring radionuclides from previous non-nuclear industrial operations)

Summary Table S *Total doses* due to all sources at major UK sites, 2018[a]

Establishment	Exposure, mSv[b] per year	Contributors[c]
Nuclear fuel production and processing		
Capenhurst	0.16	Direct radiation
Springfields	0.075	Direct radiation
Sellafield[e]	0.37	Crustaceans, ^{210}Po
Research establishments		
Dounreay	0.035	Meat - game, ^{137}Cs
Harwell	0.028	Direct radiation
Winfrith	0.027	Direct radiation
Nuclear power stations		
Berkeley and Oldbury	<0.005	Milk, ^{14}C, ^{35}S[c]
Bradwell	0.011	Direct radiation
Chapelcross	0.019	Milk, ^{90}Sr, ^{241}Am[d]
Dungeness	0.022	Direct radiation
Hartlepool	0.012	Direct radiation, gamma dose rate over sediment
Heysham	0.010	Gamma dose rate over sediment
Hinkley Point	0.041	Gamma dose rate over sediment
Hunterston	<0.005	Direct radiation
Sizewell	0.026	Direct radiation
Torness	<0.005	Wild fruit and nuts, root vegetables, ^{14}C, ^{90}Sr
Trawsfynydd	0.017	Exposure over sediment
Wylfa	0.006	Gamma dose rate over sediment
Defence establishment		
Aldermaston and Burghfield	0.010	Direct radiation
Barrow	0.046	Gamma dose rate over sediment
Derby	<0.005	Water, ^{60}Co[d]
Devonport	<0.005	Fish, gamma dose rate over sediment, ^{241}Am[d]
Faslane	0.008	Fish, gamma dose rate over sediment, ^{137}Cs, ^{241}Am
Rosyth	0.010	Gamma dose rate over sediment
Radiochemical production		
Amersham	0.14	Direct radiation
Cardiff	<0.005	Gamma dose rate over sediment
Industrial and landfill		
LLWR near Drigg[e]	0.37	Crustaceans, ^{210}Po
Whitehaven[e]	0.37	Crustaceans, ^{210}Po

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

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

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

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

[e] *The doses from man-made and naturally occurring radionuclides were 0.034 and 0.33 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*

The highest dose near Sellafield was mostly due to historical liquid discharges. In 2018, the representative person in the vicinity of the Sellafield site was a high-rate consumer of crustacean shellfish (who also consumed significant quantities of other seafood) and a change in the representative person from that in 2017 (adults consuming molluscan shellfish). The estimated dose was 0.37 mSv in 2018. Most of this dose (0.33 mSv) was due to the effects from the historical discharges of Technologically Enhanced Naturally Occurring Radioactive Material (TENORM) from the former phosphate processing plant near Whitehaven. The remainder of the dose (0.034 mSv) was due to the discharges of artificial radionuclides by the nuclear industry. In the previous year (for 2017), the representative person received a dose of 0.25 mSv (including a contribution of 0.18 mSv and 0.077 mSv related to the former phosphate processing plant and the nuclear industry, respectively). The increase in dose in 2018 near Sellafield was attributed to higher polonium-210 concentrations in crustaceans (both crabs and lobsters). 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 to convert an intake of radioactivity into a radiation dose). Polonium-210 is naturally present in the environment from radioactive decay of Naturally Occurring Radioactive Materials (NORM). Another source (in this region) has been from the radioactive decay of TENORM. TENORM 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 2018. 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 maximum dose for the representative person most affected by pathways related to gaseous discharge and direct radiation sources at Sellafield was 0.006 mSv in 2018 (down from 0.011 mSv in 2017). The decrease in the dose was attributed to the revision of habits information in 2018. The most exposed age group was infants in 2018 (a change in the representative person from that in 2017) and the dominant contribution to this dose was from the consumption of milk.

In Scotland, the representative person consuming food (fish, shellfish and wildfowl) harvested from areas along the Dumfries and Galloway coastline received the highest dose from authorised releases of radioactivity. The dose to adults (representative person) was 0.029 mSv in 2018. The decrease in dose from 0.035 mSv in 2017 was mostly due to lower americium-241 concentrations in crustacean shellfish (lobster). As in previous years, most of the dose in 2018 was due to the effects of past discharges from the Sellafield site.

In Wales, the representative person consuming locally produced food in the vicinity of the Trawsfynydd nuclear power station received the highest dose from permitted releases of radioactivity. The dose to 1 year-old infants (representative person) was 0.025 mSv in 2018. The dose in 2017 was 0.028 mSv and the decrease was mostly due to a lower reported less than value for americium-241 in milk in 2018.

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 2018 compared to those in 2017. Near Sellafield, the environmental concentrations of most radionuclides have declined over the last three decades, albeit much slower in recent years. However, in 2018, the concentration of plutonium-239+240 in lobsters collected near Sellafield is the lowest reported value in recent years.

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). As a result, reductions were made in sampling and analysis of some foods representing a very low radiological risk.

In 2018, a review of the 2009 UK Radioactive Discharge Strategy was published (BEIS, 2018a). 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 (RSS). 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 by taking it into account in setting and reviewing permit/authorisation limits and conditions.

External dose rates measured around UK nuclear licensed sites

Radioactivity in sediments in intertidal areas can potentially make a significant contribution to the total radiation exposure of members of the public. For this reason, *in situ* measurements of radiation dose rates are taken over exposed areas of sediment. These 'external doses' are included in the assessment of doses to the public where they are higher than natural background rates. To determine the dose to the public from any radioactivity that may be present, as a result of authorised/permitted discharges, natural background rates are subtracted from the measured dose rates in the assessment.

There were no major changes in external dose rates in intertidal areas in 2018 compared with 2017. At most locations, the external dose rates were close to background rates. Rates 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 2018, as a result of an ongoing programme of monitoring by the operator, radioactive items (particles and objects) from Sellafield were detected on Cumbrian beaches and removed (145 in 2018 calendar year). Public Health England (PHE) has previously 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. In 2018, the Environment Agency have asked PHE to review their health risk assessment to include the additional information available since the assessment was last updated in 2012. This review is scheduled to be completed in 2019.

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 2017). Fishing restrictions in a specific area around Dounreay are still in force under the Food and Environment Protection Act (FEPA) 1985.

'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 2018.

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 observed in the population.

In 2018, 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 Sellafield in England, at Dounreay in Scotland and Trawsfynydd in Wales. The findings were used to confirm the adequacy of current monitoring programmes or strengthen and update them with a better representation of relevant exposure pathways, and to improve the assessment of doses to members of the public near nuclear licensed sites.

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

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

(i) 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 was regarded as Technologically Enhanced Naturally Occurring Radioactive Material (TENORM). Discharges of TENORM have resulted in an increase in the concentrations of naturally occurring radionuclides in the environment, through the production of radioactive decay products (from the decay of long-lived radionuclides, previously discharged to sea).

Historically, concentrations of two of the decay products, polonium-210 and lead-210, in fish and shellfish (near Whitehaven) have been found to be higher than the

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

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 within or close to the expected ranges of natural background. Estimates of the activity concentrations 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 concentrations above background significantly influence the dose contribution from these radionuclides and similarly the estimated combined dose. The representative person in the area who consumed large amounts of seafood was estimated to receive a dose of 0.37 mSv in 2018. Polonium-210 was the most contributing radionuclide to the dose and results from the historical discharges from the former phosphate processing plant (near Whitehaven). The dose also includes a much smaller contribution from the effects of discharges from the nearby site at Sellafield.

Concentrations of tritium were found in leachate from some landfill sites, at quantities 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 radioactive contamination is ongoing at Dalgety Bay, Fife. Public protection measures have been established and these were maintained during 2018 and into 2019. This includes continuing a monthly beach monitoring and particle recovery programme. The FEPA Order issued by Food Standards Scotland (FSS) (then FSA in Scotland), prohibiting the collection of seafood from the Dalgety Bay area, remains in force. Work continues towards the implementation of the preferred management option for the remediation works. SEPA is continuing to work with the Ministry of Defence (MoD) and their contractors with regard to the remediation methodology for the site.

Further details can be found in Section 7.5 of this report and on the Radioactive Substances pages of SEPA's website: **https://www.sepa.org.uk/regulations/radioactive-substances/dalgety-bay/**.

(ii) Regional monitoring of radioactivity across the UK

Regional monitoring in areas remote from nuclear licensed sites has continued in 2018 (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 approximately 1 per cent (or less) of the annual limit of 1 mSv for members of the public in 2018. 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 0.5 per cent of the limit.

Food and sources of public drinking water that make up a general diet for people were analysed for radioactivity across the UK. Results show that artificial radionuclides only contributed a small proportion (less than 0.005 mSv) of the total public radiation dose in people's general diet in 2018.

The distribution of radionuclides in coastal seas continues to be monitored away from nuclear licensed sites. 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 dredged material from harbours and other areas is licensed under the Marine and Coastal Access Act (MCAA), 2009. In 2018, no requests were received by the Marine Management Organisation (MMO) to apply for additional licences for the disposal of dredged material at sea. Following an application to NRW for a licence in 2017 from NNB Genco (a subsidiary of EDF Energy), a programme of works was carried out to dredge material from the Severn Estuary (from near the Hinkley Point C power station development) for disposal to the estuary near Cardiff.

(iii) 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. European Commission (EC) controls on imported food and animal feed products from Japan continued in 2018. Following amendments in November 2017, only certain foods specified in the controls continue to require certification by the Japanese authorities. In addition, a proportion of Japanese imports into the European Union (EU) were monitored at ports of entry. None of the imports to the UK have contained radioactivity exceeding the maximum permissible levels in 2018. 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 2018, no significant radioactivity was detected at entry points and there was no need to introduce food safety controls on any consignments.

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 the Welsh Government. The monitoring programmes involved four specialist laboratories working together, each with rigorous quality assurance procedures, and a wide range of sample collectors throughout the UK. Overall, around 10,000 analyses and dose rate measurements were completed in 2018.

The results of the monitoring programmes 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 five 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 concentrations;
(vi) Reporting of detection limits (where the data are an average of more than one result) 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 (**https://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 2018 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 2013 (BSSD 13)
- The monitoring programme results support the UK meeting its international treaty obligations
- Annual doses are summarised for major industrial sites; all doses were below the legal limit in 2018

1.1 Scope and purpose of the monitoring programmes

In England and Wales, the FSA and the Environment Agency* conduct food and non-food (seawater, sediments, dose rate etc.) 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 2018. The regular national 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, and FSS has responsibility in Scotland. The Environment Agency, NIEA, NRW and SEPA, referred to together as the environment agencies in this report, are responsible for the regulation of environmental protection in England, Wales, Northern Ireland and Scotland, respectively; this includes the regulation of radioactive discharges and radioactive waste disposal from nuclear and other sites.

The Euratom Treaty provides for the establishment of uniform safety standards to protect the health of workers and of the general public. Basic safety standards are established through European Council Directives, the most recent one being the Basic Safety Standards Directive 2013 or "BSSD 13" (EC, 2014), laying down basic safety standards for protection against the dangers arising from exposure to ionising radiation. The RIFE report and the associated monitoring programmes conform to the requirements in Article 36 of the Euratom Treaty. Specifically, it provides estimates of annual 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 BSSD 13.

The Ionising Radiation (Basic Safety Standards) (Miscellaneous Provisions) Regulations 2018 (UK Statutory Instruments, 2018) came in to force on 8 May 2018 to transpose parts of BSSD 13 that could not be transposed within existing statutory regimes. These regulations impose duties on appropriate ministers to ensure that certain functions are carried out in relation to exposures from contaminated land, exposures from buildings or contaminated commodities and raising awareness and issuing guidance about orphan sources.

The requirements for the regulation of public exposure from the disposal of radioactive waste in England and Wales are set out in the Environmental Permitting (England and Wales) Regulations 2016 (EPR 16) (United Kingdom - Parliament, 2016), in particular in Schedule 23 of those regulations dedicated to "radioactive substances activities". These were amended by the Environmental Permitting (England and Wales) (Amendment) (No. 2) Regulations 2018 (EPR 18) which came into force on 2 May 2018 (United Kingdom - Parliament, 2018). The amended version makes minor revisions in order to transpose changes brought about by BSSD 13.

On 1 June 2018, the Radioactive Substances (Modification of Enactments) Regulations (Northern Ireland) 2018 (RSR 18) came into force for radioactive substances activities in Northern Ireland (Statutory Rules of Northern Ireland, 2018) by amending the Radioactive Substances Act 1993

* *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.*

(RSA 93) (United Kingdom - Parliament, 1993). A guidance document was published in August 2018, providing the scope of and exceptions from the radioactive substances legislation in England, Wales and Northern Ireland (BEIS, Defra, Welsh Government and DAERA, 2018)

On 1 September 2018, the Environmental Authorisations (Scotland) Regulations 2018 (EASR 18) came into force for radioactive substances activities in Scotland (Scottish Statutory Instruments, 2018) and replaced RSA 93 transposing BSSD 13. There are four types of authorisation under EASR 18: general binding rules, notification, registration and permit (more information can be found at: **https://www.sepa.org.uk/regulations/how-we-regulate/environmental-authorisations-scotland-regulations-2018/**). The new regulations aim to deliver an integrated authorisation framework, which will integrate, as far as possible, the authorisation, procedural and enforcement arrangements relating to water; waste management; radioactive substances and pollution prevention and control. The integrated authorisation framework is being developed in a phased manner, and currently, the regulations only apply to radioactive substances activities.

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 BSSD 13. The new Ionising Radiations Regulations 2017 (IRR 17) (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 IRR 17 (HSE, 2018). IRR 17 controls the radiation exposure of workers and the public other than that resulting from the permitted disposal of radioactive waste which are regulated by the environment agencies under the various permitting legislation described previously.

The Environment Agency and SEPA also have broader responsibilities under the Environment Act 1995 (United Kingdom – Parliament, 1995a) for environmental protection including determining general concentrations of pollution in the environment.

The monitoring programmes have several purposes:

- 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 legal dose limits
- 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

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).

In recent years, the Environment Agency, FSA, FSS and SEPA 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 was changed for the second half of the year (in 2018) to reflect the review outcomes, with reductions in sampling and analysis of some foods representing a very low radiological risk. 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.

In 2018, the Environment Agency carried out additional analyses of polonium-210 in shellfish samples, using samples collected by the FSA and NIEA (as part of their annual monitoring programmes). This work was undertaken to obtain baseline data of naturally sourced polonium-210 concentrations in the Irish Sea.

The analysis and measurements 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
- Public Health England (PHE)
- LGC Limited (LGC)

Building on the information derived from previous RIFE reports (RIFE 10 – 22, inclusive), the Environment Agency, FSA, FSS, NRW, NIEA, SEPA and BEIS 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 radiation doses

1.2.1 The assessment process

Most of the monitoring was carried out to check the effects of discharges from nuclear and non-nuclear operations on the food people consume and their environment. The results are used to assess annual radiation doses to the public that can then be compared with the relevant dose limits. Dose assessments are retrospective in that they apply to 2018, using monitoring results for that year. The radioactivity concentrations and dose rates reported include the combined radiological impact of all discharges, 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 the direct exposure (direct radiation) and radioactive discharges (gaseous and liquid) to the environment from nuclear licensed sites. This assessment gives an estimate of the annual *total dose* to people living in the vicinity of the nuclear licensed sites. *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 Office for Nuclear Regulation (ONR). For the 2018 calendar year (and beyond), EDF (Electricité de France) Energy have revised their method of direct dose assessment based on readings at the site boundary, distances and occupancy data (EDF Energy, 2018). This is different to the previous method based on generic arguments considering the low dose rates from Advanced Gas-cooled Reactor (AGR) and Pressurised Water Reactor (PWR) power stations. Therefore, the values will differ from the generic values given previously. The 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 have been profiled using an agreed method (Camplin *et al.*, 2005).

The second type of assessment estimates annual dose from specific sources and associated exposure pathways. These dose assessments check on the adequacy of the annual *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 - 'representative person'. These results are for comparison with legal limits.

The effective doses are calculated and compared with the legal dose limit of 1 mSv per year for members of the public. All legal radiation dose limits in the UK are based on recommendations made by the International Commission on Radiological Protection (ICRP, 2007) which are consistent with BSSD 13 (EC, 2014). The radiation dose specifically to skin is also assessed in some cases and compared with the legal limit for skin exposure.

The radiation doses resulting from human activities may be compared with the exposure from natural radioactivity. The average individual radiation dose in the UK population (in 2010) from natural radiation is estimated by Public Health England to be 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 people who may be exposed as a result of their work, but do not specifically work 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). Those people who work with ionising radiation have their radiation doses assessed and recorded, as part of their employer's programme to assess occupational exposure (United Kingdom - Parliament, 2017).

1.2.2 *Total dose* results for 2018

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

* *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.*

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 Liquid discharges 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

representative person receiving the highest annual 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 2018 were less than the annual 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 (from the relevant site), where it was applicable. The people most affected from liquid discharges were generally adult consumers of seafood or people who spend long periods of time over contaminated sediments.

The representative person, who received the highest annual *total dose*, consumed crustacean 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. The next highest annual *total doses* were received by inhabitants living near the Capenhurst and Amersham sites; these doses were almost entirely due to direct radiation from the sites.

1.2.3 *Total dose* trends

A time-series of annual *total dose* from 2007 - 2018 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 variation (from year to year) at most of the power station sites, and small variations in external dose rates had relatively large effects at some sites where intertidal occupancy were recorded at high-rates. Following the cessation of power production by Magnox reactors (e.g. at Dungeness), the effect has been a reduction in direct radiation at these sites.

The most significant trend in annual *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 in radiation doses 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 recent years, doses to these people have varied due to small differences in the concentrations of polonium-210 in local seafood.

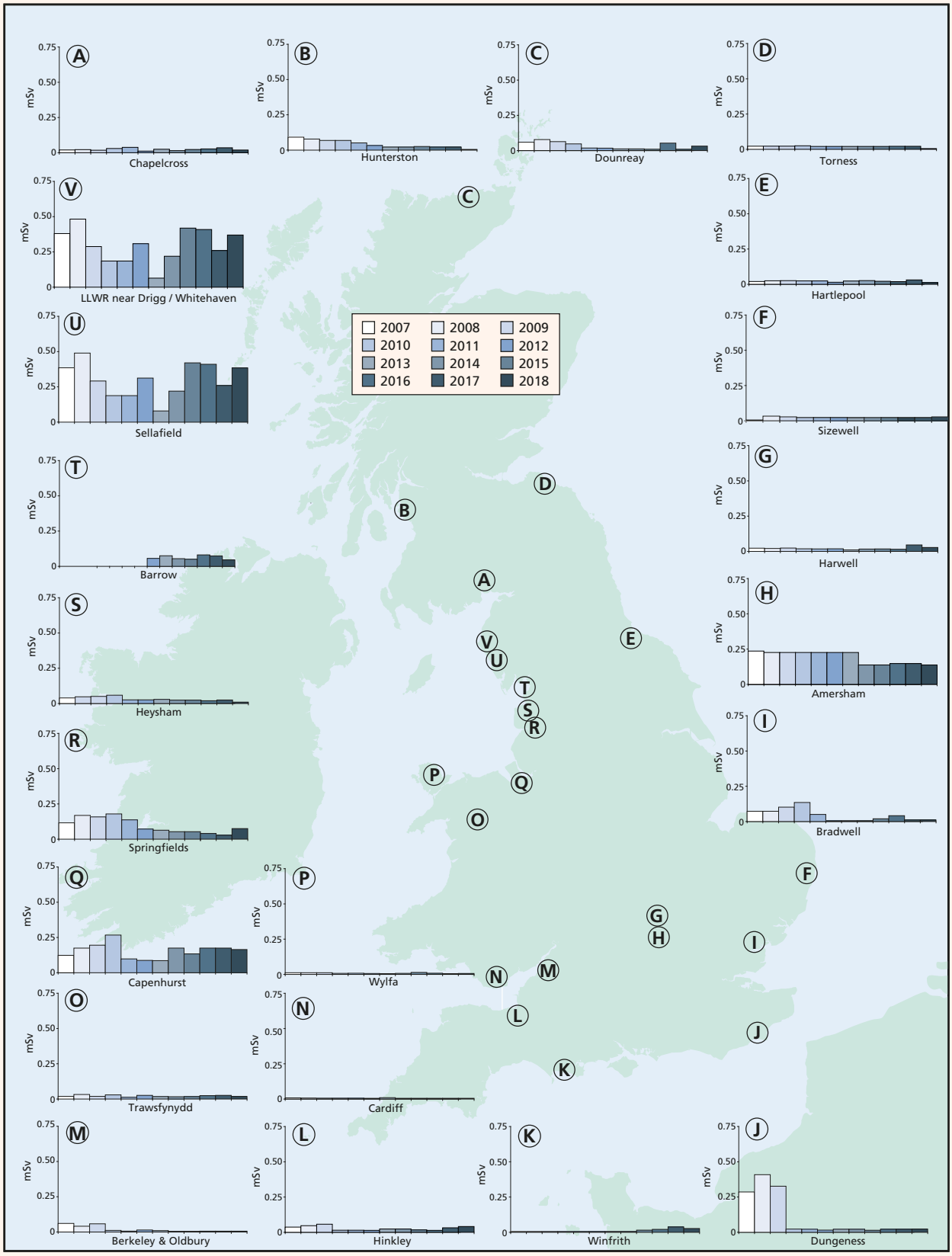


Figure 1.2. *Total doses* around the UK's nuclear sites due to radioactive waste discharges and direct radiation (2007-2018). (Exposures at Sellafield/Whitehaven/LLWR receive a significant contribution to the dose from technologically enhanced naturally occurring radionuclides from previous non-nuclear industrial operations)

Figure 1.3. Source specific doses in the UK, 2018 (Exposures at Whitehaven and Sellafield receive a significant contribution to the dose from technologically enhanced naturally occurring radionuclides from previous non-nuclear industrial operations)

The estimate of the annual *total dose* at Dounreay has decreased in recent years from the peak value in 2008. The increase in *total dose* at Dounreay in 2016 and 2018 was mostly due to the inclusion of the concentration of caesium-137 found in venison (game), which had not been sampled in other recent years. The changes in *total dose* at Heysham (2011), Hinkley Point (2010 and 2017) and Springfields (2012) were largely due to findings from new habits surveys. At Springfields, the increase in *total dose* in 2018 was due to higher estimate of direct radiation. At Capenhurst, any changes in annual *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 2018

The results of the source specific assessments for the main industrial sites in the UK are summarised in Figure 1.3 and Table 1.4. 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 from seafood consumption were at the LLWR near Drigg, and near Sellafield and Whitehaven. The majority of the dose was from non-nuclear industrial operations resulting in technologically enhanced concentrations of natural radionuclides, and to a much lesser 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*.

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 provide reassurance that the *total dose* approach is reasonable. Radiation doses to adults and children, calculated using the source specific method, were all found to be well below the legal limit of 1 mSv per year.

1.2.5 Protecting the environment

This report focusses on the risk to the public (i.e. that radiation doses remain below limits), but the protection of wildlife and the environment from radiation exposure resulting from human activity is also routinely considered by the environment agencies. The 2007 recommendations of the ICRP concluded that a systematic approach for the radiological assessment of non-human species was required to support the management of radiation effects in the environment (ICRP, 2007). ICRP therefore introduced the concept of Reference Animals and Plants (RAPs) for a system of radiological environmental protection (ICRP, 2008). ICRP have published their aims covering (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 and (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 European Commission directives, on the conservation of wild birds (CEC, 2009) and on the conservation of natural habitats and wild flora and fauna (CEC, 1992). These are implemented through the Conservation of Habitats and Species Regulations 2017, known as the "Habitats Regulations" (Statutory Instruments, 2017).

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 radiation dose to the worst affected organism was less than the agreed dose guideline (40 μGy h^{-1}) and hence it may be concluded that there was no significant impact on the integrity of habitat sites (Environment Agency, 2009a; 2009b). The assessment of impacts on non-human species is also an essential part of the Environment Agency's determination of applications for new and varied environment permits. 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.

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

In December 2018, SEPA opened a public consultation on a draft Nuclear Power Generation and Decommissioning Sector Plan to improve the Scottish environment. The plan presents SEPA's vision for the sector and sets out actions to maintain the current high levels of compliance obligations and continue to go beyond compliance standards. More information describing the consultation can be found at: **https://consultation.sepa.org.uk/sector-plan/nuclear-power-generation-and-decommissioning/**.

The Nuclear Power Generation and Decommissioning Sector Plan was published in May 2019 and is available on SEPA's website: **https://sectors.sepa.org.uk/nuclear-power-generation-and-decommissioning-sector-plan/**.

1.3 Sources of radiation exposure

1.3.1 Radioactive waste disposal from nuclear licensed sites

The permits* and authorisations issued by the environment agencies to nuclear sites require the operators to minimise the generation of radioactive waste in all its forms. Also, to ensure that any liquid or gaseous discharges that are necessary are subject to strict limits and conditions. Solid Low Level Waste (LLW) from nuclear licensed sites may be transferred to the Low Level Waste Repository (LLWR) near Drigg for disposal and solid wastes containing low quantities of radioactivity can also be disposed of to permitted 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.

Figure 1.4 shows the nuclear licensed sites that produce waste containing artificial radionuclides. Nuclear licensed sites are permitted/authorised to dispose of radioactive waste and are also subject to the Nuclear Installations Act 1965 (United Kingdom - Parliament, 1965). The monitoring programmes reported here cover all of these sites.

Discharges of radioactive waste from other "non-nuclear" sites such as hospitals, industrial sites and research establishments were also regulated under RSA 93 or EPR 16 (and thereafter, under EPR 18, RSR 18 or EASR 18) in 2018, but not subject to the Nuclear Installations Act. Occasionally, radioactivity is detected in the environment during monitoring programmes because of discharges from these other sites. For example, iodine-131 discharged 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 historical 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.

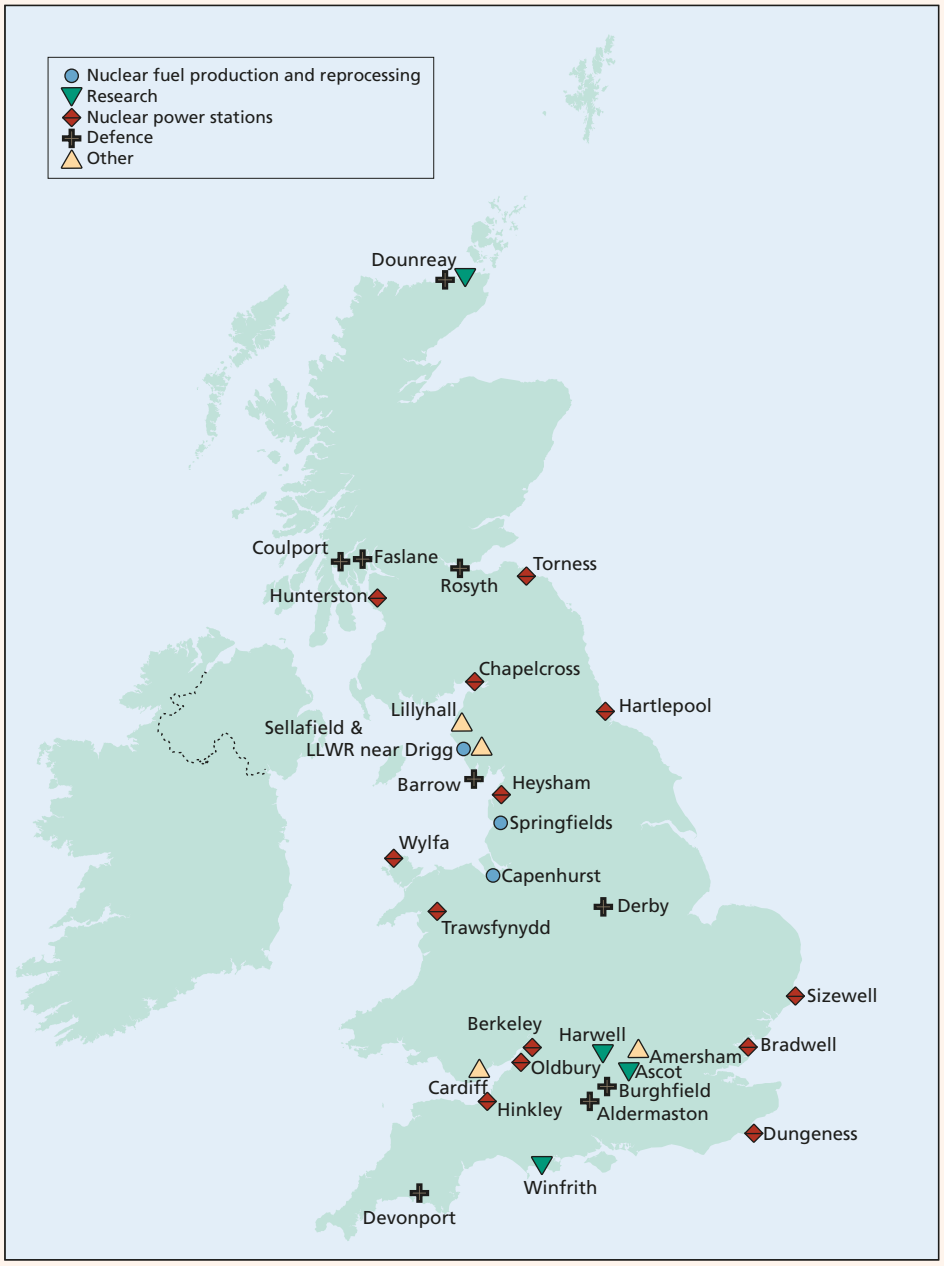
Principal permitted/authorised discharges, disposals of radioactive wastes and solid waste transfers from nuclear establishments in 2018, are given in Appendix 2 (Tables A2.1 - A2.4, inclusive). The tables also list the main discharge and disposal limits that are specified or, in the case of the MoD, administratively agreed. In 2018, discharges and disposals were all below the limits. 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 ensure that discharges and their impact are minimised. The principles of Best Practicable Means (BPM) continue to be applied in Scotland (SEPA, 2012a).

The discharges and disposals made by sites do not normally fluctuate significantly. 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

* *In England and Wales, the term 'permit' replaced 'authorisation' under the Environmental Permitting Regulations (EPR). 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 EPR coming into force in 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, 2018 (Showing main initial operation. Some operations are undergoing decommissioning)



has been a breach of limits, or if appropriate actions have not been undertaken to ensure discharges are minimised, 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 2018.

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 (formerly DECC) 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 Environment Agency, BEIS and the Scottish and Welsh Governments (collectively/individually) have issued guidance and developed environmental principles. These are also summarised in earlier RIFE reports (e.g. Environment Agency, FSA, FSS, NIEA, NRW and SEPA, 2018).

In June 2018, the UK Government published its review of the 2009 UK Strategy for Radioactive Discharges (BEIS, 2018a). 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 (RSS). 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 **https://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, 2019). 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, 2018b; c). 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 long been established in the UK. The reports *"Safeguarding Our Seas"* in 2002 (Defra, Scottish Executive and Welsh Assembly Government, 2002) and "*Charting Progress 2*" in 2010 (Defra, 2010), provide the strategy and an assessment on the state of the UK seas. Further information concerning other individual and fully integrated assessments is available in earlier RIFE reports (e.g. Environment Agency, FSA, FSS, NIEA, NRW and SEPA, 2018).

The EC has also considered various options for a 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. More information concerning the basis of the White Paper, 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 regulators completed Generic Design Assessments (GDAs) for Westinghouse's AP1000® design and for Hitachi GE's UK ABWR design in 2017. ONR and the Environment Agency are currently assessing one new nuclear reactor design, the GDA of the China General Nuclear (CGN) designed UK HPR1000 (intended for deployment at Bradwell B in Essex). 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 2017. ONR and the Environment Agency began the first assessment step of GDA (Step 2) in November 2017. On 15 November 2018, the regulators concluded that the information submitted by GNS during Step 2 was sufficient to allow the start of Step 3. A statement of findings following the initial stage of generic design assessment has been reported (Environment Agency, 2018).

Construction of NNB GenCo's new twin UK European Pressurised Reactor™ (EPR™) nuclear power station at Hinkley Point C in Somerset continues at pace. In 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 in order 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 Agency are continuing to work with the companies seeking to construct new nuclear power stations at:

- 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 (United Kingdom - Parliament, 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), manages the decommissioning and clean-up of the civil public sector nuclear sites (plus the associated liabilities and assets). The NDA reports to BEIS and is responsible to Scottish ministers. 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 business plan for 2019/22 is available (NDA, 2019). The health and socio-economic impacts of the strategy have been considered (NDA, 2016b). In 2017, the NDA published an inventory and forecast of radioactive wastes in the UK (as of 1 April 2016) jointly with BEIS (NDA and BEIS, 2017). In July 2018, the NDA published a strategy seeking to review the NDA's approach to collecting and compiling inventory data, with regard to identifying credible options (Stage A) and proposing a preferred option (Stage B) and an Integrated Waste Management Strategy that applies to all radioactive waste generated within the NDA estate (NDA, 2018a; b).

In 2007, the UK Government and Devolved Administrations issued a UK-wide policy document, setting out principles

Figure 1.5. Potential sites for new nuclear power stations

for the long-term management of LLW (Defra, DTI and the Devolved Administrations, 2007). In response to the policy, the NDA developed and published a strategy for the management of solid low level radioactive waste in the nuclear industry; "*UK Strategy for the Management of Solid Low-Level Radioactive Waste from the Nuclear Industry*" (NDA, 2010). It was also acknowledged that a UK-wide strategy was needed for solid radioactive waste arising from the non-nuclear industry. A new UK LLW Strategy was published in 2016 (DECC, Scottish Government, Welsh Government and Northern Ireland Department of Environment, 2016).

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

The UK Government's framework was set out in the 2008 Implementing Geological Disposal White Paper for managing HAW in the long-term through geological disposal and includes the possibility of hosting a Geological Disposal Facility (GDF) at some point in the future (Defra, Department for Business, Enterprise and Regulatory Reform, Welsh Assembly Government and Northern Ireland Assembly, 2008). An updated framework was set out in the 2014 White Paper (as a replacement in England and Northern Ireland) and sets out the policy for managing HAW in the long term through geological disposal (DECC, 2014a). The 2014 White Paper also 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" underpin the work: National Geological Screening (NGS); Working with Communities;

and Land-use Planning. A summary of the responses to the Government consultation for Working with Communities, and an updated framework for the long-term management of HAW, were published in December 2018 (BEIS, 2018b; c). The NDA has developed an "Industry Guidance" on the interim storage of packaged HAW, effective from January 2017 (NDA, 2016c). In supporting the Secretary of State for BEIS, in meeting his obligations under the Habitats Regulations, a draft report has been produced regarding the National Policy Statement for Geological Disposal Infrastructure in January 2018 (BEIS, 2018d). It will apply to the development of these facilities in England only.

No specific GDF sites have been selected or are currently under consideration (BEIS, 2018c). Further information on the aspects of GDF is available on the GOV.UK website: **https://www.gov.uk/government/collections/geological-disposal-facility-gdf-for-high-activity-radioactive-waste**.

Radioactive waste management is a devolved policy issue. Therefore, the Scottish Government, Welsh Government and Northern Ireland Executive each have responsibility for determining 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 HAW 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 HAW following consultation in 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. The Welsh Government consulted on 'Geological Disposal of Radioactive Waste: Working with Communities' between January and April 2018 and their policy on this issue was published on 16 January 2019 (Welsh Government, 2019).

The Northern Ireland Executive also 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 HAW, recognising that it is in the best interests of Northern Ireland that these wastes are managed in the safest and most secure manner. The recent 'Working with Communities' consultation was published jointly by BEIS and the Department of Agriculture, Environment and Rural Affairs (DAERA) in Northern Ireland (BEIS and DAERA, 2018). Future policy decisions in relation to geological disposal in Northern Ireland would be a matter for the Northern Ireland Executive, which is currently suspended. Accordingly, in the continued absence of the Executive, no further policy commitments can be given at this time.

The Committee on Radioactive Waste Management (CoRWM) continues to provide independent scrutiny of the Government's long-term management, storage and disposal of radioactive waste. CoRWM has published its annual report for 2017 – 18 (CoRWM, 2018a) and proposed work programme for 2018 – 2021 (CoRWM, 2018b). On 25 October 2018, CoRWM presented a position paper on selecting a site based on the 'best geology' for a GDF (CoRWM, 2018c).

Some low level radioactive waste, mostly from non-nuclear sites, and some very low level radioactive waste is currently disposed of in landfill by controlled burial (Section 7). There is still a large amount of solid low level radioactive wastes that will require disposal. Some will be sent to the LLWR near Drigg. The low level radioactive waste from Dounreay can be disposed of at the new Dounreay LLW Facility close to the site, and further alternative disposal options are also being considered.

Guidance on requirements for authorisation for geological and near-surface disposal facilities has been issued (Environment Agency and NIEA, 2009; Environment Agency, NIEA and SEPA, 2009; 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 2017, SEPA issued guidance on the shipment of wastes which contain Naturally Occurring Radioactive Material (NORM) (SEPA, 2017b). Also, in 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 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 responses to a consultation (completed in 2016) 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. Further information relevant to the UK NORM Waste Strategy, published in 2014, is available in earlier RIFE reports (e.g. Environment Agency, FSA, FSS, NIEA, NRW and SEPA, 2018).

1.3.4 Solid radioactive waste disposal at sea

In the past, packaged solid waste of low radioactivity concentrations 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. In Northern Ireland, Scotland and Wales, licences for disposal of dredged material at sea are the responsibility of the Department of Environment (NIEA), the Scottish Government (Marine Scotland) and NRW, respectively.

The protection of the marine environment is considered before a licence is issued. Since dredged 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 dredged spoil disposal (IAEA, 2003; 2015) and which has been adapted to reflect operational practices in England and Wales (McCubbin and Vivian, 2006). In 2018, no new requests were received to apply for additional licences for the disposal of dredged material at sea, however following an application to NRW for a licence in 2017 from NNB Genco, a program of works was carried out in 2018. This comprised of removing dredged material from the Severn Estuary (near the Hinkley Point C power station development) for disposal in the estuary near Cardiff. This activity was regulated by NRW with scientific support from Cefas. The work, which included specific monitoring requirements and radiological assessment, was completed within the conditions and parameters of the licence, and there was no concern on food and the environment from the works.

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, 2019). General monitoring of the British Isles is carried out as part of the programmes described in this report, to detect any significant effects from the sources above. No such effects were found in 2018. 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 March 2019) 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 concentrations 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 Shale Environmental Regulator Group (SERG) was launched on the 5 October 2018. It brings the onshore oil and gas regulators (Environment Agency, Health and Safety Executive and the Oil and Gas Authority) together as a virtual regulatory group for the environmental aspects of shale gas exploration and production. SERG acts as a single face for local communities, local authorities and industry, provides transparency and clarity to the public and helps to resolve regulatory issues on sites and shares best practice with local authorities considering shale gas applications.

To date, the Environment Agency has granted two permits for hydraulic fracturing at the sites Preston New Road, near Blackpool 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. 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. In Scotland, clear dose criteria are set for homogeneous and heterogeneous contamination. Also, the risk (probability, or frequency, of occurrence) receiving the dose should be taken into account for the designation of radioactive contaminated land. To date, no site has been designated as 'contaminated land' due to radioactivity in Scotland.

In January 2018, BEIS undertook a targeted consultation process on proposed updates on the statutory guidance for radioactive contaminated land on behalf of the UK and Welsh Governments. Updates have subsequently been made to the statutory guidance for England, which was published in June 2018 (BEIS, 2018e).

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 activity concentrations 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 gases). The average individual dose from exposure to all significant sources of ionising radiation was estimated to be about 2.7 mSv per year, 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 per year, 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 annual dose was from man-made sources; and of this, the majority was from radionuclides released (global fallout) during historical testing of nuclear weapons in the atmosphere from the 1950s and 1960s (hereafter referred to as "nuclear weapons testing"), with exposure to radionuclides routinely discharged by industry contributing less than 0.01 per cent to the total dose. The average individual dose from medical sources was about 0.4 mSv per year, or about 16 per cent of the dose from all sources of radiation. Occupational exposure contributed significantly less than 1 per cent of the dose. Further information, including the most recent breakdown of the average individual dose to the UK population by source of exposure (as a pie chart), is available on the website: **https://www.gov.uk/government/publications/ionising-radiation-exposure-of-the-uk-population-2010-review**.

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, 2018*

Site	Exposure[a], mSv
Nuclear fuel production and reprocessing	
Capenhurst	0.16
Sellafield	0.004
Springfields	0.075
Research establishments	
Dounreay	0.003
Harwell	0.028
Winfrith	0.027
Nuclear power stations	
Berkeley	Bgd[b]
Bradwell	0.011
Chapelcross	Bgd[b]
Dungeness	0.021[c,#]
Hartlepool	<0.006
Heysham	<0.004[d]
Hinkley Point	<0.001[e]
Hunterston	0.003[f]
Oldbury	Bgd[b]
Sizewell	<0.025[g,#]
Torness	<0.003
Trawsfynydd	Bgd[b]
Wylfa	Bgd[b]
Defence establishments	
Aldermaston	0.010
Barrow	Bgd[b]
Burghfield	Bgd[b]
Derby	Bgd[b]
Devonport	Bgd[b]
Faslane	<0.001
Rosyth	0.002
Dounreay (Vulcan)	Bgd[b]
Radiochemical production	
Amersham	0.14
Cardiff	Bgd[b]
Industrial and landfill sites	
LLWR near Drigg	0.051
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*

\# *Reported dose to site workers, adjacent to the station, is higher than that to a member of the public outside of the combined site boundary*

[a] *Data presented to 2 significant figures or 3 decimal places. Data below 0.001 are reported as <0.001. For EDF sites, the highest dose, irrespective of age group and activity is reported*

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

[c] *Datum for Dungeness A. Dungeness B (<0.001) not used. The dose to workers at Dungeness A from Dungeness B was <0.003 The dose to workers at Dungeness B from Dungeness A was 0.040*

[d] *Datum for Heysham 1. Heysham 2 (<0.003) not used*

[e] *Datum for Hinkley B. Hinkley A (Bgd[b]) not used. The dose to workers at Hinkley A from Hinkley B was 0.002*

[f] *Datum for Hunterston B. Hunterston A (0.002) not used*

[g] *Datum for Sizewell B. Sizewell A (Bgd[b]) not used. The dose to workers at Sizewell A from Sizewell B was <0.035*

Table 1.2 *Total doses* integrated across pathways, 2018

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)	0.14[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	Local child inhabitants (0–0.25km)	0.16[g]	Direct radiation
Cardiff	Infant milk consumers	<0.005	Milk, ^{14}C, ^{32}P[c], ^{35}S
Chapelcross	Infant milk consumers	0.019	Milk, ^{90}Sr, ^{241}Am[c]
Derby	Children potato consumers	<0.005[g]	Potatoes, ^{234}U[c], ^{235}U, ^{238}U
Devonport	Prenatal children of root vegetable consumers	<0.005	Fish, root vegetables, ^{3}H[c]
Dounreay	Adult game meat consumers	0.035	Meat - game, ^{137}Cs
Dungeness	Local adult inhabitants (0–0.25km)	0.022	Direct radiation
Faslane	Adult honey consumers	<0.005	Gamma dose rate over sediment, honey, ^{137}Cs
Hartlepool	Local adult inhabitants (0–0.25km)	0.012	Direct radiation, gamma dose rate over sediment
Harwell	Local adult inhabitants (0–0.25km)	0.028	Direct radiation
Heysham	Local adult inhabitants (0–0.25km)	0.007	Direct radiation, gamma dose rate over sediment, external and inhalation, ^{14}C
Hinkley Point	Infant milk consumers	0.006	Milk, ^{14}C, ^{35}S, ^{60}Co[d]
Hunterston	Prenatal children of local inhabitants (0.5–1km)	<0.005	Direct radiation
LLWR near Drigg	Local infant inhabitants (0.5–1km)	0.053	Direct radiation
Rosyth	Local adult inhabitants (0.5–1km)	0.007	Direct radiation, gamma dose rate over sediment
Sellafield	Infant milk consumers	0.006[g]	Milk, ^{14}C, ^{90}Sr, ^{129}I, ^{137}Cs
Sizewell	Local adult inhabitants (0–0.25km)	0.026	Direct radiation
Springfields	Local adult inhabitants (0.5–1km)	0.075[g]	Direct radiation
Torness	Prenatal children of wild fruit and nut consumers	<0.005	Wild fruit and nuts, root vegetables, ^{14}C, ^{90}Sr
Trawsfynydd	Prenatal children of green vegetable consumers	<0.005	Exposure over sediment, potatoes, ^{14}C, ^{137}Cs
Winfrith	Local adult inhabitants (0.25–0.5km)	0.027	Direct radiation
Wylfa	Local infant inhabitants (0.25–0.5km)	<0.005	Direct radiation, milk, ^{14}C, ^{35}S
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	0.046	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	<0.005	Gamma dose rate over sediment
Cardiff	Adult occupants over sediment	<0.005	Gamma dose rate over sediment
Chapelcross	Adult wildfowl consumers	0.008	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, gamma dose rate over sediment, ^{241}Am[c]
Dounreay	Adult occupants over sediment	0.005	Gamma dose rate over sediment
Dungeness	Adult fish consumers	<0.005	Fish, ^{241}Am
Faslane	Adult fish consumers	0.008	Fish, gamma dose rate over sediment, ^{137}Cs, ^{241}Am
Hartlepool	Adult occupants over sediment	0.012	Direct radiation, gamma dose rate over sediment
Harwell	Adult occupants over sediment	<0.005	Gamma dose rate over riverbank
Heysham	Adult occupants over sediment	0.010	Gamma dose rate over sediment
Hinkley Point	Adult occupants over sediment	0.041	Gamma dose rate over sediment
Hunterston	Adult fish consumers	<0.005	Fish, ^{137}Cs, ^{241}Am

Table 1.2 continued

Site	Representative person[a]	Exposure, mSv Total	Dominant contributions[b]
LLWR near Drigg[e]	Adult crustacean consumers	0.37[f]	Crustaceans, ^{210}Po
Rosyth	Adult occupants over sediment	0.010	Gamma dose rate over sediment
Sellafield[e]	Adult crustacean consumers	0.37[f]	Crustaceans, ^{210}Po
Sizewell	Adult occupants over sediment	0.008	Direct radiation
Springfields	Adult occupants on houseboats	0.033	Gamma dose rate over sediment
Torness	Adult mollusc consumers	<0.005	Fish, molluscs, ^{110m}Ag, ^{241}Am
Trawsfynydd	Adult occupants over sediment	0.017	Exposure over sediment
Whitehaven[e]	Adult crustacean consumers	0.37[f]	Crustaceans, ^{210}Po
Winfrith	Prenatal children of occupants over sediment	0.009	Direct radiation
Wylfa	Adult occupants over sediment	0.006	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)	0.14[g]	Direct radiation
Barrow	Adult occupants on houseboats	0.046	Gamma dose rate over sediment
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	Local child inhabitants (0–0.25km)	0.16[g]	Direct radiation
Cardiff	Adult occupants over sediment	<0.005	Gamma dose rate over sediment
Chapelcross	Infant milk consumers	0.019	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, gamma dose rate over sediment, ^{241}Am[c]
Dounreay	Adult game meat consumers	0.035	Meat - game, ^{137}Cs
Dungeness	Local adult inhabitants (0–0.25km)	0.022	Direct radiation
Faslane	Adult fish consumers	0.008	Fish, gamma dose rate over sediment, ^{137}Cs, ^{241}Am
Hartlepool	Local adult inhabitants (0–0.25km)	0.012	Direct radiation, gamma dose rate over sediment
Harwell	Local adult inhabitants (0–0.25km)	0.028	Direct radiation
Heysham	Adult occupants over sediment	0.010	Gamma dose rate over sediment
Hinkley Point	Adult occupants over sediment	0.041	Gamma dose rate over sediment
Hunterston	Prenatal children of local inhabitants (0.5–1km)	<0.005	Direct radiation
LLWR near Drigg[e]	Adult crustacean consumers	0.37[f]	Crustaceans, ^{210}Po
Rosyth	Adult occupants over sediment	0.010	Gamma dose rate over sediment
Sellafield[e]	Adult crustacean consumers	0.37[f]	Crustaceans, ^{210}Po
Sizewell	Local adult inhabitants (0–0.25km)	0.026	Direct radiation
Springfields	Adult mushroom consumers	0.075	Direct radiation
Torness	Prenatal children of wild fruit and nut consumers	<0.005	Wild fruit and nuts, root vegetables, ^{14}C, ^{90}Sr
Trawsfynydd	Adult occupants over sediment	0.017	Exposure over sediment
Whitehaven[e]	Adult crustacean consumers	0.37[f]	Crustaceans, ^{210}Po
Winfrith	Local adult inhabitants (0.25–0.5km)	0.027	Direct radiation
Wylfa	Adult occupants over sediment	0.006	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*

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

[f] *The doses from man-made and naturally occurring radionuclides were 0.034 and 0.33 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	2018
Aldermaston & Burghfield	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	0.010	0.010
Amersham	0.22	0.22	0.22	0.14	0.14	0.15	0.15	0.14
Barrow		0.057	0.076	0.055	0.051	0.082	0.074	0.046
Berkeley & Oldbury	0.006	0.014	0.010	<0.005	<0.005	0.006	<0.005	<0.005
Bradwell	0.048	<0.005	<0.005	<0.005	0.017	0.036	0.011	0.011
Capenhurst	0.095	0.085	0.080	0.17	0.13	0.17	0.17	0.16
Cardiff	0.006	0.005	0.010	<0.005	<0.005	<0.005	<0.005	<0.005
Chapelcross	0.037	0.011	0.024	0.014	0.022	0.026	0.035	0.019
Derby	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Devonport	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Dounreay	0.018	0.017	0.012	0.012	0.010	0.058	0.010	0.035
Dungeness	0.021	0.015	0.021	0.021	0.014	0.021	0.021	0.022
Faslane	<0.005	<0.005	<0.005	<0.005	<0.005	0.009	<0.005	0.008
Hartlepool	0.025	0.015	0.024	0.027	0.022	0.020	0.031	0.012
Harwell	0.017	0.018	0.010	0.016	0.017	0.015	0.046	0.028
Heysham	0.025	0.025	0.028	0.023	0.023	0.019	0.025	0.010
Hinkley Point	0.014	0.013	0.022	0.022	0.016	0.013	0.032	0.041
Hunterston	0.050	0.032	0.021	0.021	0.025	0.021	0.023	<0.005
LLWR near Drigg[b]	0.18	0.30	0.061	0.22	0.42	0.41	0.25	0.37
Rosyth	<0.005	<0.005	<0.005	<0.005	0.006	0.017	0.026	0.010
Sellafield[b]	0.18	0.30	0.076[c]	0.22	0.42	0.41	0.25	0.37
Sizewell	0.021	0.021	0.021	0.020	0.021	0.021	0.021	0.026
Springfields	0.13	0.068	0.060	0.050	0.050	0.038	0.028	0.075
Torness	0.020	0.020	0.020	0.020	0.020	0.021	0.021	<0.005
Trawsfynydd	0.012	0.025	0.017	0.013	0.014	0.019	0.024	0.017
Whitehaven[b]	0.18	0.30	0.061	0.22	0.42	0.41	0.25	0.37
Winfrith	<0.005	<0.005	<0.005	<0.005	0.014	0.019	0.038	0.027
Wylfa	0.008	0.006	<0.005	0.007	0.013	0.008	<0.005	0.006

[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, 2018*

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	0.006	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	0.012	Ext
	Terrestrial foods, external and inhalation near site	G	<0.005[i]	^{14}C, $^{90}Sr^{d}$, $^{129}I^{d}$, ^{234}U, ^{238}U
	External in intertidal areas (children playing)[a,h]	L	<0.005	Ext
	Occupancy of houseboats	L	0.034	Ext
	External in intertidal areas (farmers)	L	0.023	Ext
	Wildfowl consumers	L	<0.005	Ext
	External (skin) to fishermen	L	0.010[g]	Beta
Sellafield[f]	Fish and shellfish consumption and external in intertidal areas (2014-2018 surveys) (excluding naturally occurring radionuclides)[l]	L	0.070	Ext, ^{241}Am
	Fish and shellfish consumption and external in intertidal areas (2014-2018 surveys) (including naturally occurring radionuclides)[m]	L	0.40	^{210}Po
	Fish and shellfish consumption and external in intertidal areas (2018 surveys) (excluding naturally occurring radionuclides)[l]	L	0.066	Ext, ^{241}Am
	Terrestrial foods, external and inhalation near Sellafield[j]	G	0.011	^{14}C, ^{90}Sr, ^{129}I, ^{241}Am
	Terrestrial foods at Ravenglass[j]	G/L	0.018	$^{106}Ru^{d}$, $^{144}Ce^{d}$
	External in intertidal areas (Ravenglass)[a]	L	0.008	Ext
	Occupancy of houseboats (Ribble estuary)	L	0.034	Ext
	Occupancy of houseboats (Barrow)	L	0.045	Ext
	External (skin) to bait diggers	L	0.064[g]	Beta
	Handling of fishing gear	L	0.092[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	0.006	Ext
	Terrestrial foods, external and inhalation near site	G	0.019	^{137}Cs, $^{238}Pu^{c}$, $^{239+240}Pu$, ^{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, ^{241}Am
	Occupancy of houseboats	L	0.013	Ext
	Terrestrial foods, external and inhalation near site[j]	G	<0.005	^{14}C, $^{35}S^{c}$
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	0.011	Ext, $^{239+240}Pu$ ^{241}Am
	Crustacean consumption	L	<0.005	^{90}Sr, $^{137}Cs^{d}$, $^{239+240}Pu$, ^{241}Am
	Terrestrial foods, external and inhalation near site[j]	G	0.014	^{90}Sr, $^{241}Am^{d}$
Dungeness	Fish and shellfish consumption and external in intertidal areas	L	<0.005	^{241}Am
	Occupancy of houseboats	L	<0.005	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	0.011	Ext, ^{241}Am
	Terrestrial foods, external and inhalation near site[j]	G	<0.005	^{14}C, $^{60}Co^{d}$
Heysham	Fish and shellfish consumption and external in intertidal areas	L	0.015	Ext, ^{241}Am
	External in intertidal areas (turf cutters)	L	<0.005	Ext
	Terrestrial foods, external and inhalation near site[j]	G	0.005	^{14}C, $^{35}S^{d}$

Table 1.4 continued

Establishment	Radiation exposure pathways	Gaseous or liquid source[e]	Exposure, mSv[b] per year	Contributors[c]
Hinkley Point	Fish and shellfish consumption and external in intertidal areas	L	0.025	Ext
	Terrestrial foods, external and inhalation near site[j]	G	0.005	^{14}C, ^{35}S
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	0.013	^{14}C, ^{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
Torness	Fish and shellfish consumption and external in intertidal areas	L	<0.005	^{110m}Ag, ^{241}Am
	Terrestrial foods, external and inhalation near site[j]	G	0.007	^{35}S, ^{90}Sr, ^{241}Am[d]
Trawsfynydd	Fish consumption and external to anglers	L	0.018	Ext
	Terrestrial foods, external and inhalation near site[j]	G	0.025	^{241}Am
Wylfa	Fish and shellfish consumption and external in intertidal areas	L	0.008	Ext, ^{241}Am
	Terrestrial foods, external and inhalation near site[j]	G	0.006	^{14}C, ^{35}S
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]	^{234}U, ^{238}U
Barrow	Occupancy of houseboats	L	0.045	Ext
	Terrestrial food consumption	G	<0.005	^{137}Cs[d]
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[d], ^{235}U, ^{238}U
Devonport	Fish and shellfish consumption and external in intertidal areas	L	<0.005	Ext, ^{137}Cs, ^{241}Am[d]
	Occupancy of houseboats	L	<0.005	Ext
	Terrestrial foods, external and inhalation near site[p]	G	<0.005	^{3}H[d]
Faslane	Fish and shellfish consumption and external in intertidal areas	L	0.010	Ext, ^{137}Cs, ^{241}Am
	Terrestrial food consumption	G	<0.005	^{137}Cs
Holy Loch	External in intertidal areas	L	0.009	Ext
Rosyth	Fish and shellfish consumption and external in intertidal areas	L	0.013	Ext

Table 1.4 continued

Establishment	Radiation exposure pathways	Gaseous or liquid source[e]	Exposure, mSv[b] per year	Contributors[c]
Radiochemical production				
Amersham	Fish consumption and external to anglers	L	<0.005	Ext
	Terrestrial foods, external and inhalation near site[j]	G	0.008	^{222}Rn
Cardiff	Fish and shellfish consumption and external in intertidal areas	L	0.008	Ext
	Terrestrial foods, external and inhalation near site[j]	G	0.006	^{14}C, ^{32}P[d], ^{35}S
	Inadvertent ingestion and riverbank occupancy (River Taff)[p]	L	<0.005	^{3}H[d], ^{14}C[d]
Industrial and landfill				
LLWR near Drigg	Terrestrial foods[j]	G	0.006	^{14}C, ^{90}Sr, ^{106}Ru[d], ^{137}Cs
	Fish and shellfish consumption and external in intertidalareas (2014-2018 surveys) (including naturally occurring radionuclides)[f,m]	L	0.40	^{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 (2014-2018 surveys) (excluding artificial radionuclides)[f,k]	L	0.33	^{210}Po
	Fish and shellfish consumption and external in intertidal areas (2014-2018 surveys) (including artificial radionuclides)[f,n]	L	0.40	^{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 representative person 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; and Sellafield, a site where irradiated fuel is reprocessed from nuclear power stations and a range of decommissioning and legacy waste management activities are being carried out.

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 Urenco Nuclear Stewardship Limited (UNS), a company of the Urenco Group. Another Urenco Group company, Urenco ChemPlants Limited (UCP), is currently building a new facility (Tails Management Facility) 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 licensed 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.

Windscale, also owned by the NDA, is located on the Sellafield site. In 2008, the site licence for Windscale site was transferred to Sellafield Limited. The site operators were granted a revised permit in 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 37 per cent (or less) of the annual dose limit for all assessed sites. *Total doses* increased in the vicinity of Sellafield, compared to the values in 2017, but remained well below the limit

Capenhurst, Cheshire

- *Total dose* for the representative person was 0.16 mSv and decreased in 2018

Springfields, Lancashire

- *Total dose* for the representative person was 0.075 mSv and increased in 2018
- Gaseous discharges of uranium were the lowest value reported from this site, and liquid discharges of technetium-99, neptunium-237, uranium and "other transuranic radionuclides" decreased, in 2018

Sellafield, Cumbria

- *Total doses* for the representative person were 0.37 mSv (or less) of the public dose limit and increased in 2018
- 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 historical discharges of naturally occurring radionuclides (non-nuclear industry) was higher in 2018. The contribution to *total dose* from Sellafield discharges decreased in 2018
- Gaseous discharges of radon-222 decreased in 2018
- The concentration of plutonium-239+240 in lobsters in 2018 is the lowest reported value in recent years

Gaseous and liquid discharges from each of these sites are regulated by the Environment Agency. In 2018, gaseous and liquid discharges were below permit limits for each of the sites (see Appendix 2, Tables A2.1 and A2.2).

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 and UCP. UUK operates three plants producing enriched uranium for nuclear power stations. UNS 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. Commissioning has commenced and operations are planned to start in 2019. 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 habits survey to determine the consumption and occupancy rates by members of the public was undertaken in 2008 (Tipple *et al.*, 2009).

Doses to the public

The *total dose* from all pathways and sources of radiation was 0.16 mSv in 2018 (Table 2.1), or 16 per cent of the dose limit (down from 0.17 mSv in 2017). This dose was almost entirely due to direct radiation from the Capenhurst site. The representative person was children (10 year-old) living near to the site and a change from that in 2017 (infants living near the site). The decrease in *total dose* and change in representative person was due to a lower estimate of direct radiation (resulting in a change in different contributions from food consumption between age groups) from the site in 2018. The trend in annual *total dose* over the period 2007 – 2018 is given in Figures 1.2 and 2.1. Any changes in annual *total doses* with time were due 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 0.006 mSv in 2018 (down from 0.010 mSv in 2017). The decrease in dose was due to lower gamma dose rates measured over the riverbank at Rivacre Brook in 2018. 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. The focus for terrestrial sampling was the analyses of technetium-99 and uranium in food (including milk), grass and soil. Results for 2018 are given in Table 2.2(a). Concentrations of radionuclides in milk and food samples around the site were very low and generally similar to those in previous years. Figure 2.2 shows the trends over time (2007 – 2018) 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.

Liquid waste discharges and aquatic monitoring

The permit for the UUK Capenhurst site allows liquid waste discharges to the Rivacre Brook for uranium and uranium daughters, technetium-99 and non-uranium alpha (mainly neptunium-237).

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 2018 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 concentrations in fish and shellfish reflect the distant effects of discharges from Sellafield. Low concentrations of thorium-234 were detected in cockles in 2018.

As in previous years, sediment samples collected downstream from the Rivacre Brook contained very low but measurable concentrations of uranium (enhanced above natural concentrations) and technetium-99. As expected, enhanced concentrations of these radionuclides (and others) were measured close to the discharge point (Rivacre Brook). Technetium-99, thorium-234 and uranium radionuclide concentrations from this location were lower in 2018 (compared to slightly elevated values in 2017), but

Figure 2.1. *Total dose* at nuclear fuel production and reprocessing sites, 2007-2018
(Exposures at Sellafield/Whitehaven/LLWR receive a significant contribution to the dose from technologically enhanced naturally occurring radionuclides from previous non-nuclear industrial operations)

similar to those in recent years. 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 at other freshwater locations) were very low in 2018, and similar to those in 2017. Measured gamma dose rates near to the discharge point were lower in 2018, in comparison to those in recent years. Downstream of the Rivacre Brook, at the location where children play, dose rates were also lower (compared with those in 2017) and these are the lowest reported values in recent years.

Figure 2.2 also shows the trends over time of the releases of a number of other permitted radionuclides and activity concentrations in environmental samples. Since 2007, 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 in 2018 (albeit lower in comparison to those in 2017). The peak value reported 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 activities of both concentrations were reported in 2016.

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 plants and buildings, under contract to the NDA, who retain responsibility for the historical nuclear liabilities on the site.

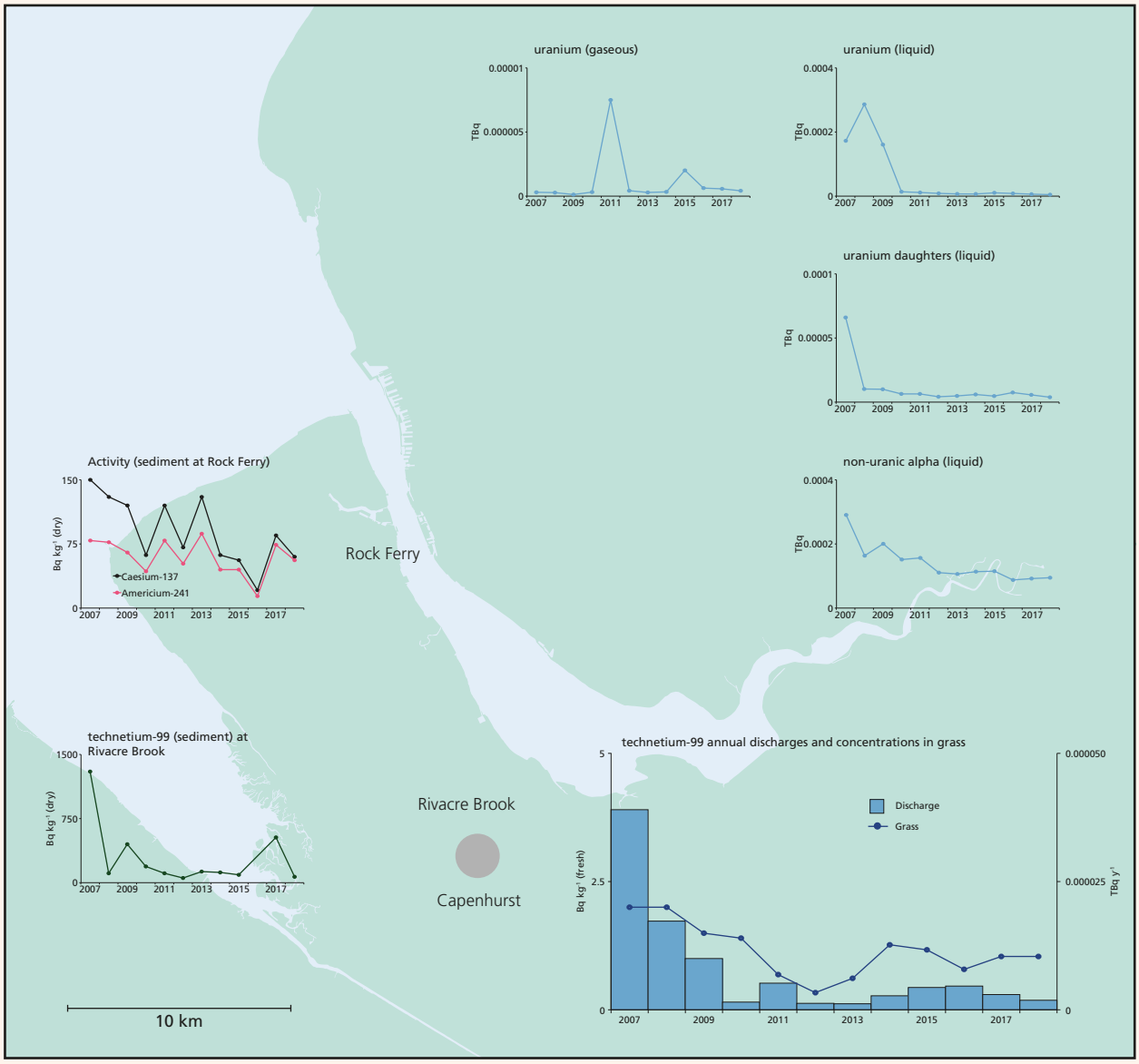


Figure 2.2. Discharges of gaseous and liquid radioactive wastes and monitoring of the environment, Capenhurst (2007-2018) (Note different scales used for discharges and activity concentrations)

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). In September 2017, the National Nuclear Laboratory were granted a variation to its permit by the Environment Agency. This was to allow the processing of unused uranium carbide fuel pins and to enable the recovery of the uranium for use in the fuel cycle. The permit variation introduced a new radioactive gaseous discharge limit of 0.72 TBq (7.2E+11 Bq) for krypton-85. The processing of the uranium carbide fuel pins commenced in autumn 2018.

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 decay 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 2018, based on a five-year rolling average (2014 – 2018), 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).

Doses to the public

The *total dose* from all pathways and sources of radiation was 0.075 mSv in 2018 (Table 2.1), or less than 8 per cent of the dose limit, up from 0.028 mSv in 2017. In 2018, the representative person was adults consuming mushrooms at high-rates and a change from that in 2017 (adult houseboat dweller). The dominant contribution to

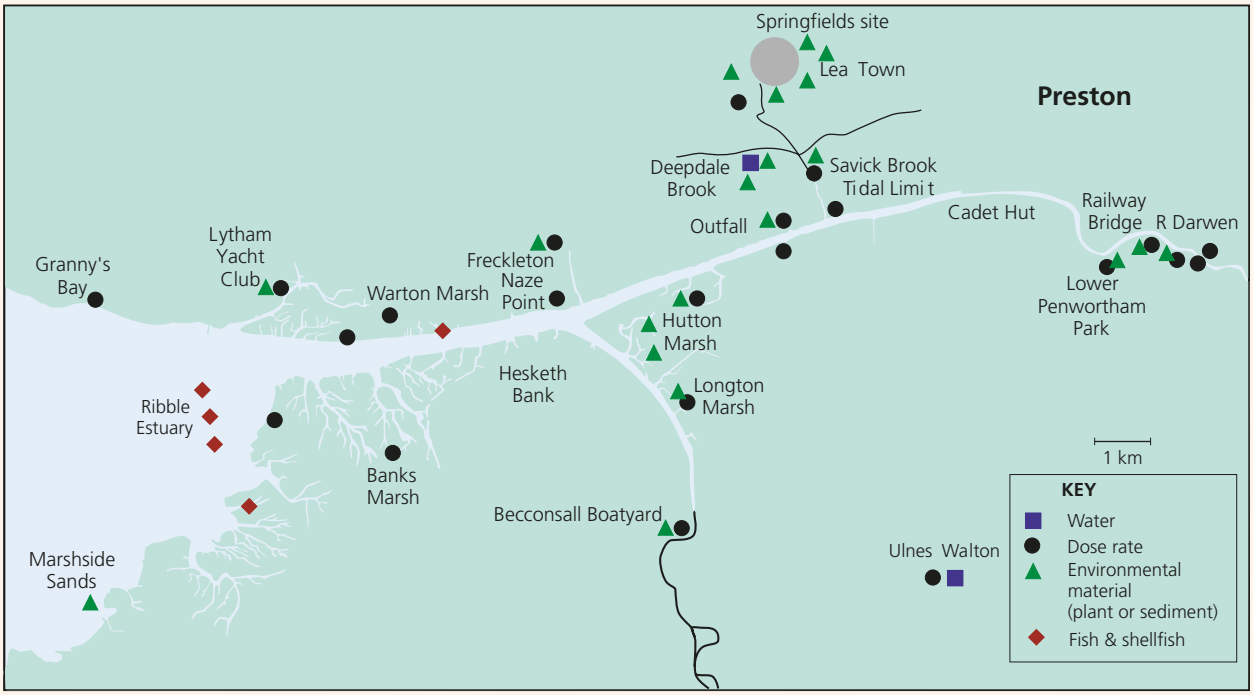


Figure 2.3. Monitoring locations at Springfields, 2018 (not including farms)

the dose in 2018 was direct radiation. The annual direct radiation exposure (given in Table 1.1) was higher in 2018 (0.075 mSv), in comparison to that in 2017 (0.018 mSv). The increase in the *total dose* and the change in the representative person from 2017 was mostly due to the higher contribution of direct radiation included in the assessment in 2018.

Annual *total doses* (together with dose rates) over the period 2007 – 2018 are given in Figure 2.4. The estimated *total dose* decreased in 2012, following on from direct measurements (measured beneath the houseboats at Becconsall). Thereafter (up to 2017), the change in *total dose* was due to the variation in gamma dose rates.

Source specific assessments indicated that exposures were all less than the *total dose* in 2018 (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

A source specific assessment for a high-occupancy houseboat dweller gives an estimated exposure that was 0.034 mSv in 2018, or approximately 3 per cent of the dose limit for members of the public of 1 mSv, and up from 0.028 mSv in 2017. The reason for the change in dose (from 2017) was attributed to using a revised (more cautious) method, by using the gamma dose rates measured in the vicinity of two houseboat locations (at Becconsall and Freckleton) in 2018. Gamma dose rate measurements at Becconsall were not taken directly underneath a houseboat in 2018 (as in previous years). Prior to 2018, the dose rates were derived by using measurements outside the houseboat and then adjusting these values by the ratio of on-board and outside dose, rates from results of measurements taken directly underneath a houseboat. The revised assessment of dose in the vicinity of the two houseboat locations (0.034 mSv) is more conservative than that estimated using historical results reported underneath a houseboat at Becconsall (0.021 mSv) in 2018.

The dose for high-rate consumers of seafood (including a contribution from external exposure) was 0.012 mSv in 2018. Of this dose, approximately 0.010 mSv was from external exposure and the remainder was from the consumption of fish and shellfish. The dose in 2017 was 0.013 mSv. The most important radionuclides were caesium-137 and americium-241 from past discharges from the Sellafield site.

The estimated doses 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 were less than 0.005 mSv, 0.023 mSv, less than 0.005 mSv and less than 0.005 mSv, respectively in 2018 (Table 2.1).

The equivalent dose to skin as a result of fishermen handling their fishing gear (which is potentially contaminated with radioactivity) was 0.010 mSv in 2018. This was less than 0.5 per cent of the annual dose limit of 50 mSv for skin.

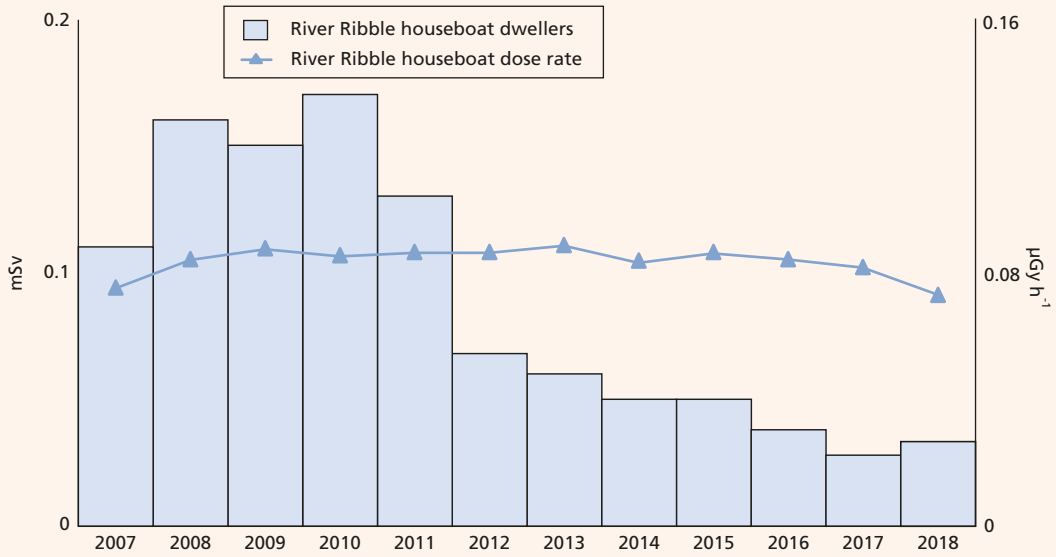


Figure 2.4. *Total dose* from all sources and dose rates at Springfields, 2007-2018

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

Gaseous discharges and terrestrial monitoring

Uranium is the main radioactive constituent of gaseous discharges, with small amounts of other radionuclides present in discharges from the National Nuclear Laboratory's research and development facilities.

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 2018 are given in Table 2.3(a). Uranium isotope concentrations in beetroot were lower in 2018 (compared to slightly elevated values in 2017), but similar to those in recent years. Concentrations of thorium were also low in vegetable and silage samples. As in previous years, elevated concentrations of uranium isotopes were measured in soils around the site, but the isotopic ratio showed that they were most likely to be naturally occurring. Overall, results were broadly similar to those of previous years.

Figure 2.5 shows the trends over time (2007 – 2018) of gaseous uranium discharges and total uranium radionuclide concentrations in food (cabbage; 2007 – 2013: beetroot; 2014 – 2018). Over the period, uranium discharges have declined, with the lowest value reported from this site in 2018. Total uranium was detected in cabbage and beetroot samples during the period, 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, uranium and "other transuranic radionuclides" decreased (due to the reduced processing of particular residues) in 2018, in comparison to releases in 2017. Discharges of beta-emitting radionuclides were generally lower than those in most recent years. This includes 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.

Results for 2018 are shown in Table 2.3(a). As in previous years, radionuclides due to discharges from both Springfields and Sellafield were detected in sediment and biota in the Ribble Estuary. Radionuclides found in the Ribble Estuary originating from Sellafield were

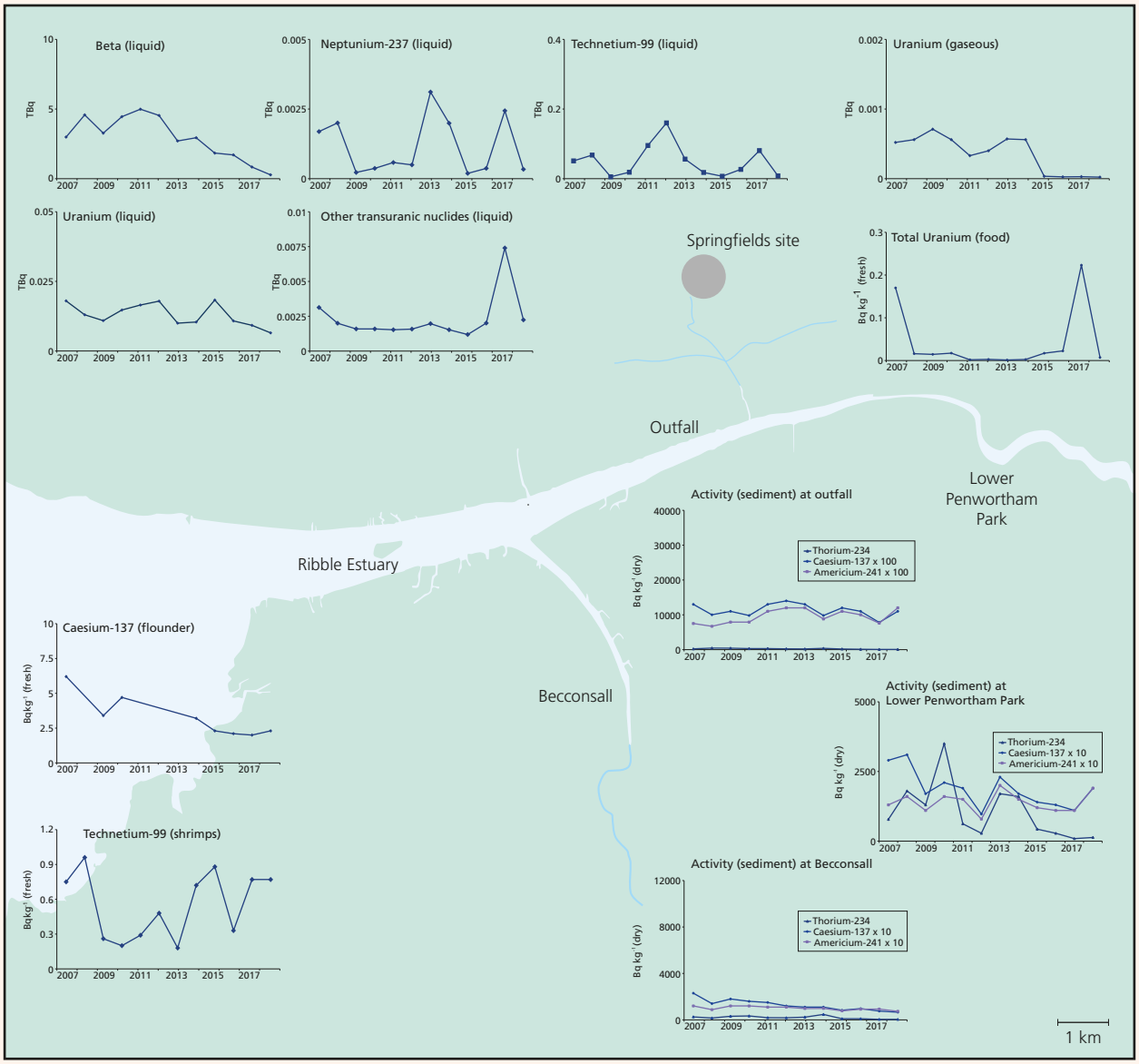


Figure 2.5. Discharges of gaseous and liquid radioactive wastes and monitoring of the environment, Springfields 2007–2018 (Note different scales used for discharges and activity concentrations)

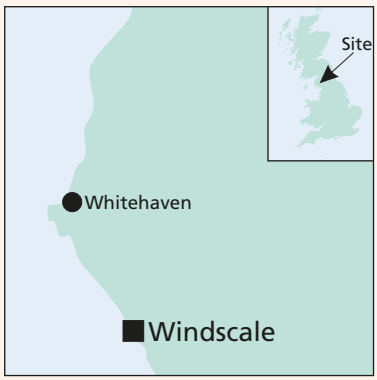
technetium-99, caesium-137 and americium-241. Isotopes of uranium and the short half-life radionuclide thorium-234 were also found from Springfields. Concentrations of the latter were closely linked to recent discharges from the Springfields site. In 2018, thorium-234 concentrations in sediments (over the range of sampling sites) were generally similar compared to those in 2017. Over a much longer timescale these concentrations have declined due to reductions in discharges as shown by the trend of sediment concentrations at the outfall, Lower Penwortham and Becconsall (Figure 2.5, Environment Agency, FSA, FSS, NIEA, NRW and SEPA, 2018). 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. In more recent years, thorium-234 concentrations have generally declined by small amounts in sediments at Lower Penwortham and Becconsall (Figure 2.5).

Caesium-137, americium-241 and plutonium radionuclides were found in biota and sediments from the Ribble Estuary in 2018. 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 (2007 – 2018) 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.

Gamma dose rates (Table 2.3(b)) in the estuary were generally higher than expected natural background rates (see Appendix 1, Section 3.7), and this is due to Sellafield-derived gamma-emitting radionuclides (caesium-137 and americium-241). In 2018, gamma dose rates in the estuary, including rates measured for houseboat assessments (at Becconsall), were generally lower (by small amounts) to those in 2017, but with some small variations at some sites. 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. In 2018, the main operations on the Sellafield site were: 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.

Nuclear fuel reprocessing at THORP ceased in November 2018. The last piece of nuclear fuel has been "sheared" (i.e. fuel is cut into pieces at the beginning of the reprocessing cycle). THORP will continue to serve the UK until the 2070s as a storage facility for spent fuel. Cessation of THORP reprocessing marks one of the final steps in Sellafield's transformation towards becoming a site that is solely focussed on decommissioning and hazard reduction. The Sellafield 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 (and Wylfa) is expected in 2020 (NDA, 2019). Windscale (amalgamated with the Sellafield site) is discussed in Section 2.4.

In October 2018, Sellafield Limited submitted an application to vary its environmental permit, given the projected reduction in radioactive discharges to the environment following the completion of reprocessing operations. Subsequently, the Environment Agency launched a consultation on the application between October and December 2018. The Environment Agency expect to issue a varied permit in 2020.

The main changes being sought are:

- Significantly reducing site discharge limits and introducing a two-tier (upper and lower) site discharge limit structure
- Removing some site discharge limits where discharges have fallen below significant levels and they do not meet the Environment Agency's criteria for setting limits
- Replacing plant discharge limits with plant notification levels so that Sellafield Limited can make most effective use of the available discharge routes and treatment plants
- Removing discharges limits related to the rate of fuel reprocessing (throughput) to reflect the end of reprocessing operations
- Introducing a specific tritium limit for solid waste disposals at the on-site landfill known as the Calder Landfill Extension Segregated Area (CLESA)

Sellafield Limited continued retrievals of sludge from legacy pond facilities in 2018 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 2018, a number of decommissioning projects continued including that of the Calder Hall reactors.

During the period April to November 2018, 280 tonnes of fuel were processed through THORP (compared to 305 tonnes in the previous financial year, 2017/18). Opened in 1994, THORP was one of only two commercial nuclear fuel reprocessing plants in the world and has reprocessed more than 9,000 tonnes of fuel. In respect of Magnox fuel, 342 tonnes of fuel were processed for 2018/19 (compared with 384 tonnes in 2017/2018).

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 to direct radiation. Annual review surveys are also 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 2018 (Moore *et al*., 2019). In 2018, some changes were found in the amounts (and mixes) of seafood species consumed and in handling (of fishing gear and sediment) and intertidal occupancy rates from the annual habits survey review in 2017 (Moore *et al*., 2018a). 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). 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 phosphate processing plant near Whitehaven in Cumbria. Although the plant closed in 1992, the effects of these past operations continue due to the decay of the long-lived parent radionuclides (historical discharges to sea) and the production of the decay 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 annual *total dose* from all pathways and sources of radiation is assessed using consumption and occupancy data from the full habits survey of 2018 (Moore *et al*., 2019) and the yearly review of shellfish and fish consumption, and intertidal occupancy in 2017 (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 historical discharges 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 annual *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 from historical discharges is difficult to determine above a variable background (see Appendix 1, Annex 4).

In 2018, the highest *total dose* in the vicinity of Sellafield was assessed to have been 0.37 mSv (Table 2.17), or 37 per cent of the dose limit to members of the public, and up from 0.25 mSv in 2017. As in previous years, most of this dose was due to radioactivity from sources other than those resulting from Sellafield discharges (predominately from historical discharges of naturally occurring radionuclides from past non-nuclear industrial activity). The representative person was adults consuming crustacean shellfish at high-rates in the vicinity of Sellafield, who also consumed significant quantities of other seafood. In 2018, this represents a change in the representative person from that in 2017 (adults consuming molluscan shellfish), mostly due to the revision of habits information (a reduction in mollusc consumption rates). The increase in *total dose* in 2018 was mostly attributed to higher concentrations of polonium-210 in locally caught crustacean (crabs and lobsters), in comparison to those in 2017. Polonium-210 (and lead-210) are important radionuclides in that small changes in concentrations above background significantly influence the dose contribution from these radionuclides (due to a relatively high dose coefficient used to convert an intake of radioactivity into a radiation dose) 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*.

The most significant contributors to the *total dose* in 2018 were from crustacean, mollusc and fish consumption and (92, 4 and 3 per cent, respectively). The contribution from external exposure over sediments was less than these significant food pathways (1 per cent). The important radionuclides were polonium-210, americium-241 and iodine-129, (89, 3, 2 per cent, respectively).

The dose from artificial radionuclides discharged by Sellafield (including external radiation) and from historical discharges of naturally occurring radionuclides (from past non-nuclear industrial activity) contributed 0.034 mSv and 0.33 mSv, respectively (values are rounded to two significant figures). In 2017, the contributions were 0.077 mSv and 0.18 mSv, respectively. In 2018, the contribution from the external radiation was 0.003 mSv (0.016 mSv in 2017). 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 0.034 mSv in 2018 from artificial radionuclides (including external radiation) was lower, in comparison to that in 2017 (0.077 mSv). The decrease in the contribution to the *total dose* from 2017 was mostly attributed to the revision of habits information (a decrease in mollusc consumption rates in 2018), and to a lesser extent, lower americium-241 concentrations in crustaceans (lobsters) in 2018. The contributing radionuclides in 2018 were mostly americium-241, iodine-129, plutonium-239+240 and carbon-14 (33, 26,

8 and 7 per cent, respectively). External exposure (including direct radiation) was 13 per cent (21 per cent in 2017) of the *total dose* from artificial radionuclides.

The contribution to the *total dose* of 0.33 mSv in 2018 from naturally occurring radionuclides (from past non-nuclear industrial activity) was higher, in comparison to that in 2017 (0.18 mSv). In 2018, the most contributing radionuclide was polonium-210 (~ 98 per cent). The increase in the *total dose* was mostly attributed to higher concentrations of polonium-210 in locally caught crustaceans (crabs and lobsters) in 2018, in comparison to those in 2017. In 2018, polonium-210 concentrations (above expected background) in locally caught lobsters and other crustaceans (including crabs) contributed 0.18 mSv and 0.14 mSv (values are rounded to two significant figures), respectively to the *total dose*. Polonium-210 concentrations (above expected natural background) in mollusc samples contributed 0.008 mSv to the *total dose* in 2018.

Contributions to the highest annual *total dose* each year (2007 – 2018), from all pathways and sources by specific radionuclides, are given in Figure 2.6. 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. Over a longer period, the trend is of generally declining dose (Figure 2.6, Environment Agency, FSA, FSS, NIEA, NRW and SEPA, 2018).

Since 2007, the larger step changes (from 2008 to 2009 and from 2012 to 2013) were due to variations in naturally occurring radionuclides (mainly polonium-210 and lead-210) from past non-nuclear industrial activity. 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 – 2017, was mostly due to enhanced naturally occurring radionuclides (from past non-nuclear industrial activity) 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 polonium-210 (naturally occurring radionuclide from past non-nuclear industrial activity) 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 annual *total dose* from the non-nuclear and nuclear industries, and from each pathway of exposure (for adults), are also given in Figures 2.7 (2007 – 2018) and 2.8 (2014 – 2018), respectively. The overall trend from the nuclear industries is a generally declining dose (Figure 2.7), broadly reflecting a general reduction in concentrations in seafood of artificial radionuclides from the nuclear industry, over the period 2007 – 2018. The pathways of exposure contributing the highest dose were mollusc, crustacean and sea fish consumers.

Other age groups received less exposure than the adults *total dose* of 0.37 mSv in 2018 (10 year-old children: 0.19; 1 year-old infants: 0.13; prenatal children: 0.051, 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 natural radiation in the environment (Oatway *et al.*, 2016) and to the annual dose limit to members of the public of 1 mSv.

Total dose from gaseous discharges and direct radiation

In 2018, the dose to a representative person receiving the highest *total dose* from the pathways predominantly relating to gaseous discharges and direct radiation was 0.006 mSv (Table 2.17), and down from 0.011 mSv in 2017. The most exposed age group in 2018 was infants consuming local cows' milk at high-rates. This represents a change in the representative person from 2017 (adults consuming other domestic vegetables). The decrease in the *total dose* was mostly attributed to the revision of habits information (a small increase in milk consumption and a lower consumption of vegetables (other domestic, potatoes and root vegetables)) in 2018 (Moore *et al.*, 2019). The most significant contributors in 2018 to the *total dose* for infants were from consumption of milk and direct radiation from the site (89 and 8 per cent, respectively), the most important radionuclides were carbon-14, strontium-90, iodine-129, caesium-137 and iodine-131 (28, 22, 14, 11 and 8 per cent, respectively). Other age groups received less exposure than the *total dose* for infants of 0.006 mSv in 2018 (adults: 0.005; 10 year-old children: 0.005; prenatal children: 0.005, equivalent values rounded to one significant figure).

Contributions to the highest annual *total dose*, from gaseous discharge and direct radiation sources and by specific radionuclides, are given in Figure 2.9 over the period 2007 – 2018. 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 (Figure 2.9, Environment

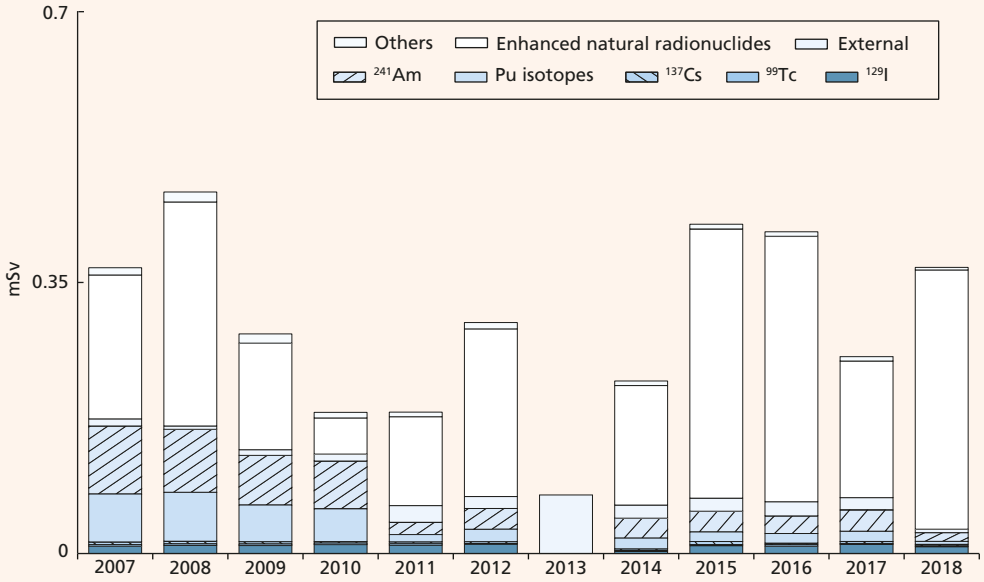


Figure 2.6. Contributions to *total dose* from all sources at Sellafield, 2007-2018 (The highest *total dose* in 2013 due to Sellafield discharges was to people living on houseboats near Barrow in Cumbria)

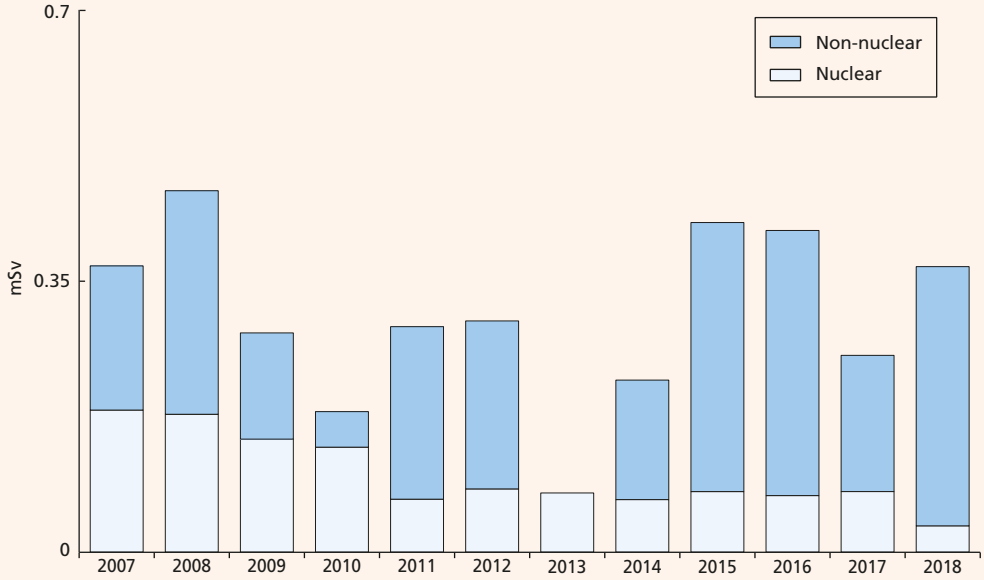


Figure 2.7. Contributions from nuclear and non-nuclear industries to *total dose* from all sources at Sellafield, 2007-2018 (The highest *total dose* in 2013 due to Sellafield discharges was to people living on houseboats near Barrow in Cumbria)

Agency, FSA, FSS, NIEA, NRW and SEPA, 2018). Since 2007, 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

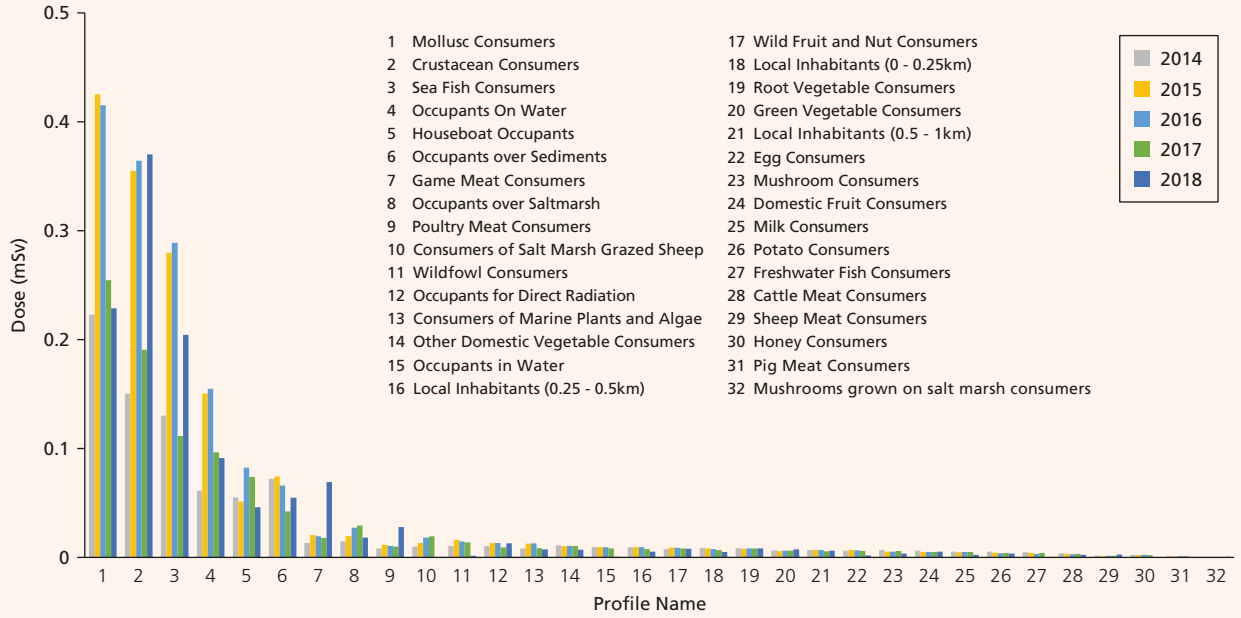


Figure 2.8. Contributions from each pathway of exposure to the *total dose* from all sources, 2014-2018

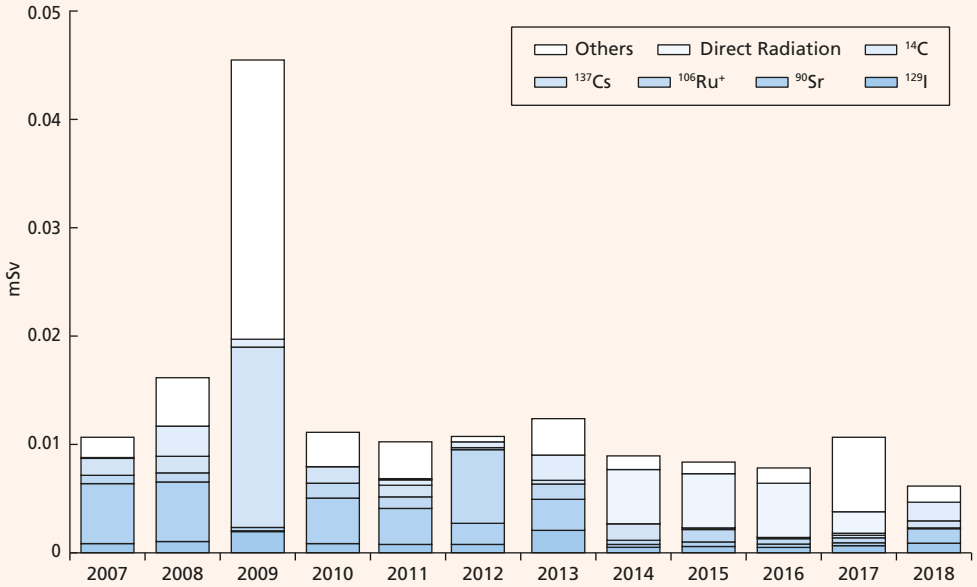


Figure 2.9. Contributions to *total dose* from gaseous discharge and direct radiation sources at Sellafield, 2007-2018 (+ based on limits of detection for concentrations in foods)

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-emitting radionuclides during handling of sediments and/or handling of fishing gear.

Doses from terrestrial food consumption

In 2018, 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 in 2018 (Table 2.17), or approximately 1 per cent of the dose limit to members of the public, and unchanged from 2017 (0.011 mSv). Other age groups received less exposure than the infants (1 year-old) dose of 0.011 mSv in 2018 (adults: 0.008; 10 year-old children: 0.009; 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 (2018 habits survey). The second is based on a five-year rolling average using habits data gathered from 2014 to 2018. Some changes were found in the amounts (and mixes) of species consumed compared to those in the 2017 and 2013 – 2017 datasets. For crustaceans (crab, lobster, and other crustaceans), overall consumption rates

increased in 2018, but were similar for the 2014 – 2018 datasets. Fish consumption rates (cod, other fish), and the occupancy rate over sediments, decreased for the 2018 dataset. For molluscs (winkles and other molluscs), the overall consumption rates were unchanged in both the 2018 and the 2014 – 2018 datasets. 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 (e.g. Moore *et al.*, 2018a). 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 2018. The doses from artificial radionuclides to people, who consume a large amount of seafood, were 0.066 mSv (0.082 mSv in 2017) and 0.070 mSv (0.085 mSv in 2017) using the annual and five-year rolling average habits data, respectively, in 2018. These doses each include a contribution due to external radiation exposure over sediments. Doses were similar using both sets of habits data in 2018.

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 0.33 mSv in 2018. Most of this was due to polonium-210 (97 per cent). The reason for the change in dose in 2018 (from 0.18 mSv in 2017) is the same as that contributing to the *total dose* for all sources, i.e. higher concentrations of polonium-210 in locally caught crabs and lobsters in 2018, in comparison to those in 2017. 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 2018, and values rounded to two significant figures) was 0.38 mSv (Table 2.17).

Taking artificial and enhanced natural radionuclides together, the source specific doses were 0.44 and 0.40 mSv (values are rounded to two significant figures) for the annual and five-year rolling average habits data, respectively. These estimates are larger than the estimate of *total dose* from all sources of 0.37 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 expected, and are within the uncertainties in the assessments.

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 2018 (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 2018 (Table 2.16), in comparison to those in 2017. For example, on the Dumfries and Galloway coast, the decrease in dose to 0.029 mSv in 2018 (from 0.035 mSv in 2017) was mostly due to lower americium-241 concentrations in crustaceans (lobster). All annual 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 2018.

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-emitting radionuclides 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 2018 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 2018, the dose was 0.045 mSv, or less than 5 per cent of the dose limit, and down from 0.071 mSv in 2017 (see Section 5.2). Other people received lower external doses

in 2018. The estimated annual dose to a high-occupancy houseboat dweller in the River Ribble was 0.034 mSv (see Section 2.2). The dose to a person who spends a long time over the marsh in the Ravenglass Estuary was 0.008 mSv in 2017, and similar to that in 2017 (0.007 mSv).

The doses to people in 2018 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 exposure to residents was assessed for two different environments (at a number of locations) and at a distance from the Sellafield influence. The two different environments are i) residents that visit and use beaches, and ii) 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 2018, the doses to people from recreational use of beaches varied from 0.005 to 0.010 mSv (Table 2.17), 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 0.010 mSv but were of a similar order of magnitude. The values for these activities were similar to those in recent years. The annual 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-emitting radionuclides 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 2018, 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 0.092 mSv and 0.064 mSv, respectively (Table 2.17) 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 2018, the dose (including contributions from Chernobyl and fallout from nuclear weapons testing) was estimated to be 0.018 mSv, which was less 2 per cent of the dose limit for members of the public, and lower (by a small amount) than that in 2017 (0.020 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 annual 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 that the exposure pathway for a high-rate consumer of laverbread is of low radiological significance. Harvesting of *Porphyra* in west Cumbria, for consumption in the form of laverbread, was reported in the 2018 habits survey (Moore *et al.*, 2019); this exposure pathway has remained dormant in previous years. Previously reported doses from the consumption of vegetables using seaweed (as a fertiliser) 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. A research study (relevant to the Scottish islands and coastal communities) conducted by PHE on behalf of the FSA and SEPA, investigated the potential transfer of radionuclides from seaweed to meat products and also to crops grown on land where seaweed had been applied as a soil conditioner (Brown *et al*., 2009). The study concluded that the highest levels of dose to people using seaweed, as a soil conditioner or an animal feed, were in the range of a few microsieverts and the majority of the doses are at least a factor of 100 lower. The report is available on SEPA's website: **http://www.sepa.org.uk/environment/radioactive-substances/environmental-monitoring-and-assessment/reports/**.

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 2018 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 2018 and generally similar to those in 2017. Discharges of radon-222 decreased (reported as nil), whilst caesium-137, krypton-85 and iodine-129 increased by small amounts in 2018.

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 2018 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 2018 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 (cattle and sheep), and game (rabbit) 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 tritium and 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 foods (including fruit and vegetables) and terrestrial indicator materials was sampled in 2018 and the activity concentrations were generally similar to those found in previous years. In common with meat and offal samples, only limited evidence of the atmospheric discharges from Sellafield was found in some of these foods. Tritium was positively detected in locally grown beetroot and strontium-90 was positively detected in a number of food samples (including milk) at low concentrations. In 2018, the maximum iodine-129 and iodine-131 concentrations in milk were positively detected (unlike in recent years), just above the 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. Trends in maximum concentrations of radionuclides in milk (near Sellafield), and corresponding discharges, 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 2018 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 2018. Liquid discharges were generally similar (in comparison to those in 2017). To date, the discharges continue to reflect the varying amounts of fuel reprocessed in THORP (up to cessation in November 2018) and the Magnox reprocessing plant, and periods of planned and unplanned reprocessing plant shutdowns that occur from year to year.

The downward trend of technetium-99 discharges from Sellafield is given in Figure 2.11 (2007 – 2018) and Figure 2.12 (1990 – 2018). 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.

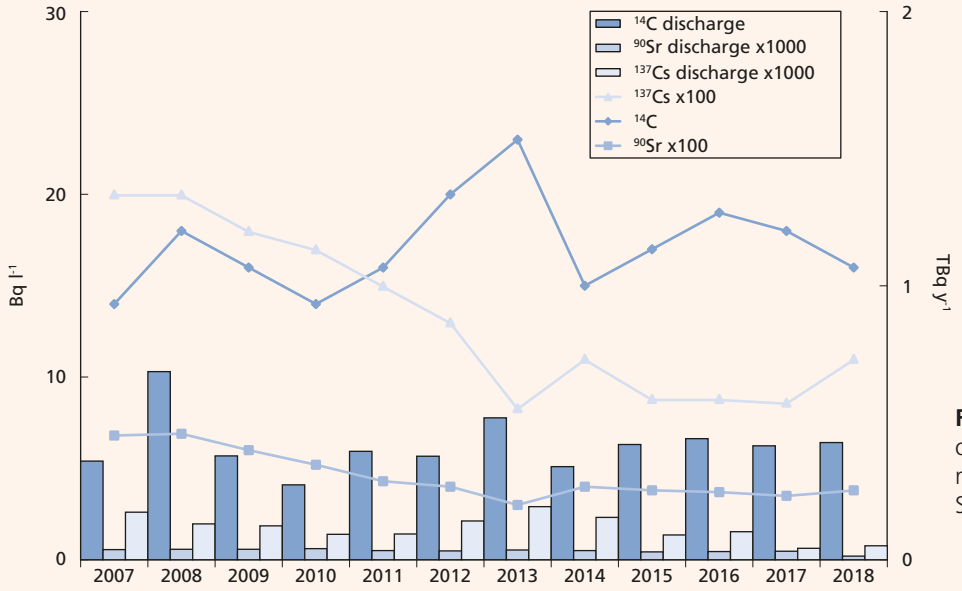


Figure 2.10. Discharges of gaseous wastes and monitoring of milk near Sellafield, 2007-2018

Monitoring of the marine environment

Regular monitoring of the marine environment near to Sellafield and further afield was conducted during 2018, 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.

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 (e.g. Figures 2.8 – 2.13, Environment Agency, FSA, FSS, NIEA, NRW and SEPA, 2011). Concentrations generally continue to reflect changes in discharges over time periods, characteristic of radionuclide mobility and organism uptake. More recent trends in concentrations of radionuclides, and corresponding discharges, 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 and concentrations of technetium-99 in fish and shellfish in 2018 (Figure 2.17) were similar, in comparison to their respective values in recent years. Over a longer timescale, technetium-99 concentrations in fish and shellfish have shown a continued reduction, from the relatively elevated values in the previous decade (e.g. Figure 2.10, Environment Agency, FSA, FSS, NIEA, NRW and SEPA, 2011). For the transuranic elements (Figures 2.19 and 2.20), the trend of reductions in concentrations is not evident, unlike in earlier decades (e.g. Figure 2.12, Environment Agency, FSA, FSS, NIEA, NRW and SEPA, 2011). Over the last decade, discharges and concentrations of americium-241 and plutonium-239+240 in fish and shellfish have continued to show some variations from year to year (Figures 2.19 and 2.20). The mean concentrations of caesium-137, plutonium-239+240 and americium-241 in fish and shellfish were lower in 2018, in comparison to those in 2017 (including lower americium-241 concentrations in crustaceans in 2018).

Beta- and 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 2018, in comparison to those in 2017. 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

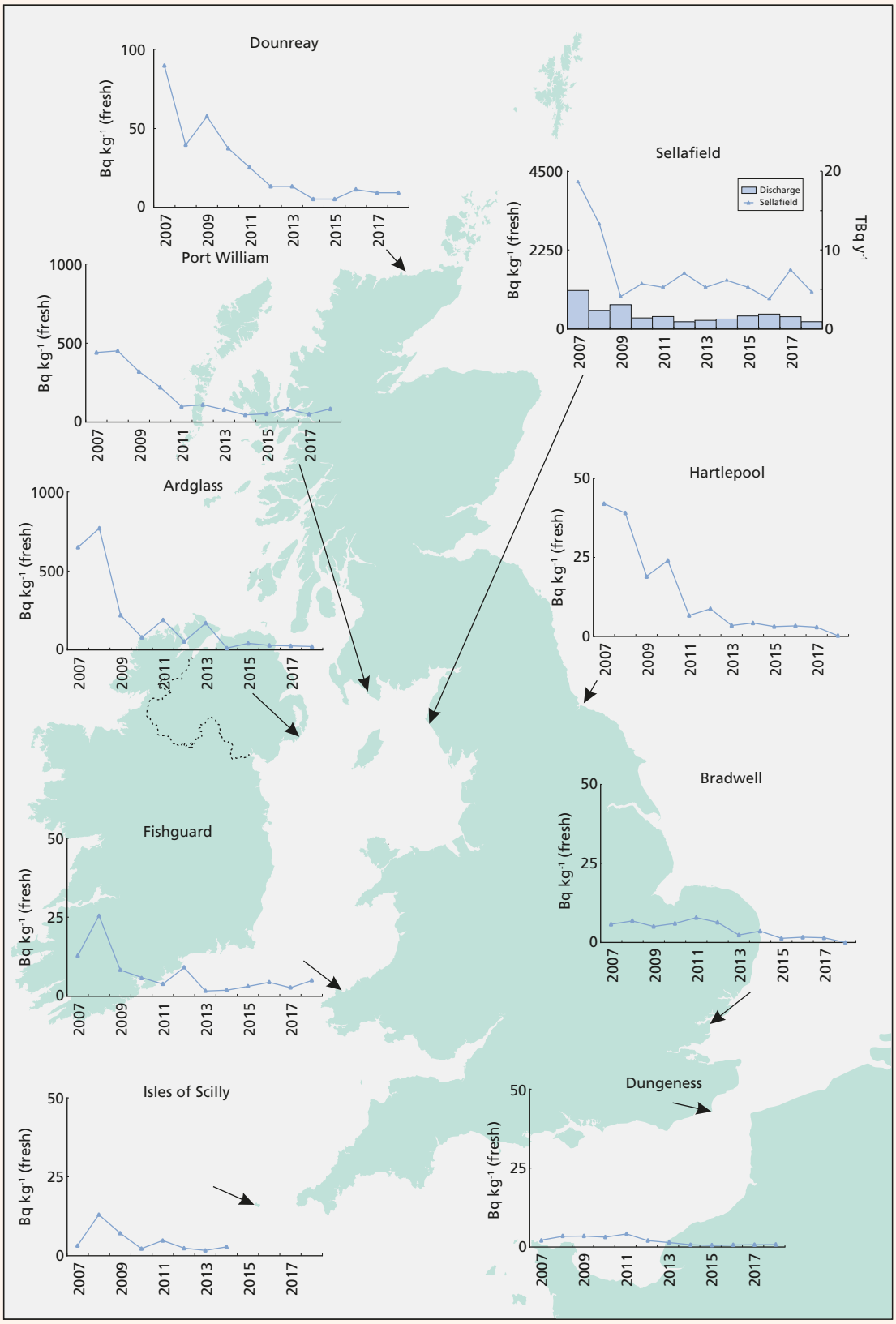


Figure 2.11. Technetium-99 in UK seaweed (*Fucus vesiculosus*) from Sellafield liquid discharges between 2007-2018 (Note different scales used for Sellafield, Ardglass, Port William and Dounreay)

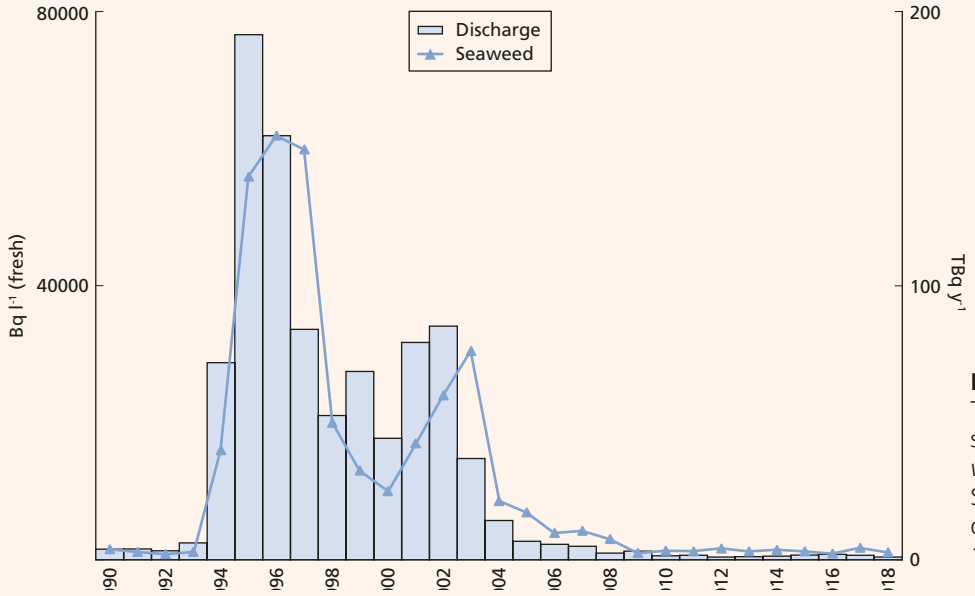


Figure 2.12. Technetium-99 in UK seaweed (*Fucus vesiculosus*) from Sellafield liquid discharges between, 1990-2018

to be due to 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- and 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 X 4.1), the data suggest a continued local enhancement of carbon-14 due to discharges from Sellafield. In 2018, carbon-14 is reported as the highest activity concentration in marine fish (plaice, 84 Bq kg^{-1}) from Ravenglass. Promethium-147 was detected at a very low concentration (reported as just above the less than value) in fish (plaice) in 2018.

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- and 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 in the marine environment from Sellafield discharges were carbon-14, tritium and technetium-99. Comparing 2018 and 2017 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 2018 were also broadly similar (where comparisons can be made) to those in 2017.

Transuranic radionuclide data for fish and shellfish samples (chosen on the basis of potential radiological significance) in 2018 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 2018 and 2017 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 lower (by small amounts) for plutonium radionuclides and americium-241 in 2018 (in comparison to those in 2017) at most of the north-eastern Irish Sea locations (e.g. lobsters and winkles from Sellafield coastal area and Nethertown, respectively). Americium-241 concentrations in mussels (near Sellafield) were also generally lower (by small amounts) in 2018, in comparison to those in 2017. Overall, plutonium-239+240 and americium-241 concentrations in lobsters and winkles (near Sellafield) were generally lower (with minor variations) in 2018, in comparison to those in recent years. The concentration of plutonium-239+240 in lobsters (Sellafield coastal area) in 2018 is the lowest reported value in recent years (Figure 2.19). 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. Concentrations 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 2018 are shown in Table 2.8. Radionuclides positively detected were cobalt-60, strontium-90, caesium-137,

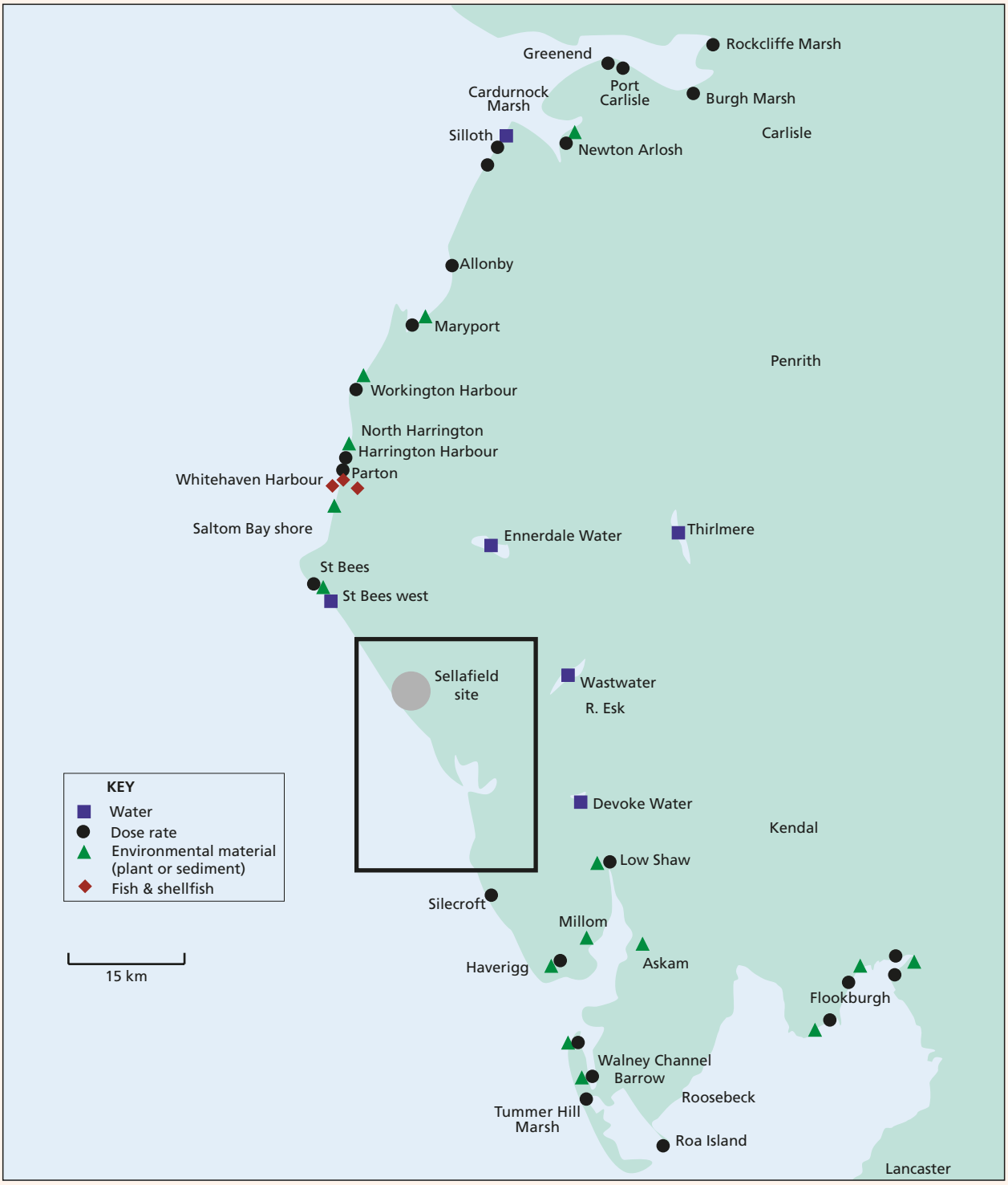


Figure 2.13. Monitoring locations in Cumbria, 2018 (not including farms)

europium-154 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. In 2018, the concentrations of caesium-137, americium-241 and plutonium radionuclides increased in the River Mite Estuary and are the highest reported values in recent years. 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 a number of decades discharges have fallen significantly as the site provided enhanced treatment to remove radionuclides prior to discharge. Overall, concentrations in sediments were generally similar in 2018, in comparison to those in 2017.

The trends over time (1990 – 2018) 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 declined over the time period in response to decreases in discharges, with sustained reductions in discharges of caesium-137

Figure 2.14. Monitoring locations at Sellafield, 2018 (not including farms)

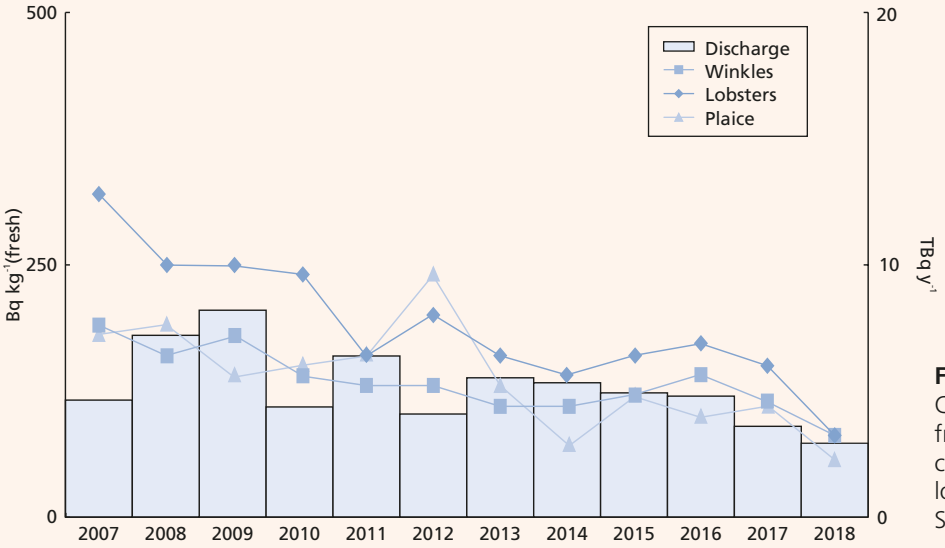


Figure 2.15.
Carbon-14 liquid discharge from Sellafield and concentrations in plaice, lobsters and winkles near Sellafield, 2007-2018

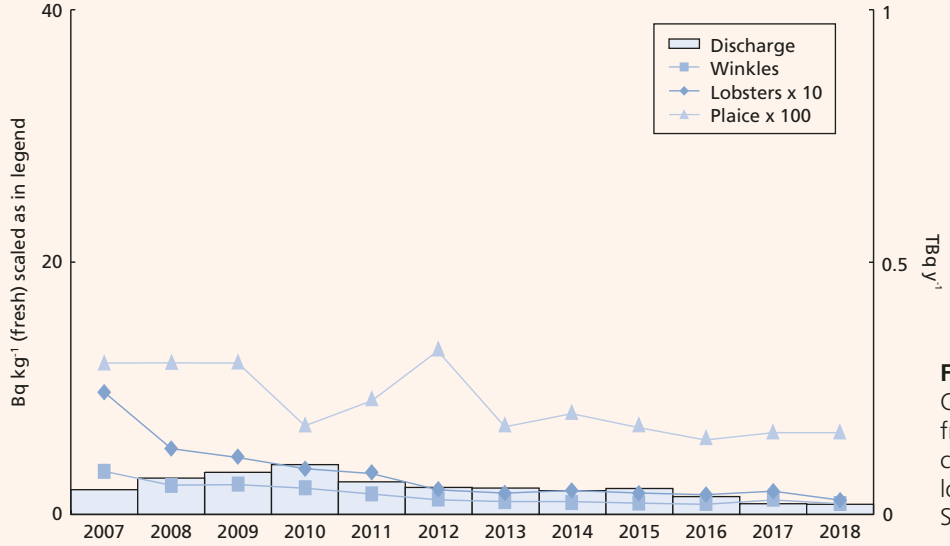


Figure 2.16.
Cobalt-60 liquid discharge from Sellafield and concentrations in plaice, lobsters and winkles near Sellafield, 2007-2018

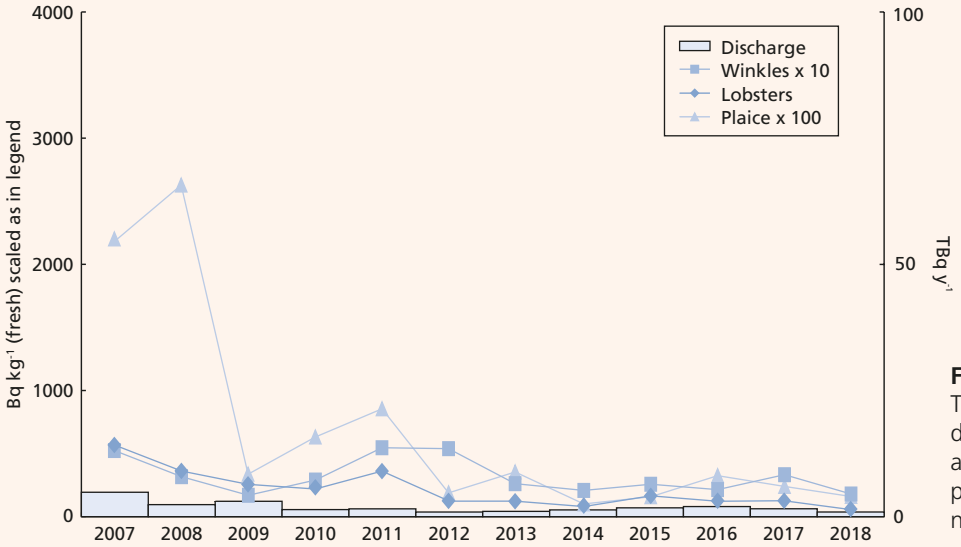


Figure 2.17.
Technetium-99 liquid discharge from Sellafield and concentrations in plaice, lobsters and winkles near Sellafield, 2007-2018

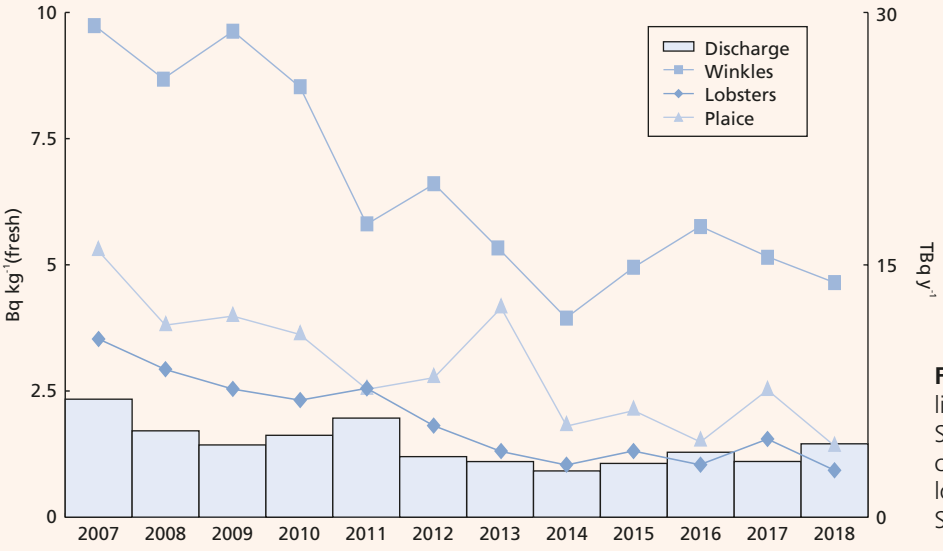


Figure 2.18. Caesium-137 liquid discharge from Sellafield and concentrations in plaice, lobsters and winkles near Sellafield, 2007-2018

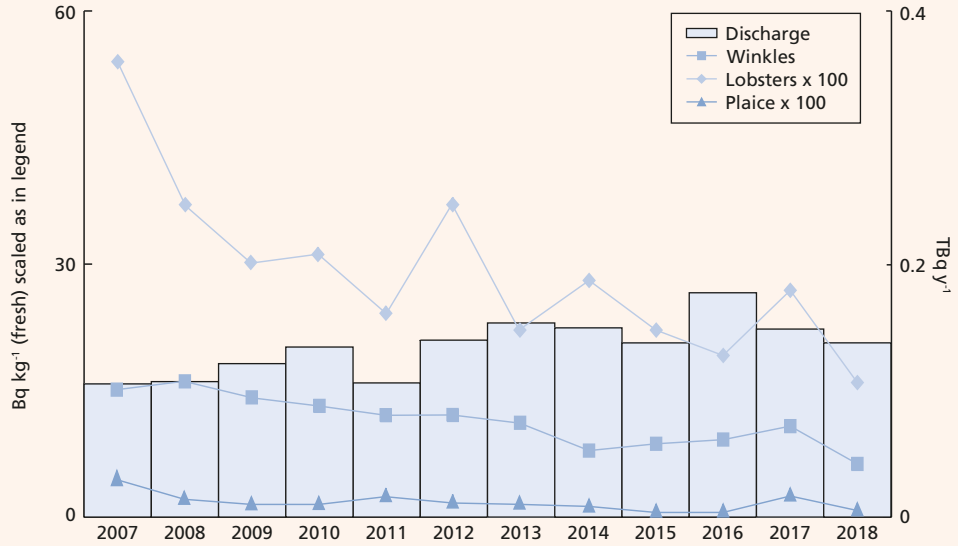


Figure 2.19. Plutonium-239+240 liquid discharge from Sellafield and concentrations in plaice, lobsters and winkles near Sellafield, 2007-2018

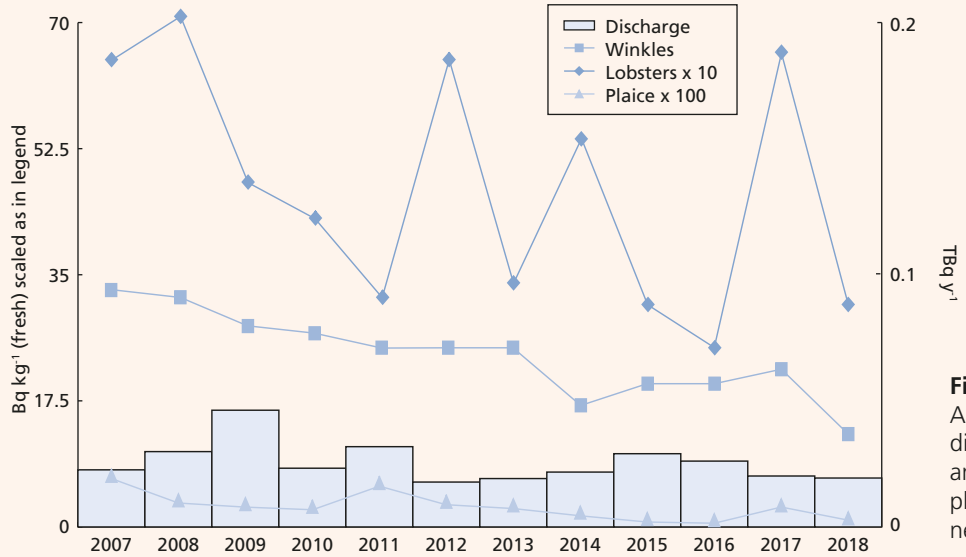


Figure 2.20. Americium-241 liquid discharge from Sellafield and concentrations in plaice, lobsters and winkles near Sellafield, 2007-2018

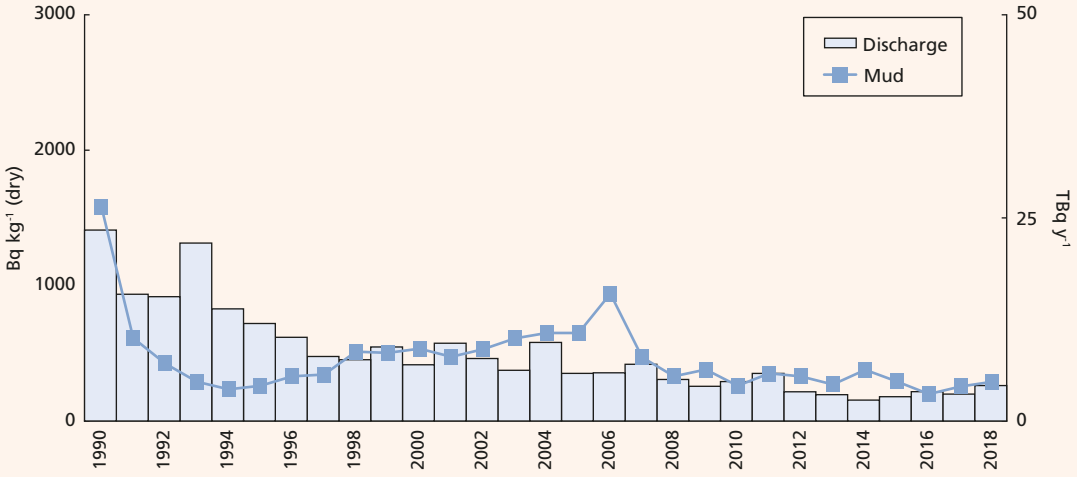


Figure 2.21. Caesium-137 liquid discharge from Sellafield and concentration in mud at Ravenglass, 1990-2018

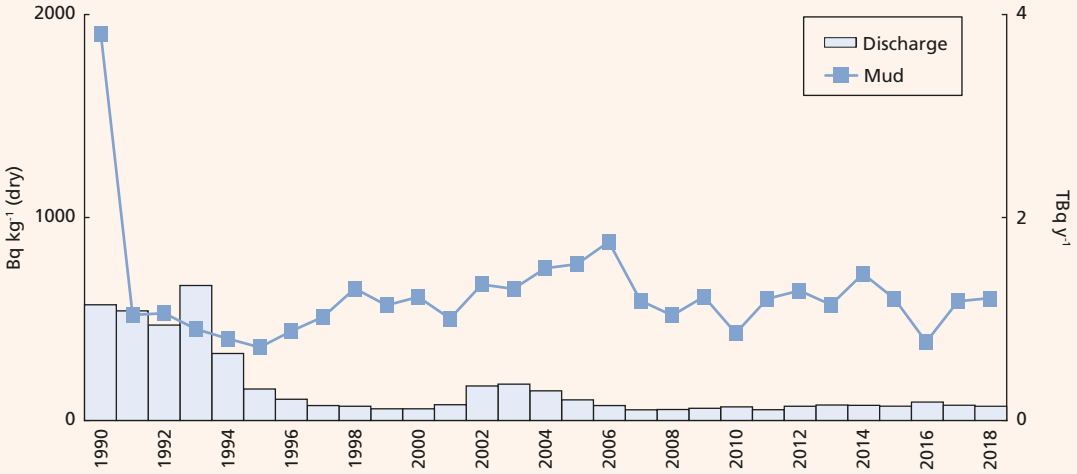


Figure 2.22. Plutonium-alpha liquid discharge from Sellafield and plutonium-239+240 concentration in mud at Ravenglass, 1990-2018

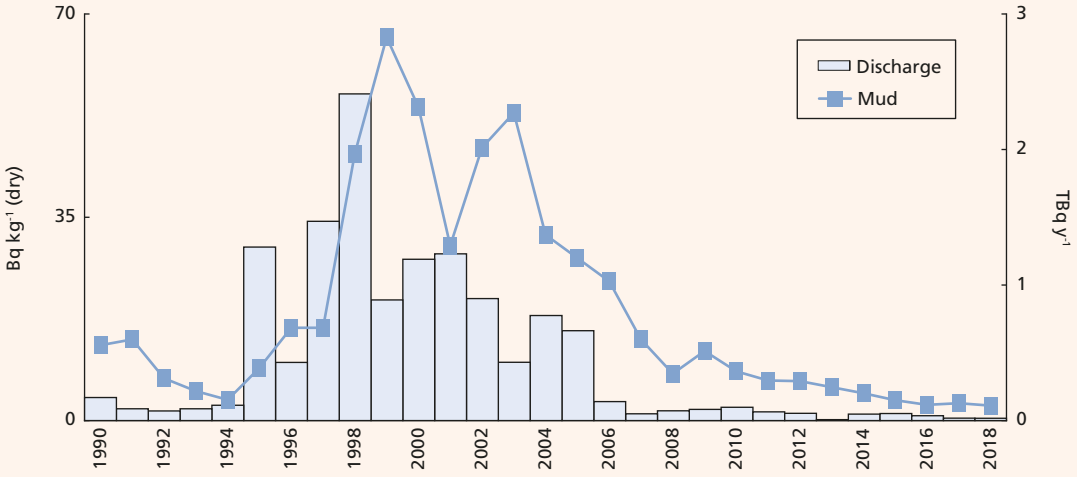


Figure 2.23. Cobalt-60 liquid discharge from Sellafield and concentration in mud at Ravenglass, 1990-2018

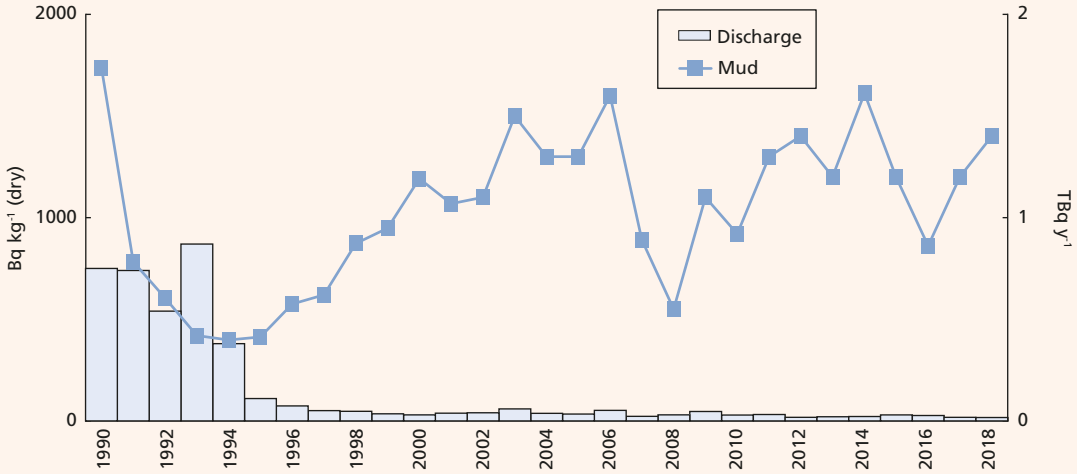


Figure 2.24. Americium-241 liquid discharge from Sellafield and concentration in mud at Ravenglass, 1990-2018

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). In 2018, the reported cobalt-60 concentration in mud from Ravenglass (Newbiggin) is the lowest reported value 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 low, 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 2018 at a given location were generally similar to those in recent years, and any fluctuations were most likely due to the normal variability expected to be in the environment. The americium-241 concentration in sediment at Carlton Marsh was higher in 2018, compared to those reported over the last decade. 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 (except at Carsluith) are still below peak values reported in much earlier years (following the start of the century). 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 provides 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 2018 were generally similar to those in recent years (with small variations in comparison to those in 2017). 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 2018, 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 (2007 – 2018). 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 are recorded over areas with finely divided sediments. For each location, there has been variation over time. Close to Sellafield (at Carleton

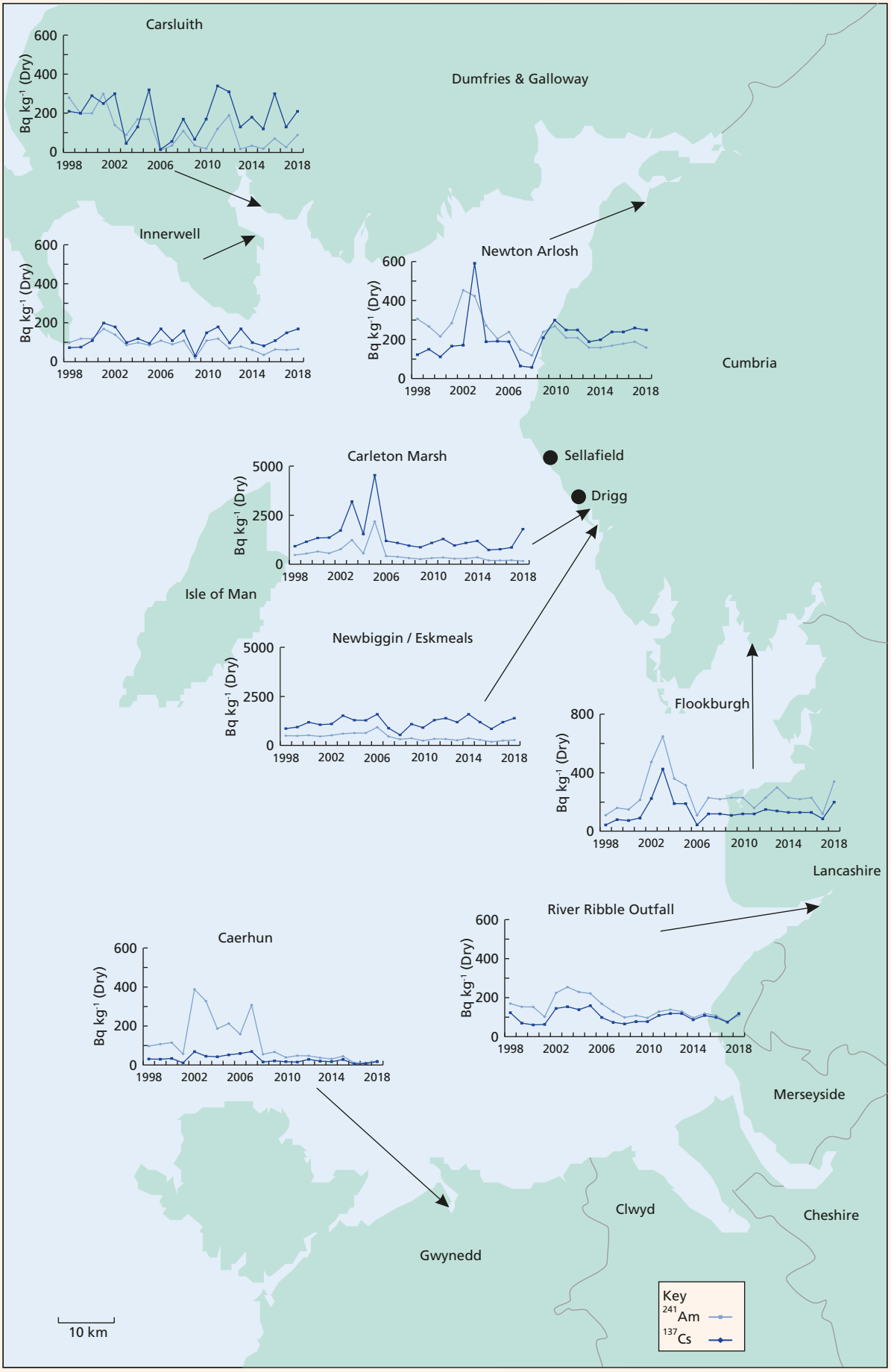


Figure 2.25. Concentrations of americium-241 and caesium-137 in coastal sediments in North West England and South West Scotland between 1998-2018 (Note different scales used for Newbiggin and Carleton Marsh)

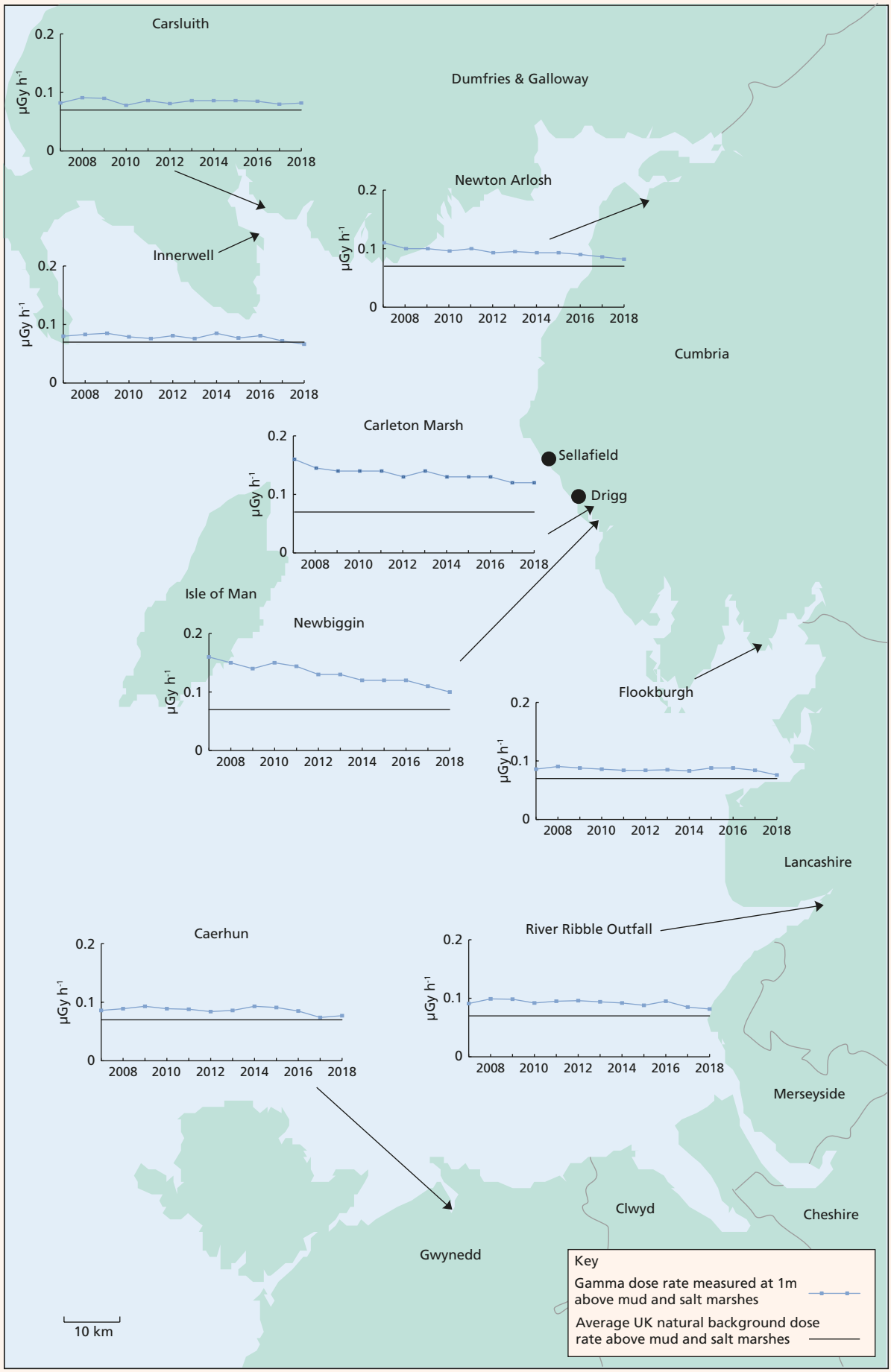


Figure 2.26. Gamma dose rates above fine coastal sediments (mud and salt marshes) in North West England, North Wales and South West Scotland between 2007-2018

Marsh and Newbiggin), there is some evidence to suggest that dose rates were slowly declining over the time period. Locations that are further afield from Sellafield show dose rate values that only marginally exceeded average UK natural background rates.

Over a number of decades, concentrations of radioactivity in the environment around Sellafield have declined as a result of reduced discharges. In more recent years the values 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 sediment (from depth) 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 more 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 2018 are given in Table 2.10. Overall, where comparisons can be made, measured dose rates in 2018 were generally similar to those in 2017 (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 2018 were generally similar to those in 2017 (where comparisons can be made from similar ground types and locations). Beta dose rates in sand were higher at Sellafield beach (North of discharge point) and lower at Tarn Bay in 2018 (in comparison to those in 2017). However, reported beta dose rates are low, with no radiological significance.

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 2018, 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 and objects* 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.

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 to detect of particles containing americium-241. The Synergy2 system was designed and introduced to further improve detection of americium-241 and strontium-90/yttrium-90.

Further beach monitoring for the 2018 calendar year was completed in line with the Environment Agency's specification. A total area of 159 hectares was surveyed against a programme target of 152 hectares (Sellafield Limited, 2019). 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 was 145 in 2018, of which approximately 88 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 2018 (May and October), two of the finds detected (particles) exceeded the characterisation triggers set within the Environment Agency's intervention trigger levels: **https://www.gov.uk/government/publications/sellafield-radioactive-objects-intervention-plan**. Both finds were within the range of previous measurements, and therefore do not require immediate further consideration

* *"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.*

nor does it challenge the PHE risk assessment (Brown and Etherington, 2011).

Monitoring along the Cumbrian coast will continue for 2019, with the current proposal being a further 150 hectares to be surveyed. As in 2018, the 2019 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 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. More recently, PHE have been requested by the Environment Agency to update their recommendations, if supported by available evidence. This is to account for the information from the beach monitoring programme and from the further analysis of finds that has been collected since 2012. It is expected that an updated assessment of the health risk to the public from radioactive particles and larger objects found on the beaches near the Sellafield site will be available and will be reported in future RIFE reports.

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

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

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**.

Monitoring of seaweed

Seaweeds are useful indicator materials, in addition to their occasional use in foods and as fertilisers. Seaweeds have the capability to readily accumulate radionuclides and thereby assist in the detection of these radionuclides in the environment. Table 2.12 gives the results of measurements in 2018 of seaweeds from shorelines of the Cumbrian coast and further afield. Comparing 2018 and 2017 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 are shown in Figure 2.11 (2007 – 2018) and Figure 2.12 (1990 – 2018). 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 lower by small amounts in 2018, in comparison to those in 2017. Over the last 5 years, small variations 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, technetium-99 concentrations in seaweed (*Fucus*) were lower in 2018 compared with those in 2017. 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 tide-washed 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 per year, 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 2018, samples of milk and livestock were collected and analysed, for radionuclides which were released in liquid effluent discharges from Sellafield. Results from surveys for activity concentrations in crops, fruit and environmental indicators are available in earlier RIFE reports (e.g. Environment Agency, FSA, NIEA, NRW and SEPA, 2014).

The results of measurements in 2018 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 2018, a low concentration of tritium was positively detected in a sheep sample (muscle), just above the less than value. As in previous years, the evidence for sea to land transfer was very limited in 2018. Technetium-99 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. As 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 from nuclear weapons testing. 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 2018 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.

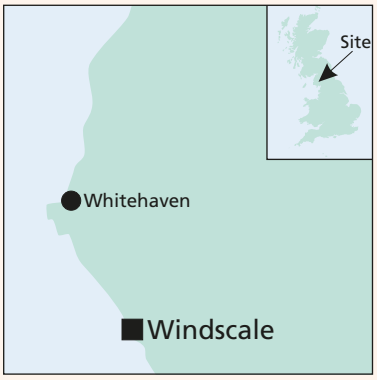
Small amounts of radioactivity are discharged from Sellafield under permit via the factory sewer outfall to the River Ehen Estuary, immediately prior to the confluence with the River Calder. In 2018, there was no evidence of tritium downstream, nor upstream of the outfall (Table 2.14). These are not potable waters and any low concentrations observed previously are of no radiological significance. Table 2.14 also includes the results of monitoring from Ehen Spit beach (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 2018 with concentrations similar to those in recent years. The annual dose from inadvertent consumption of water from Ehen Spit has been shown to be insignificant (Environment Agency, 2002).

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 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 2018 are included in Table 2.4. The maximum caesium-137 concentration in the muscle of wood pigeon was reported at the limit of detection in 2018 and generally similar to those in recent years. These caesium-137 concentrations fluctuated in value prior to 2011, but elevated concentrations have not been sustained thereafter. 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 2018 are shown in Table 2.15. Overall, activity concentrations are generally similar to those in recent years, although plutonium-239+240 and americium-241 concentrations were reduced (by small amounts) in 2018. 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 values 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. In 2017, a new site licence was issued that covers Sellafield only (amalgamating the Sellafield and Windscale nuclear sites). In October 2018, Sellafield Limited submitted an application to vary its environmental permit.

At Windscale there are three nuclear reactors, two of which were shut down in 1957 and the third in 1981. Most of the radioactive wastes derive from decontamination and decommissioning operations, some of which are of the early Windscale reactor buildings. Decommissioning activities began in the mid-1980s and these activities are continuing. The decommissioning of the Windscale 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 from Windscale; 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 Windscale 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, 2018

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**	**Local children inhabitants (0–0.25 km)**	**0.16[c]**	**-**	**<0.005**	**-**	**-**	**<0.005**	**0.16**
Source specific doses	Infant inhabitants and consumers of locally grown food	<0.005[c]	-	<0.005	-	-	<0.005	-
	Children playing at Rivacre Brook	0.006[c]	-	-	0.006	<0.005	-	-
Springfields								
***Total dose* – all sources**	**Adult mushroom consumers**	**0.075**	**-**	**<0.005**	**-**	**<0.005**	**-**	**0.075**
Source specific doses	Seafood consumers	0.012[c]	<0.005	-	0.010	-	-	-
	Fishermen handling nets or pots[b]	0.010	-	-	0.010	-	-	-
	Houseboat occupants	0.034	-	-	0.034	-	-	-
	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 substracting background and cosmic sources from measured gamma dose rates)*

Table 2.2(a) Concentrations of radionuclides in food and the environment near Capenhurst, 2018

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	^{237}Np
Marine samples										
Dab	Liverpool Bay	1	<25		1.1					
Shrimps	Wirral	1	<25	0.11	0.71					
Mussels	Liverpool Bay	1	<25		0.81					
Cockles	Dee Estuary[e]	1	<25	0.87	1.7	7.3				
Sediment	Rivacre Brook	2[E]		69	1.8	55	90	3.1	36	<2.0
Sediment	Rivacre Brook (1.5 km downstream)	2[E]		39	1.2	24	36	1.6	28	<2.0
Sediment	Rossmore (3.1 km downstream)	2[E]		34	0.92	20	25	1.7	19	<2.0
Sediment	Rivacre Brook (4.3 km downstream)	2[E]		7.9	<0.28	<8.2	7.3	<0.62	5.9	<2.0
Freshwater	Rivacre Brook	2[E]	<2.8	<0.22			0.034	<0.0016	0.014	<0.060
Freshwater	Rivacre Brook (1.5 km downstream)	2[E]	<2.9	<0.25			0.026	<0.0019	0.015	<0.060
Freshwater	Rossmore (3.1 km downstream)	2[E]	<3.0	<0.22			0.016	<0.00086	0.010	<0.060
Freshwater	Rivacre Brook (4.3 km downstream)	2[E]	<2.8	<0.22			0.016	<0.0015	0.008	<0.060

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									
Dab	Liverpool Bay	1			<0.14				
Shrimps	Wirral	1	0.00061	0.0041	0.013	*	*		
Mussels	Liverpool Bay	1			1.5				
Cockles	Dee Estuary[e]	1	0.15	1.1	2.3	0.001	0.002		
Sediment	Rivacre Brook	2[E]						380	980
Sediment	Rivacre Brook (1.5 km downstream)	2[E]						260	670
Sediment	Rossmore (3.1 km downstream)	2[E]						220	560
Sediment	Rivacre Brook (4.3 km downstream)	2[E]						<72	310
Freshwater	Rivacre Brook	2[E]						<0.041	0.31
Freshwater	Rivacre Brook (1.5 km downstream)	2[E]						<0.033	0.23
Freshwater	Rossmore (3.1 km downstream)	2[E]						<0.037	0.19
Freshwater	Rivacre Brook (4.3 km downstream)	2[E]						<0.027	0.18

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	<4.0	<0.0070	0.0034	0.00040	<0.0013
Milk	max		<4.3	<0.0075	0.0047	0.00042	0.0022
Potato		1		<0.035	0.0026	0.00047	0.0035
Silage		1		<0.065	0.075	0.0032	0.072
Grass/herbage	North of Ledsham	1[E]		<1.2	0.70	<0.11	0.76
Grass/herbage	South of Capenhurst	1[E]		<1.1	<0.069	<0.070	<0.077
Grass	East of Capenhurst	1[E]		<0.77	0.088	<0.047	0.091
Grass	Dunkirk Lane (0.9 km South of Site)	1[E]		<0.82	0.26	<0.017	0.24
Soil	North of Ledsham	1[E]		<6.5	26	1.5	23
Soil	South of Capenhurst	1[E]		<6.4	20	1.2	20
Soil	East of Capenhurst	1[E]		<3.4	20	<1.8	19
Soil	Dunkirk Lane (0.9 km South of Site)	1[E]		<6.9	19	0.73	18

* *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] *The concentration of ^{210}Po was 24 Bq kg^{-1}, measurement made on behalf of the Environment Agency*

[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, 2018			
Location	Ground type	No. of sampling observations	μGy h^{-1}
Mean gamma dose rates at 1m over substrate			
East of railway station	Grass	1	0.078
Dunkirk Lane	Grass and mud	1	0.075
Near Lower Brook Farm	Grass	1	0.074
Rivacre Brook Plant outlet	Grass	2	0.077
Rivacre Brook 1.5 km downstream	Grass	2	0.073
Rossmore Road West 3.1 km downstream	Grass	1	0.066
Rossmore Road West 3.1 km downstream	Grass and stones	1	0.071
Rivacre Brook 4.3 km downstream	Pebbles and sand	2	0.075
North of Ledsham	Grass	1	0.073

Table 2.3(a) Concentrations of radionuclides in food and the environment near Springfields, 2018

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	^{234}Th
Marine samples												
Flounder	Ribble Estuary	1						2.3				
Grey Mullet	Ribble Estuary	1						2.5				
Shrimps[d,e]	Ribble Estuary	1		51		0.12		1.1	0.0065	0.0046	0.0016	
Mussels[f]	Ribble Estuary	1						0.23	0.22	0.16	0.10	
Wildfowl	Ribble Estuary	1	<4.2	33	<0.042		<1.1	0.56		0.0053	0.0034	
Samphire	Marshside Sands	1				0.21		0.12				
Sediment	River Ribble outfall	4[E]						110	29	53	29	43
Sediment	Lea Gate	2[E]						210	38	95	42	<340
Sediment	Lower Penwortham Park	4[E]						190	43	97	41	130
Sediment	Penwortham road bridge - West bank	2[E]						87	30	51	34	190
Sediment	Lytham Yacht Club	1[E]						140	31	60	36	36
Sediment	Becconsall	4[E]						66	28	37	26	42
Sediment	Freckleton	1[E]						210	45	90	41	61
Sediment	Hutton Marsh	1[E]						330	50	120	37	41
Sediment	Longton Marsh	1[E]						480	44	280	49	<24
Grass (washed)	Hutton Marsh	1[E]				<1.7						
Grass (unwashed)	Hutton Marsh	1[E]				<1.6						
Soil	Hutton Marsh	1[E]				36						

Material	Location	No. of sampling observ-ations	Mean radioactivity concentration (fresh)[b], Bq kg^{-1}								
			^{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							<0.19		
Grey Mullet	Ribble Estuary	1							<0.27		
Shrimps[d,e]	Ribble Estuary	1				0.00022	0.0014	0.0086	0.019		
Mussels[f]	Ribble Estuary	1					0.073	0.44	0.90		
Wildfowl	Ribble Estuary	1					0.0012	0.0077	<0.14		
Samphire	Marshside Sands								<0.08		
Sediment	River Ribble outfall	4[E]	21	<1.3	22				120	420	770
Sediment	Lea Gate	2[E]	37	1.4	34				200	750	1500
Sediment	Lower Penwortham Park	4[E]	32	1.7	32				190	670	1400
Sediment	Penwortham road bridge - West bank	2[E]	21	1.00	24				97	300	840
Sediment	Lytham Yacht Club	1[E]	26	1.3	29				150	840	1300
Sediment	Becconsall	4[E]	20	<1.3	21				74	380	760
Sediment	Freckleton	1[E]	27	1.3	32				220	680	1600
Sediment	Hutton Marsh	1[E]	32	1.4	34				280	640	1600
Sediment	Longton Marsh	1[E]	38	2.2	38				330	1300	1400

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	^{234}U
Terrestrial samples												
Milk		2										<0.0014
Milk	Max											0.0019
Beetroot		1	<2.7	12	<0.043	<0.018	<0.06	<0.057	0.0030	0.0029		0.0036
Sediment	Deepdale Brook	2[E]					0.95				59	48
Silage		1	<3.8	34	0.24	<0.039	<0.05	<0.048	0.037	0.039		0.044
Grass	Opposite site entrance	1[E]										0.54
Grass	Opposite windmill	1[E]										0.70
Grass	Deepdale Brook	1[E]										1.4
Grass	N of Lea Town	1[E]										<0.10
Soil	Opposite site entrance	1[E]										91
Soil	Opposite windmill	1[E]										110
Soil	Deepdale Brook	1[E]										97
Soil	N of Lea Town	1[E]										45
Freshwater	Deepdale Brook	4[E]										0.26
Freshwater[e]	Ulnes Walton	1[E]	<2.6				<0.22		<0.0025	<0.0022		0.024

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	<0.0014	<0.00048	<0.00062						
Milk	Max		0.0019	<0.00058	<0.00076						
Beetroot		1	0.0036	<0.00033	0.0032	<0.00011	0.00016	<0.45	0.00015		
Sediment	Deepdale Brook	2[E]	48	2.8	51					320	990
Silage		1	0.044	0.0016	0.037	<0.00016	0.00074	0.15	0.76		
Grass	Opposite site entrance	1[E]	0.54	<0.12	0.14						
Grass	Opposite windmill	1[E]	0.70	<0.14	0.39						
Grass	Deepdale Brook	1[E]	1.4	<0.16	0.74						
Grass	N of Lea Town	1[E]	<0.10	<0.057	<0.063						
Soil	Opposite site entrance	1[E]	91	4.8	79						
Soil	Opposite windmill	1[E]	110	4.2	100						
Soil	Deepdale Brook	1[E]	97	4.8	93						
Soil	N of Lea Town	1[E]	45	2.2	46						
Freshwater	Deepdale Brook	4[E]	0.26	0.011	0.26					0.38	0.66
Freshwater[g]	Ulnes Walton	1[E]	0.024	0.0026	0.021					<0.089	0.85

[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 concentrations of ^{242}Cm and $^{243+244}$Cm were not detected and 0.0012 Bq kg^{-1}, respectively*

[f] *The concentration of ^{210}Po was 8.1 Bq kg^{-1}, measurement made on behalf of the Environment Agency*

[g] *The concentration of ^{228}Th was <0.0081 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, 2018

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	0.088
Warton Salt Marsh	Salt marsh	2	0.086
Warton Salt Marsh	Salt marsh[a]	2	0.087
Freckleton	Salt marsh	1	0.086
Naze Point	Salt marsh	2	0.091
Banks Marsh (alternative)[b]	Salt marsh	2	0.10
Banks Marsh (alternative)[b]	Salt marsh[a]	2	0.10
Becconsall Boatyard	Grass	2	0.072
Becconsall Boatyard	Mud and sand	1	0.077
Becconsall Boatyard	Salt marsh	1	0.073
Longton Marsh	Salt marsh	1	0.10
Hutton Marsh	Salt marsh	1	0.12
River Ribble outfall	Mud	1	0.079
River Ribble outfall	Mud and salt marsh	1	0.082
River Ribble outfall	Mud and sand	2	0.084
Savick Brook, confluence with Ribble	Salt marsh	2	0.080
Savick Brook, Lea Gate	Grass	2	0.083
South bank opposite outfall	Salt marsh	1	0.10
Penwortham road bridge	Mud	2	0.077
Lower Penwortham Park	Grass	4	0.071
River Darwen	Grass	4	0.073
Riverbank Angler Location 1	Grass	3	0.069
Ulnes Walton, BNFL area survey	Grass	3	0.078
Mean beta dose rates			µSv h^{-1}
Banks Marsh (alternative)[b]	Salt marsh	1	0.052
Granny's Bay	Sand	1	0.18
Warton Salt Marsh	Salt marsh	2	0.047
Springfields	Fishing net	1	0.031
Springfields	Tarpaulin	1	0.026

[a] *15cm above substrate*
[b] *As in 2017, no monitoring was undertaken at Banks Marsh in 2018 (as reported in earlier RIFE reports)*

Table 2.4 Concentrations of radionuclides in terrestrial food and the environment near Sellafield, 2018

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	<4.6	<4.7	16	<0.05	<0.038	<0.070	<0.40	<0.10	<0.0070	<0.0039	<0.05
Milk	max		<5.8	<6.0	19		0.051	<0.073	<0.44	<0.11	0.015	0.011	
Apple		1	<6.6	<6.6	16	<0.05	0.088	<0.035	<0.33	<0.10	<0.021		<0.04
Beef kidney		1	12	12	30	<0.11	<0.12	<0.063	<1.3	<0.49			<0.12
Beef liver		1	<3.4	<3.4	29	<0.06	<0.043	<0.042	<0.64	<0.14	<0.014		<0.07
Beef muscle		1	<3.8	<3.8	39	<0.05	0.026	<0.041	<0.43	<0.11	<0.015		<0.04
Beetroot		1	4.1	4.1	8.6	<0.06	0.083		<0.45	<0.12	<0.021		<0.06
Cabbage		1	<2.2	<2.2	8.0	<0.03	0.083		<0.25	<0.07	<0.022		<0.03
Eggs		1	<3.0	<3.0	33	<0.10	<0.043		<0.58	<0.13	<0.013		<0.06
Mushrooms		1	<6.0	<6.0	5.7	<0.05	0.055		<0.36	<0.09	<0.020		<0.05
Pheasant		1	<3.9	<3.9	38	<0.05	<0.045	<0.041	<0.43	<0.12	<0.025		<0.06
Potatoes		2	<2.4	<2.4	19	<0.05	<0.027		<0.33	<0.10	<0.018		<0.04
Potatoes	max				22		0.030		<0.34		<0.024		
Rabbit		1	9.7	9.7	9.9	<0.04	0.045	<0.033	<0.27	<0.08	<0.021		<0.03
Sheep muscle		2	12	12	28	<0.05	<0.044	<0.092	<0.27	<0.10	<0.023		<0.05
Sheep muscle	max				33		0.058	<0.066		<0.11	<0.026		
Sheep offal		2	<7.0	<7.0	30	<0.03	<0.054	<0.055	<0.29	<0.12	<0.021		<0.04
Sheep offal	max		11	11	33	<0.04	<0.057	<0.062	<0.36				<0.05
Wood pigeon muscle		2	<4.5	<4.5	27	<0.04	<0.047		<0.27	<0.08	<0.014		<0.03
Wood pigeon muscle	max		<5.4	<5.4	28	<0.05	<0.050		<0.30	<0.09	<0.015		
Grass	Braystones	1[E]		<21	13		<1.1		<8.1	<4.5			
Grass	River Calder (upstream)	1[E]		<16	10		<1.6		<7.6	<4.4			
Grass	River Calder (downstream)	1[E]		36	<3.6		<0.68		<8.8	<5.0			
Soil[d]		1	<2.0		3.3	<0.09	<1.8	<0.60	<1.1	<0.36	<0.066		<0.12
Soil	Braystones	1[E]		<13	<5.3		<0.74		<5.9	<3.2			
Soil	River Calder (upstream)	1[E]		<9.3	12		<0.84		<3.4	<2.0			

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	<0.11	<0.11				<0.000060	<0.000066	<0.22	<0.000032
Milk	max		0.18	0.21				<0.000076	<0.000091	<0.27	0.000043
Apple		1	0.22	0.22				0.000055	0.0018	<0.23	0.00093
Beef kidney		1	0.3	0.30	0.0046	0.00058	0.0038	<0.00013	0.00013	<0.30	0.00032
Beef liver		1	0.29	0.30				0.00025	0.0022	<0.23	0.0017
Beef muscle		1	0.51	0.51				0.000024	0.000085	<0.23	0.00011
Beetroot		1	<0.05	<0.053	0.013	0.00065	0.0099	0.000052	0.00012	<0.23	0.000078
Cabbage		1	0.07	0.068				<0.000011	0.000044	<0.21	0.000038
Eggs		1	<0.05	<0.051				0.000059	0.000074	<0.21	0.00018
Mushrooms		1	1.2	1.2				0.0089	0.057	0.19	0.098
Pheasant		1	<0.06	<0.055				<0.000019	0.000019	<0.22	0.000024
Potatoes		2	<0.05	<0.054	0.011	0.00037	0.0097				<0.10
Potatoes	max		0.07	0.070							<0.12
Rabbit		1	0.33	0.33				0.000045	0.000060	<0.22	0.000056
Sheep muscle		2	0.19	0.19				0.000037	0.00015	<0.22	0.00028
Sheep muscle	max		0.21	0.21				0.000053	0.00016	<0.25	0.00030
Sheep offal		2	0.15	0.15	0.0036	0.00029	0.0026	0.00054	0.0042	<0.22	0.0032
Sheep offal	max		0.16	0.16	0.0050		0.0030	0.00063	0.0053	<0.24	0.0036
Wood pigeon muscle		2	<0.04	<0.045				<0.00013	0.000091	<0.42	0.00011
Wood pigeon muscle	max		<0.05	<0.054					0.000092	<0.50	0.00016
Grass	Braystones	1[E]	<0.98					<0.075	0.12	<22	<1.1
Grass	River Calder (upstream)	1[E]	1.9					<0.10	<0.076	<8.6	<1.2
Grass	River Calder (downstream)	1[E]	<1.1					0.11	0.51	<15	<1.1
Soil[d]		1	35	35				0.11	1.1	<12	1.1
Soil	Braystones	1[E]	58					0.50	6.2	<24	5.5
Soil	River Calder (upstream)	1[E]	38					<0.57	7.1	<46	2.7

[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 9.1 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, 2018

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
Cumbria									
Parton	Cod[c]	2			57	<0.07	0.014	<2.1	<0.51
Whitehaven	Cod[c]	2			28	<0.06	0.024	<0.09	<0.12
Whitehaven	Plaice[a,c]	1	30	32	57	<0.06	0.020	<0.64	<0.34
Ravenglass	Plaice[b,c]	1			84	<0.08	0.017	<1.2	<0.47
Lancashire and Merseyside									
Morecambe Bay (Morecambe)	Flounder	2	<29	40	44	<0.08	0.033	<0.41	<0.27
Ribble Estuary	Flounder	1				<0.08		<0.35	<0.31
Ribble Estuary	Grey Mullet	1				<0.10		<0.44	<0.39
Liverpool Bay	Dab	1		<25		<0.08		<1.1	<0.43
Scotland									
The Minch	Herring	1[S]				<0.10		<0.16	<0.11
The Minch	Mackerel	1[S]				<0.10		<0.14	<0.13
Shetland	Fish meal (salmon)	1[S]				<0.10		<0.18	<0.24
Shetland	Fish meal (herring)	1[S]				<0.11		0.23	<0.23
Shetland	Fish oil (salmon)	1[S]				<0.10		<0.12	<0.17
Shetland	Fish oil (herring)	1[S]				<0.10		<0.12	<0.18
Ardrossan South Bay	Mackerel	1[S]				<0.10		<0.20	<0.14
Ardrossan South Bay	Salmon	1[S]				<0.10		<0.24	<0.16
Kirkcudbright	Plaice	2[S]			41	<0.10		<0.22	<0.15
Inner Solway	Salmon	1[S]		<5.0		<0.10		<0.41	<0.35
Inner Solway	Sea trout	1[S]		<5.0		<0.10		<0.44	<0.36
Wales									
North Anglesey	Plaice	1	<25	<25	26	<0.07		<0.59	<0.34
Northern Ireland									
North coast	Lesser spotted dogfish	4[N]				<0.19		<1.1	<0.78
Ardglass	Herring	2[N]				<0.10		<0.95	<0.53
Kilkeel	Cod	4[N]			23	<0.07		<0.32	<0.22
Kilkeel	Plaice	4[N]				<0.11		<0.48	<0.32
Kilkeel	Skates / rays	4[N]				<0.12		<0.60	<0.47
Kilkeel	Haddock	4[N]				<0.07		<0.28	<0.28
Further afield									
Norwegian Sea	Haddock	2				<0.07		<0.26	<0.16

Table 2.5 continued

Location	Material	No. of sampling observ-ations	Mean radioactivity concentration (fresh), Bq kg^{-1}						
			^{99}Tc	^{106}Ru	^{125}Sb	^{134}Cs	^{137}Cs	^{144}Ce	Gross beta
Cumbria									
Parton	Cod[c]	2	0.20	<0.59	<0.17	<0.07	3.2	<0.42	200
Whitehaven	Cod[c]	2	<0.25	<0.43	<0.14	<0.05	1.0	<0.28	130
Whitehaven	Plaice[a,c]	1	1.8	<0.55	<0.15	<0.06	1.3	<0.30	96
Ravenglass	Plaice[b,c]	1	2.0	<0.65	<0.18	<0.07	1.8	<0.38	
Lancashire and Merseyside									
Morecambe Bay (Morecambe)	Flounder	2	<0.23	<0.67	<0.18	<0.07	3.0	<0.36	
Ribble Estuary	Flounder	1		<0.67	<0.19	<0.07	2.3	<0.38	
Ribble Estuary	Grey Mullet	1		<0.77	<0.24	<0.10	2.5	<0.49	
Liverpool Bay	Dab	1		<0.70	<0.16	<0.08	1.1	<0.36	
Scotland									
The Minch	Herring	1[S]		<0.19	<0.10	<0.10	0.13	<0.14	
The Minch	Mackerel	1[S]		<0.33	<0.10	<0.10	0.21	<0.21	
Shetland	Fish meal (salmon)	1[S]		<0.99	<0.29	<0.12	0.20	<0.59	
Shetland	Fish meal (herring)	1[S]		<0.90	<0.26	0.19	0.24	<0.55	
Shetland	Fish oil (salmon)	1[S]		<0.71	0.35	<0.10	<0.10	<0.43	
Shetland	Fish oil (herring)	1[S]		<0.82	<0.27	<0.10	<0.10	<0.52	
Ardrossan South Bay	Mackerel	1[S]		<0.28	<0.10	<0.10	0.63	<0.20	
Ardrossan South Bay	Salmon	1[S]		<0.31	<0.10	<0.10	0.21	<0.22	
Kirkcudbright	Plaice	2[S]	<0.25	<0.27	<0.10	<0.10	<0.10	<0.18	
Inner Solway	Salmon	1[S]		<0.84	<0.26	<0.10	0.13	<0.52	
Inner Solway	Sea trout	1[S]		<0.83	<0.24	<0.10	<0.10	<0.50	
Wales									
North Anglesey	Plaice	1		<0.55	<0.14	<0.05	0.59	<0.30	
Northern Ireland									
North coast	Lesser spotted dogfish	4[N]		<1.4	<0.44	<0.17	1.2	<0.70	
Ardglass	Herring	2[N]		<0.87	<0.24	<0.09	0.31	<0.50	
Kilkeel	Cod	4[N]		<0.60	<0.17	<0.07	1.2	<0.34	
Kilkeel	Plaice	4[N]		<0.77	<0.22	<0.10	0.25	<0.40	
Kilkeel	Skates / rays	4[N]		<1.0	<0.28	<0.11	0.77	<0.64	
Kilkeel	Haddock	4[N]		<0.52	<0.16	<0.06	0.45	<0.31	
Further afield									
Norwegian Sea	Haddock	2		<0.48	<0.13	<0.07	0.15	<0.27	

[a] *The concentrations of ^{129}I and ^{147}Pm were <0.95 Bq kg^{-1} and 0.020 Bq kg^{-1}, respectively*
[b] *The concentrations of ^{129}I and ^{147}Pm were <0.97 and <0.024 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, 2018

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			83	<0.08	0.12	<0.30	<0.24	2.1	<5.7
Parton	Lobsters[d]	2			76	<0.04	0.031	<0.23	<0.20	56	<0.36
Parton	Winkles[d]	2			71	0.32	0.37	<4.4	<1.1	28	<0.78
Whitehaven	*Nephrops*[a,d]	1	29	37	49	<0.13	0.12	<2.4	<1.1	53	<1.4
Whitehaven outer harbour	Mussels[d]	2			73	<0.10	0.25	<0.28	<0.19	8.0	<0.59
Nethertown	Winkles[b,d]	4	<25	<26	93	0.48	1.0	<0.28	<0.29	20	<1.1
Sellafield coastal area	Crabs[c,d]	2	<25	<25	100	<0.17	0.085	<0.31	<0.22	7.9	<0.47
Sellafield coastal area	Lobsters[d]	2	66	69	81	<0.08	0.042	<0.19	<0.17	72	<0.47
Ravenglass	Winkles[d]	1			150	0.71	0.53	<1.2	<0.79	15	<1.8
Seascale Area	Common prawns[d]	2	<25	36	91	<0.15	<0.11	<0.25	<0.39	0.30	<1.1
Lancashire and Merseyside											
Morecambe Bay (Morecambe)	Shrimps[d]	2	<25	<25	54	<0.07	<0.040	<2.4	<0.71	0.53	<0.63
Morecambe Bay (Morecambe)	Mussels	2	71	68	55	<0.06	0.14	<0.14	<0.20	6.9	<0.55
Morecambe Bay (Middleton Sands)	Winkles	2	340	370	46	<0.13	0.16	<0.73	<0.41	11	<0.99
Ribble Estuary	Shrimps	1			51	<0.09		<0.14	<0.18	0.12	<0.58
Ribble Estuary	Mussels	1				<0.03		<0.06	<0.06		<0.22
Liverpool Bay	Mussels	1		<25		<0.17		<0.93	<0.50		<1.3
Dee Estuary	Cockles	1		<25		<0.08		<0.14	<0.10	0.87	<0.64
Wirral	Shrimps	1		<25		<0.07		<0.11	<0.16	0.11	<0.51
Scotland											
Kinlochbervie	Crabs	2[S]				<0.10		<0.33	<0.25	<0.24	<0.57
Lewis	Mussels	1[S]				<0.10		<0.33	<0.29		<0.80
Skye	Lobsters	1[S]				<0.10		<0.87	<0.53	4.0	<0.91
Skye	Mussels	1[S]				<0.10		<0.27	<0.16		<0.27
Islay	Crabs	1[S]				<0.10		<0.50	<0.32		<0.66
Islay	Scallops	1[S]				<0.10		<0.26	<0.17		<0.32
Kirkcudbright	Crabs[d]	1[S]			40	<0.10	<0.10	<0.22	<0.24	<0.30	<0.75
Kirkcudbright	Lobsters[d]	1[S]			23	<0.10	<0.10	<0.25	<0.27	4.5	<0.83
Kirkcudbright	Limpets[d]	1[S]				<0.10		<2.0	<0.75		<0.83
Kirkcudbright	Winkles[d]	1[S]				<0.10	<0.10	<2.2	<0.75	4.1	<0.77
Kirkcudbright	Scallops	2[S]				<0.10		<0.29	<0.16	<0.33	<0.27
Kirkcudbright	Queens	2[S]				<0.10		<0.22	<0.15	<0.18	<0.28
Cutters Pool	Winkles	1[S]				<0.10		<2.3	<0.83		<0.97
Southerness	Winkles	1[S]		<5.0		<0.10	0.36	<2.2	<0.62	5.1	<0.52
North Solway coast	Cockles	1[S]				0.17		<0.80	<0.46		<0.80
North Solway coast	Mussels	1[S]		<5.0	19	<0.10	0.46	<0.36	<0.31	25	<0.81
Inner Solway	Shrimps	2[S]		<5.7		<0.10	<0.10	<0.28	<0.19	<0.40	<0.36
Wales											
North Anglesey	Crabs[d]	1	<25	<25	40	<0.09		<0.62	<0.37		<0.61
North Anglesey	Lobsters[d]	1	<25	<25	29	<0.08		<0.87	<0.32	7.2	<0.80
Northern Ireland											
Ballycastle	Lobsters	2[N]				<0.07		<0.40	<0.28	9.8	<0.59
County Down	Scallops	2[N]				<0.08		<0.63	<0.32		<0.38
Kilkeel	Crabs[d]	4[N]				<0.06		<0.22	<0.19		<0.50
Kilkeel	Lobsters[d]	4[N]				<0.12		<0.49	<0.49	6.9	<0.86
Kilkeel	*Nephrops*	4[N]				<0.07		<0.49	<0.34	1.6	<0.52
Minerstown	Winkles[d]	4[N]				<0.08		<0.43	<0.40		<0.81
Carlingford Lough	Mussels[d]	2[N]				<0.12		<1.2	<0.82	1.2	<1.1
Further afield											
Cromer	Crabs	2				<0.09		<0.47	<0.33		<0.79
Southern North Sea	Cockles	2				<0.04		<0.19	<0.21		<0.50

Table 2.6 continued

Location	Material	No. of sampling observ-ations	Mean radioactivity concentration (fresh), Bq kg^{-1}							
			^{110m}Ag	^{125}Sb	^{134}Cs	^{137}Cs	^{144}Ce	^{147}Pm	^{155}Eu	Gross beta
Cumbria										
Parton	Crabs[d]	2	<0.11	<0.17	<0.07	0.90	<0.39		<0.17	120
Parton	Lobsters[d]	2	<0.06	<0.12	<0.04	1.0	<0.29		<0.13	170
Parton	Winkles[d]	2	<0.15	<0.26	<0.08	3.2	<0.49		<0.19	220
Whitehaven	*Nephrops*[a,d]	1	<0.25	<0.37	<0.14	2.7	<0.88		<0.34	120
Whitehaven outer harbour	Mussels[d]	2	<0.10	<0.21	<0.07	1.2	<0.33		<0.15	79
Nethertown	Winkles[b,d]	4	<0.14	<0.26	<0.07	4.5	<0.38	0.30	<0.18	160
Sellafield coastal area	Crabs[c,d]	2	<0.09	<0.13	<0.05	0.65	<0.33	0.094	<0.14	74
Sellafield coastal area	Lobsters[d]	2	<0.09	<0.14	<0.05	0.84	<0.32		<0.14	170
Ravenglass	Winkles[d]	1	<0.23	<0.62	<0.20	4.1	<0.83		<0.34	120
Seascale Area	Common prawns[d]	2	<0.18	<0.31	<0.12	1.2	<0.57		<0.26	91
Lancashire and Merseyside										
Morecambe Bay (Morecambe)	Shrimps[d]	2	<0.12	<0.17	<0.08	3.6	<0.42		<0.16	
Morecambe Bay (Morecambe)	Mussels	2	<0.09	<0.15	<0.07	1.3	<0.35		<0.20	130
Morecambe Bay (Middleton Sands)	Winkles	2	<0.17	<0.21	<0.12	2.1	<0.55		<0.24	150
Ribble Estuary	Shrimps	1	<0.11	<0.19	<0.07	1.1	<0.33		<0.16	
Ribble Estuary	Mussels	1	<0.04	<0.06	<0.03	0.23	<0.11		<0.05	
Liverpool Bay	Mussels	1	<0.24	<0.34	<0.16	0.81	<0.75		<0.27	
Dee Estuary	Cockles	1	<0.11	<0.20	<0.08	1.7	<0.41		<0.19	
Wirral	Shrimps	1	<0.10	<0.16	<0.06	0.71	<0.29		<0.21	
Scotland										
Kinlochbervie	Crabs	2[S]	<0.10	<0.16	<0.10	<0.10	<0.33		<0.13	
Lewis	Mussels	1[S]	<0.11	<0.24	<0.10	<0.10	<0.47		<0.20	
Skye	Lobsters	1[S]	<0.14	<0.24	<0.10	0.19	<0.56		<0.21	
Skye	Mussels	1[S]	<0.10	<0.10	<0.10	<0.10	<0.14		<0.10	
Islay	Crabs	1[S]	<0.10	<0.18	<0.10	<0.10	<0.45		<0.15	
Islay	Scallops	1[S]	<0.10	<0.10	<0.10	<0.11	<0.21		<0.10	
Kirkcudbright	Crabs[d]	1[S]	<0.11	<0.23	<0.10	0.21	<0.41		<0.17	
Kirkcudbright	Lobsters[d]	1[S]	<0.13	<0.25	<0.10	0.21	<0.49		<0.21	
Kirkcudbright	Limpets[d]	1[S]	<0.18	<0.21	<0.10	2.6	<0.55		<0.19	
Kirkcudbright	Winkles[d]	1[S]	<0.15	<0.21	<0.10	0.43	<0.47		<0.16	
Kirkcudbright	Scallops	2[S]	<0.10	<0.10	<0.10	<0.10	<0.19		<0.10	
Kirkcudbright	Queens	2[S]	<0.10	<0.10	<0.10	0.53	<0.18		<0.10	
Cutters Pool	Winkles	1[S]	<0.21	<0.26	<0.10	3.3	<0.65		<0.19	
Southerness	Winkles	1[S]	<0.10	<0.13	<0.10	0.37	<0.30		<0.10	
North Solway coast	Cockles	1[S]	<0.16	<0.24	<0.10	3.5	<0.53		<0.21	
North Solway coast	Mussels	1[S]	<0.16	<0.23	<0.10	2.3	<0.51		<0.21	
Inner Solway	Shrimps	2[S]	<0.10	<0.12	<0.10	<0.10	<0.24		<0.11	
Wales										
North Anglesey	Crabs[d]	1	<0.16	<0.23	<0.06	<0.31	<0.47		<0.18	
North Anglesey	Lobsters[d]	1	<0.12	<0.18	<0.09	0.22	<0.41		<0.16	96
Northern Ireland										
Ballycastle	Lobsters	2[N]	<0.13	<0.20	<0.08	0.27	<0.44		<0.14	
County Down	Scallops	2[N]	<0.07	<0.17	<0.08	0.18	<0.38		<0.14	
Kilkeel	Crabs[d]	4[N]	<0.09	<0.15	<0.06	0.15	<0.34		<0.18	
Kilkeel	Lobsters[d]	4[N]	<0.15	<0.23	<0.11	<0.19	<0.54		<0.21	
Kilkeel	*Nephrops*	4[N]	<0.11	<0.17	<0.08	0.38	<0.39		<0.17	
Minerstown	Winkles[d]	4[N]	<0.18	<0.18	<0.10	0.27	<0.44		<0.19	
Carlingford Lough	Mussels[d]	2[N]	<0.19	<0.27	<0.13	0.33	<0.63		<0.23	
Further afield										
Cromer	Crabs	2	<0.14	<0.20	<0.11	<0.08	<0.44		<0.20	
Southern North Sea	Cockles	2	<0.07	<0.11	<0.04	<0.07	<0.27		<0.12	

[a] *The concentration of ^{129}I was <1.0 Bq kg^{-1}*
[b] *The concentration of ^{129}I was <1.3 Bq kg^{-1}*
[c] *The concentration of ^{129}I was <1.1 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, 2018

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		0.0020	0.010	<0.26	0.024	*	0.000039
Parton	Crabs	2		0.028	0.17	0.62	0.79	*	0.0017
Parton	Lobsters	2		0.023	0.13	0.64	1.1	*	*
Parton	Winkles	2	0.0036	0.82	5.1	24	10	*	0.013
Whitehaven	Cod	2		<0.0014	0.0058	<0.20	0.011	0.000020	0.000071
Whitehaven	Plaice	1	0.000076	0.0011	0.0062	<0.29	0.012	*	*
Whitehaven	*Nephrops*	1		0.065	0.38	2.2	2.6	*	0.0011
Whitehaven outer harbour	Mussels	2		0.44	2.4	13	5.3	*	0.014
Nethertown	Winkles	4	0.0090	1.1	5.7	32	12	*	0.035
Sellafield coastal area	Crabs	2	0.0019	0.060	0.30	2.0	1.0	*	*
Sellafield coastal area	Lobsters	2		0.027	0.15	0.75	3.0	*	*
Ravenglass	Plaice	1		0.00052	0.0039	<0.28	0.0084	*	*
Ravenglass	Winkles	1		1.1	5.6	30	12	*	*
Seascale	Prawns	2		0.0075	0.049	<0.59	0.090	0.00067	0.00039
Lancashire and Merseyside									
Morecambe Bay (Morecambe)	Flounder	2		0.00084	0.0051		0.010	0.000045	0.000015
Morecambe Bay (Morecambe)	Shrimps	2		0.010	0.035		0.058	*	*
Morecambe Bay (Morecambe)	Mussels	2		0.17	1.0	4.6	1.8	*	0.0025
Morecambe Bay (Middleton Sands)	Winkles	2		0.24	1.5	6.6	2.9	*	0.0030
Ribble Estuary	Flounder	1					<0.19		
Ribble Estuary	Mullet	1					<0.27		
Ribble Estuary	Shrimps	1	0.00022	0.0014	0.0086		0.019	*	*
Ribble Estuary	Mussels	1		0.073	0.44		0.90	*	0.0012
Liverpool Bay	Dab	1					<0.14		
Liverpool Bay	Mussels	1					1.5		
Dee Estuary	Cockles	1		0.15	1.1		2.3	0.0014	0.0023
Wirral	Shrimps	1		0.00061	0.0041		0.013	*	*
Scotland									
The Minch	Herring	1[S]		0.0021	0.00090		<0.0021		
The Minch	Mackerel	1[S]		<0.0012	0.0020		0.040		
Shetland	Fish meal (salmon)	1[S]		0.016	0.14		0.21		
Shetland	Fish meal (herring)	1[S]		0.0036	0.0086		0.017		
Shetland	Fish oil (salmon)	1[S]		0.0061	0.016		0.045		
Shetland	Fish oil (herring)	1[S]		0.0022	0.0041		0.055		
Kinlochbervie	Crabs	1[S]		<0.012	0.030		<0.080		
Lewis	Mussels	1[S]					<0.12		
Skye	Lobsters	1[S]					<0.13		
Skye	Mussels	1[S]					<0.10		
Islay	Crabs	1[S]					<0.10		
Islay	Scallops	1[S]					<0.10		
Ardrossan South Bay	Mackerel	1[S]		0.0019	<0.0013		0.0054		
Ardrossan South Bay	Salmon	1[S]		0.0046	0.0015		0.0054		
Kirkcudbright	Plaice	2[S]		0.00045	0.015		0.0013		
Kirkcudbright	Scallops	2[S]		0.0025	0.018		0.010		
Kirkcudbright	Queens	2[S]		0.0016	0.081		0.13		

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	Crabs	2^{S}		0.089	0.27		0.28		
Kirkcudbright	Lobsters	2^{S}		0.0057	0.0042		0.0070		
Kirkcudbright	Winkles	2^{S}		0.065	0.34		0.45		
Cutters Pool	Limpets	1^{S}					10		
Cutters Pool	Winkles	1^{S}					12		
Southerness	Winkles	2^{S}		0.28	1.8		3.3		
North Solway coast	Cockles	1^{S}		0.76	4.6		12		
North Solway coast	Mussels	2^{S}		0.58	3.5		5.4		
Inner Solway	Salmon	1^{S}					<0.13		
Inner Solway	Sea trout	1^{S}					<0.12		
Inner Solway	Shrimps	2^{S}		0.0035	0.0051		0.011		
Wales									
North Anglesey	Plaice	1					<0.17		
North Anglesey	Crabs	1					<0.19		
North Anglesey	Lobsters	1		0.00030	0.0025	<0.42	0.0068	*	*
Northern Ireland									
North coast	Lesser spotted dogfish	4^{N}					<0.25		
Ballycastle	Lobsters	2^{N}					<0.19		
County Down	Scallops	2^{N}					<0.15		
Ardglass	Herring	2^{N}					<0.26		
Kilkeel	Cod	4^{N}					<0.13		
Kilkeel	Plaice	4^{N}					<0.19		
Kilkeel	Skates / rays	4^{N}					<0.29		
Kilkeel	Haddock	4^{N}					<0.14		
Kilkeel	Crabs	4^{N}					<0.17		
Kilkeel	Lobsters	4^{N}					<0.22		
Kilkeel	*Nephrops*	1^{N}		0.0014	0.0077		0.020	*	*
Minerstown	Winkles	1^{N}		0.033	0.19		0.14	*	*
Carlingford Lough	Mussels	2^{N}					<0.24		
Further afield									
Norwegian Sea	Haddock	2					<0.13		
Cromer	Crabs	2					<0.19		
Southern North Sea	Cockles	2		0.00097	0.0078		0.0064	*	*

* *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, 2018

Location	Material	No. of sampling observations	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	<0.84		<1.4	<0.68	<6.4	<3.5	<0.94	160	<4.3
Maryport Outer Harbour	Sediment	2	<0.42		<0.59	<0.34	<2.8	<1.6	<0.48	72	<2.0
Workington Harbour	Sediment	2	<0.41		<0.66	<0.44	<2.7	<1.6	<0.49	31	<2.0
Harrington Harbour	Sediment	2	<0.48		<0.71	<0.46	<3.2	<1.8	<0.50	74	<2.0
Whitehaven Outer Harbour	Sediment	4	<0.44	<1.6	<0.51	<0.31	<2.4	<1.4	<0.38	50	<1.7
St Bees beach	Sediment	4	<0.44		<0.51	<0.24	<2.4	<1.3	<0.35	45	<1.6
Ehen spit	Sediment	4	<0.51		<0.68	<0.43	<3.3	<1.8	<0.44	120	<2.0
Sellafield beach, S of former pipeline	Sediment	4	<0.41		<0.53	<0.26	<2.4	<1.4	<0.36	31	<1.5
River Calder - downstream	Sediment	4	<0.51		<0.67	<0.34	<3.0	<1.6	<0.44	63	<1.8
River Calder - upstream	Sediment	4	<0.60		<0.78	<0.49	<3.2	<1.8	<0.52	36	<2.0
Seascale beach	Sediment	4	<0.40		<0.50	<0.28	<2.2	<1.2	<0.33	25	<1.3
Ravenglass - Carleton Marsh	Sediment	4	<1.6	77	<1.5	<0.78	<9.6	<3.9	<0.98	180	<3.7
River Mite Estuary (erosional)	Sediment	3	<1.6	160	<2.5	<1.2	<14	<7.3	<1.7	960	<6.9
Ravenglass - Raven Villa	Sediment	4	1.2		<1.1	<0.43	<4.1	<2.1	<0.50	130	<2.4
Newbiggin (Eskmeals)	Sediment	4	2.5	33	<0.88	<0.53	<5.7	<2.5	<0.59	290	<2.8
Haverigg	Sediment	2	<0.43		<0.60	<0.36	<2.8	<1.5	<0.40	54	<1.8
Millom	Sediment	2	<0.52		<0.72	<0.42	<3.1	<1.8	<0.45	71	<1.8
Askam Pier	Sediment	2	<0.41		<0.56	<0.31	<2.5	<1.4	<0.36	49	<1.6
Low Shaw	Sediment	2	<0.46		<0.66	<0.32	<3.0	<1.6	<0.42	65	<1.7
Walney Channel - N of discharge point	Sediment	2	<0.41		<0.59	<0.39	<2.7	<1.5	<0.38	84	<1.9
Sand Gate Marsh	Sediment	1	<0.38		<0.57	<0.36	<2.5	<1.4	<0.34	64	<1.7
Kents Bank	Sediment	1	<0.46		<1.2	<0.49	<4.2	<2.3	<0.56	340	<2.9
Arnside	Sediment	1	<1.2		<1.8	<0.92	<9.0	<5.2	<1.2	220	<5.5

Location	Material	No. of sampling observations	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	<2.1	<1.9				250	680	1000
Maryport Outer Harbour	Sediment	2	<1.1	<0.95				210	530	810
Workington Harbour	Sediment	2	<1.2	<0.88				34	350	630
Harrington Harbour	Sediment	2	<1.4	<0.94				48	350	880
Whitehaven Outer Harbour	Sediment	4	<1.0	<0.81	12	74	280	120	270	530
St Bees beach	Sediment	4	<1.0	<0.73				140	190	400
Ehen spit	Sediment	4	<1.3	<0.97				110	340	940
Sellafield beach, S of former pipeline	Sediment	4	<1.1	<0.70				130	180	490
River Calder - downstream	Sediment	4	<1.3	<0.81				75	220	660
River Calder - upstream	Sediment	4	<1.5	<0.95					320	1400
Seascale beach	Sediment	4	<0.96	<0.63				110	200	450
Ravenglass - Carleton Marsh	Sediment	4	<2.5	<1.8	60	350	1300	1800	1300	1100
River Mite Estuary (erosional)	Sediment	3	4.7	<3.3	150	930	3100	2800	2700	2000
Ravenglass - Raven Villa	Sediment	4	<1.5	<1.0				590	990	920
Newbiggin (Eskmeals)	Sediment	4	3.0	<2.9	100	600	2600	1400	1900	1100
Haverigg	Sediment	2	<1.2	<0.82				240	520	730
Millom	Sediment	2	<1.3	<0.85				230	350	730
Askam Pier	Sediment	2	<1.0	<0.72				150	310	580
Low Shaw	Sediment	2	<1.2	<0.78				160	230	630
Walney Channel - N of discharge point	Sediment	2	<1.0	<0.87				230	510	1600
Sand Gate Marsh	Sediment	1	<0.91	<0.76				74	220	670
Kents Bank	Sediment	1	<1.2	<8.7				200	860	1100
Arnside	Sediment	1	<3.0	<2.7				170	500	920

Table 2.8 continued

Location	Material	No. of sampling observations	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	<0.30						5.6	
Half Moon Bay	Sediment	2	<0.57						54	
Red Nab Point	Sediment	1	<0.49						15	
Potts' Corner	Sediment	2	<0.38						13	
Sunderland Point	Sediment	1	<0.44	<0.63	<0.45	<2.9	<1.6	<0.45	44	<2.2
Conder Green	Sediment	1	<0.54	<0.73	<0.53	<3.4	<1.9	<0.52	68	<2.1
Hambleton	Sediment	1	<0.80	<1.1	<0.55	<5.5	<3.0	<0.75	190	<2.7
Skippool Creek	Sediment	1	<0.57	<0.79	<0.56	<4.2	<2.2	<0.63	130	<2.9
Fleetwood	Sediment	1	<0.28	<0.36	<0.25	<1.7	<0.9	<0.26	6.7	<1.1
Blackpool	Sediment	1	<0.32	<0.43	<0.22	<1.8	<0.97	<0.29	1.8	<0.98
Crossens Marsh	Sediment	1	<0.94	<1.3	<0.64	<6.3	<3.4	<0.87	180	<2.9
Ainsdale	Sediment	1	<0.38	<0.50	<0.26	<2.2	<1.3	<0.34	3.0	<1.1
Rock Ferry	Sediment	1	<0.54	<0.64	<0.35	<3.1	<1.7	<0.46	60	<1.8

Location	Material	No. of sampling observations	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					5.4		
Half Moon Bay	Sediment	2			6.5	43	88		
Red Nab Point	Sediment	1					14		
Potts' Corner	Sediment	2					15		
Sunderland Point	Sediment	1	<1.3	<1.0			65	280	640
Conder Green	Sediment	1	<1.4	<0.96			100	350	670
Hambleton	Sediment	1	<2.1	<1.3			250	780	1100
Skippool Creek	Sediment	1	<1.6	<1.3			180	610	960
Fleetwood	Sediment	1	<0.69	<0.52			15	69	360
Blackpool	Sediment	1	<0.74	<0.48			3.6	<85	250
Crossens Marsh	Sediment	1	<2.4	<1.4			190	590	910
Ainsdale	Sediment	1	<0.94	<0.53			2.7	50	270
Rock Ferry	Sediment	1	<1.4	<0.84			56	300	770

Location	Material	No. of sampling observations	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	<0.23	<0.25	<0.64	<0.20	<0.10	5.4
Garlieston	Sediment	1[S]	<0.10	<0.10	<0.11	<0.13	<0.52	<0.18	<0.10	20
Innerwell	Sediment	2[S]	<0.10	0.22	<0.12	<0.10	<0.51	0.30	<0.10	67
Carsluith	Sediment	1[S]	<0.10	0.35	<0.34	<0.62	<1.0	<0.30	<0.14	89
Skyreburn	Sediment	2[S]	<0.10	<0.10	<0.13	<0.14	<0.41	<0.14	<0.10	22
Kirkcudbright[a]	Sediment[a]	2[S]	<0.10	0.20	<0.39	<0.45	<0.94	<0.28	<0.13	59
Rascarrel Bay[d]	Sediment[a]	1[S]	<0.19	0.19	<0.44	<0.37	<1.8	<0.69	<0.24	72
Palnackie Harbour	Sediment	2[S]	<0.10	0.30	<0.24	<0.43	<0.86	<0.37	<0.10	110
Gardenburn	Sediment	2[S]	<0.10	0.56	<0.44	<0.76	2.0	<0.49	<0.15	170
Kippford Slipway	Sediment	2[S]	<0.10	0.54	<0.59	<1.9	<1.1	<0.49	<0.13	150
Kippford Merse	Sediment	1[S]	<0.10	0.74	<0.41	<0.71	<1.3	<0.56	<0.16	260
Kirkconnell Merse	Sediment	1[S]	<0.10	0.27	<0.28	<0.55	<1.4	<0.62	<0.14	330
Southerness	Sediment	1[S]	<0.10	<0.10	<0.21	<0.42	<0.58	<0.18	<0.10	7.3

Table 2.8 continued

Location	Material	No. of sampling observations	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}	<0.59	<0.15	<0.16			0.99		
Garlieston	Sediment	1^{S}	<0.40	<0.11	<0.12	3.8	20	37		
Innerwell	Sediment	2^{S}	<0.57	0.35	<1.1	13	82	170		
Carsluith	Sediment	1^{S}	<1.2	0.64	1.4	19	110	210	220	1500
Skyreburn	Sediment	2^{S}	<0.48	<0.16	<0.38	3.8	22	33		
Kirkcudbright[a]	Sediment[a]	2^{S}	<1.1	<0.28	1.5			110		
Rascarrel Bay[d]	Sediment[a]	1^{S}	<1.4	<0.37	<0.65			180		
Palnackie Harbour	Sediment	2^{S}	<0.96	0.48	<0.91	14	91	170		
Gardenburn	Sediment	2^{S}	<1.2	0.69	<0.81	22	140	270		
Kippford Slipway	Sediment	2^{S}	<1.2	0.58	1.6	24	160	290		
Kippford Merse	Sediment	1^{S}	<1.2	<0.78	1.4	40	240	500		
Kirkconnell Merse	Sediment	1^{S}	<1.5	0.50	<0.64	37	220	400	410	2300
Southerness	Sediment	1^{S}	<0.62	<0.15	<0.30	1.9	13	22		

Location	Material	No. of sampling observations	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		<0.75	<0.96	<0.51	<4.5	<2.4	<0.67	74	<2.4
Llandudno	Sediment	1		<0.27	<0.36	<0.20	<1.6	<0.93	<0.26	1.4	<1.2
Caerhun	Sediment	1		<0.50	<0.61	<0.44	<2.8	<1.6	<0.45	23	<1.7
Llanfairfechan	Sediment	1		<0.56	<0.72	<0.38	<3.3	<1.8	<0.54	20	<1.6
Northern Ireland											
Carrichue	Mud	2^{N}	<1.3	<1.3	<1.2	<4.5	<2.1	<2.8	<1.4	3.0	<2.0
Portrush	Sand	2^{N}	<0.36	<0.23	<1.4	<3.3	<2.0	<0.54	<0.26	0.50	<1.9
Oldmill Bay	Mud	2^{N}	<0.38	<0.23	<0.72	<1.1	<2.1	<0.65	<0.43	22	<1.5
Ballymacormick	Mud	2^{N}	<0.28	<0.24	<1.8	<2.4	<2.3	<0.61	<0.39	9.4	<2.0
Strangford Lough - Nicky's Point	Mud	2^{N}	<0.32	<0.20	<0.95	<0.78	<1.7	<0.55	<0.24	14	<1.7
Dundrum Bay	Mud	2^{N}	<0.53	<0.38	<6.4	<18	<3.7	<0.98	<0.60	28	<3.3
Carlingford Lough	Mud	2^{N}	<1.9	<1.3	<1.6	<12	<3.2	<3.4	<3.1	36	<2.8

Location	Material	No. of sampling observations	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	<1.2			62			440	950
Llandudno	Sediment	1	<0.74	<0.57			1.2			<110	160
Caerhun	Sediment	1	<1.3	<0.78			19			230	590
Llanfairfechan	Sediment	1	<1.4	<0.78			18			220	530
Northern Ireland											
Carrichue	Mud	2^{N}	<3.8	<3.6	0.30	2.10	3.7	*	*		
Portrush	Sand	2^{N}	<0.72	<0.59			<1.2				
Oldmill Bay	Mud	2^{N}	<0.77	<1.2			6.8				
Ballymacormick	Mud	2^{N}	<0.80	<0.72			11				
Strangford Lough - Nicky's Point	Mud	2^{N}	<0.62	<0.90			4.8				
Dundrum Bay	Mud	2^{N}	<1.1	<1.3			8.7				
Carlingford Lough	Mud	2^{N}	<4.1	<1.1	1.8	12	9.7	*	*		

* *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, 2018

Location	Ground type	No. of sampling observations	Mean gamma dose rate in air at 1m, μGy h^{-1}
Cumbria, Rockcliffe-Harrington			
Rockcliffe Marsh	Salt marsh	2	0.075
Burgh Marsh	Salt marsh	2	0.072
Port Carlisle 1	Mud	1	0.074
Port Carlisle 1	Mud and sand	1	0.074
Port Carlisle 2	Grass	1	0.074
Port Carlisle 2	Salt marsh	1	0.075
Newton Arlosh	Salt marsh	2	0.082
Silloth harbour	Sand and pebbles	2	0.088
Allonby	Sand	2	0.075
Maryport harbour	Sand	2	0.078
Workington harbour	Sand and pebbles	1	0.10
Workington harbour	Shingle	1	0.10
Harrington harbour	Sand	1	0.10
Harrington harbour	Sand and pebbles	1	0.092
Cumbria, Whitehaven-Drigg			
Whitehaven - outer harbour	Sand	4	0.083
St Bees	Sand	4	0.062
Nethertown beach	Pebbles	2	0.11
Nethertown beach	Shingle	2	0.11
Ehen spit	Sand and pebbles	2	0.10
Ehen spit	Shingle	2	0.11
Braystones	Grass	1	0.078
Braystones beach	Pebbles	2	0.10
Braystones beach	Shingle	2	0.10
Sellafield dunes	Grass	4	0.090
North of former pipeline on foreshore	Sand	4	0.069
South of former pipeline on foreshore	Sand	4	0.068
River Calder downstream of site	Grass	4	0.081
River Calder upstream of site	Grass	1	0.088
Seascale beach	Sand	4	0.074
Cumbria, Ravenglass-Askam			
Ravenglass - Carleton Marsh	Grass	2	0.12
Ravenglass - Carleton Marsh	Salt marsh	2	0.12
Ravenglass - River Mite estuary (erosional)	Salt marsh	3	0.12
Ravenglass - Raven Villa	Salt marsh	4	0.11
Ravenglass - boat area	Sand and pebbles	2	0.096
Ravenglass - boat area	Sand and shingle	1	0.10
Ravenglass - boat area	Sand and stones	1	0.097
Ravenglass - ford	Mud and sand	1	0.085
Ravenglass - ford	Sand	3	0.088
Muncaster Bridge	Grass	4	0.10
Ravenglass - salmon garth	Mud and sand	1	0.098
Ravenglass - salmon garth	Sand	3	0.095
Ravenglass - Eskmeals Nature Reserve	Salt marsh	3	0.098
Newbiggin/Eskmeals Bridge	Salt marsh	4	0.10
Newbiggin/Eskmeals viaduct	Salt marsh	4	0.10
Tarn Bay	Sand	4	0.075
Silecroft	Pebbles	1	0.10
Silecroft	Shingle	1	0.11
Haverigg	Mud and sand	1	0.078
Haverigg	Sand	1	0.090
Millom	Mud and sand	1	0.081

Table 2.9 continued

Location	Ground type	No. of sampling observations	Mean gamma dose rate in air at 1m, μGy h^{-1}
Millom	Sand	1	0.097
Low Shaw	Salt marsh	2	0.074
Askam	Sand	4	0.058
Askam Pier	Mud and sand	1	0.065
Askam Pier	Sand	3	0.070
Cumbria, Walney-Arnside			
Walney Channel, N of discharge point	Mud and sand	3	0.077
Walney Channel, N of discharge point	Sand and silt	1	0.072
Tummer Hill Marsh	Salt marsh	2	0.095
Roa Island	Mud and sand	1	0.085
Roa Island	Sand	1	0.076
Sand Gate Marsh	Salt marsh	2	0.071
Kents Bank 2	Salt marsh	2	0.074
Arnside 2	Salt marsh	2	0.076
Lancashire and Merseyside			
Morecambe Central beach	Sand	2	0.060
Half Moon Bay	Sand	2	0.070
Pipeline (Heysham)	Sand	1	0.072
Red Nab Point	Sand and pebbles	1	0.060
Middleton Sands	Sand	2	0.069
Sunderland Point	Mud and sand	1	0.078
Sunderland Point	Sand	1	0.082
Colloway Marsh	Salt marsh	2	0.10
Lancaster	Grass	1	0.072
Aldcliffe Marsh	Salt marsh	2	0.079
Conder Green	Salt marsh	2	0.078
Pilling Marsh	Salt marsh	2	0.084
Knott End	Sand	2	0.066
Height o' th' hill - River Wyre	Salt marsh	2	0.086
Hambleton	Salt marsh	2	0.086
Skippool Creek 1	Salt marsh	2	0.093
Skippool Creek 2	Salt marsh	2	0.092
Fleetwood shore 1	Sand	2	0.073
Fleetwood shore 2	Salt marsh	2	0.10
Blackpool	Sand	2	0.055
Crossens Marsh	Salt marsh	2	0.080
Ainsdale	Sand	2	0.056
Rock Ferry	Mud and sand	1	0.080
Rock Ferry	Sand	1	0.076
West Kirby	Mud and sand	1	0.065
West Kirby	Sand	1	0.062
Scotland			
Piltanton Burn	Sediment	2^S	0.062
Garlieston	Sand and sediment	2^S	0.059
Innerwell	Mud	1^S	0.067
Bladnoch	Salt marsh	2^S	0.066
Carsluith	Sand	2^S	0.082
Skyreburn Bay (Water of Fleet)	Sediment	2^S	0.069
Kirkcudbright	Salt marsh	2^S	0.066
Cutters Pool	Sediment	4^S	0.086
Rascarrel Bay	Sand	2^S	0.072
Gardenburn	Grass	2^S	0.078
Palnackie Harbour	Grass	2^S	0.074

Table 2.9 continued

Location	Ground type	No. of sampling observations	Mean gamma dose rate in air at 1m, μGy h^{-1}
Kippford - Merse	Salt marsh	1[S]	0.084
Kirkconnell Marsh	Salt Marsh	2[S]	0.088
Southerness	Sediment	2[S]	0.050
Wales			
Flint 1	Mud	2	0.082
Flint 2	Salt marsh	2	0.086
Rhyl	Salt marsh	2	0.080
Llandudno	Shingle	2	0.095
Caerhun	Grass	1	0.081
Caerhun	Salt marsh	1	0.077
Llanfairfechan	Sand and shale	1	0.075
Llanfairfechan	Sand and shells	1	0.069
Northern Ireland			
Lisahally	Mud	1[N]	0.057
Donnybrewer	Shingle	1[N]	0.055
Carrichue	Mud	1[N]	0.070
Bellerena	Mud	1[N]	0.063
Benone	Sand	1[N]	0.059
Castlerock	Sand	1[N]	0.062
Portstewart	Sand	1[N]	0.056
Portrush, Blue Pool	Sand	1[N]	0.054
Portrush, White Rocks	Sand	1[N]	0.055
Portballintrae	Sand	1[N]	0.055
Giant's Causeway	Sand	1[N]	0.056
Ballycastle	Sand	1[N]	0.054
Cushendun	Sand	1[N]	0.057
Cushendall	Sand and stones	1[N]	0.063
Red Bay	Sand	1[N]	0.069
Carnlough	Sand	1[N]	0.059
Glenarm	Sand	1[N]	0.057
Half Way House	Sand	1[N]	0.058
Ballygally	Sand	1[N]	0.052
Drains Bay	Sand	1[N]	0.053
Larne	Sand	1[N]	0.062
Whitehead	Sand	1[N]	0.062
Carrickfergus	Sand	1[N]	0.057
Jordanstown	Sand	1[N]	0.056
Strangford	Shingle and stones	1[N]	0.094
Kilclief	Sand	1[N]	0.069
Ardglass	Mud	1[N]	0.084
Killough	Mud	1[N]	0.086
Ringmore Point	Sand	1[N]	0.073
Tyrella	Sand	1[N]	0.078
Dundrum	Sand	1[N]	0.084
Newcastle	Sand	1[N]	0.11
Annalong	Sand	1[N]	0.11
Cranfield Bay	Sand	1[N]	0.082
Mill Bay	Sand	1[N]	0.11
Greencastle	Sand	1[N]	0.091
Rostrevor	Sand	1[N]	0.11
Narrow Water	Mud	1[N]	0.096

[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, 2018

Vessel or location	Type of gear	No. of sampling observations	Mean beta dose rate in tissue, μSv h^{-1}
101	Nets	1	0.036
111	Nets	1	0.045
South 1	Lobster pots	1	0.12
South 2	Lobster pots	1	0.049
South 3	Lobster pots	1	0.073
South 4	Lobster pots	1	0.070

Table 2.11 Beta radiation dose rates over intertidal areas of the Cumbrian coast, 2018

Location	Ground type	No. of sampling observations	Mean beta dose rate in tissue, μSv h^{-1}
Whitehaven – outer harbour	Sand	3	0.13
St Bees	Sand	4	0.10
Sellafield beach, N of discharge point	Sand	4	0.14
Ravenglass – Raven Villa	Salt marsh	4	0.16
Tarn Bay	Sand	3	0.13

Table 2.12 Concentrations of radionuclides in aquatic plants from the Cumbrian coast and further afield, 2018

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	<0.62			<0.79	<0.41	81	<3.8	<0.60	<2.0
Harrington Harbour	Seaweed	2	<0.71			<0.95	<0.49	120	<4.4	<0.72	<2.5
St Bees[b]	Seaweed	2	<0.84		<0.79	<1.0	<0.53	480	<4.7	<0.78	<2.7
Sellafield[c]	Seaweed	2	<0.72		<0.88	<0.91	<0.47	1100	<4.5	<0.69	<2.5
Ravenglass	Samphire	1[F]	<0.06	<0.12		<0.13	<0.13	0.22	<0.44	<0.07	<0.12
Ravenglass[d]	Seaweed	2	<0.68		<2.3	<0.84	<0.47	180	<4.3	<0.66	<2.5
Lancashire											
Half Moon Bay[e]	Seaweed	2	<0.72			<0.89	<0.47	250	<4.1	<0.69	<2.5
Marshside Sands	Samphire	1[F]	<0.03	<0.07		<0.08	<0.10	0.21	<0.24	<0.04	<0.07
Scotland											
Lerwick	*Fucus vesiculosus*	1[S]	<0.10	<0.21		<0.37	<0.80	3.8	<0.47	<0.10	<0.11
Kinlochbervie	*Fucus vesiculosus*	2[S]	<0.10	<0.17		<0.19	<0.23	25	<0.38	<0.10	<0.13
Lewis	*Fucus vesiculosus*	1[S]	<0.10	<0.19		<0.25	<0.35	18	<0.51	<0.10	<0.14
Islay	*Fucus vesiculosus*	1[S]	<0.10	<0.15		<0.18	<0.25	26	<0.36	<0.10	<0.10
Campbeltown	*Fucus vesiculosus*	1[S]	<0.10	<0.20		<0.23	<0.24	74	<0.54	<0.10	<0.15
Port William	*Fucus vesiculosus*	4[S]	<0.10	<0.17		<0.22	<0.27	84	<0.49	<0.11	<0.16
Garlieston	*Fucus vesiculosus*	4[S]	<0.10	<0.14		<0.15	0.18	130	<0.34	<0.10	<0.12
Auchencairn	*Fucus vesiculosus*	4[S]	<0.10	<0.14		<0.17	<0.21	170	<0.37	<0.11	<0.14
Wales											
Cemaes Bay	Seaweed	2	<0.64			<0.82	<0.44	22	<4.0	<0.63	<2.3
Porthmadog	Seaweed	2	<0.50			<0.71	<0.37	4.0	<3.4	<0.53	<2.0
Lavernock Point	Seaweed	2	<0.62			<0.76	<0.42	<0.76	<3.8	<0.59	<2.1
Fishguard	Seaweed	2	<0.39			<0.58	<0.29	6.6	<2.7	<0.42	<1.6
Northern Ireland											
Portrush	*Fucus* spp.	4[N]	<0.07	<0.22		<0.22	<0.28		<0.58	<0.11	<0.15
Portaferry[a]	*Rhodymenia* spp.	4[N]	<0.07	<0.19		<0.28	<0.26	0.35	<0.53	<0.09	<0.16
Ardglass	*Fucus vesiculosus*	3[N]	<0.04	<0.14		<0.17	<0.13	22	<0.36	<0.07	<0.12
Carlingford Lough	*Ascophyllum nodosum*	1[N]	<0.12	<0.30		<0.20	<0.21		<0.65	<0.15	<0.23
Carlingford Lough	*Fucus* spp.	3[N]	<0.04	<0.16		<0.26	<0.32	13	<0.37	<0.07	<0.10

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		<0.56	4.6	<1.9				4.8
Harrington Harbour	Seaweed	2	1.4	<0.66	1.9	<1.9				2.1
St Bees[b]	Seaweed	2	6.8	<0.69	2.8	<2.1		0.78	3.9	2.6
Sellafield[c]	Seaweed	2	6.8	<0.64	5.6	<2.1		0.93	4.9	2.3
Ravenglass	Samphire	1[F]		<0.05	0.37	<0.20	<0.10			1.2
Ravenglass[d]	Seaweed	2	4.7	<0.63	18	<2.3		4.4	24	55
Lancashire										
Half Moon Bay[e]	Seaweed	2	2.1	<0.64	3.5	<1.8				<2.1
Marshside Sands	Samphire	1[F]		<0.03	0.13	<0.17	<0.07			<0.08
Scotland										
Lerwick	*Fucus vesiculosus*	1[S]		<0.10	<0.10	<0.33	<0.13			<0.12
Kinlochbervie	*Fucus vesiculosus*	2[S]		<0.10	<0.10	<0.30	<0.16			<0.17
Lewis	*Fucus vesiculosus*	1[S]		<0.10	0.10	<0.38	<0.18			<0.19
Islay	*Fucus vesiculosus*	1[S]		<0.10	0.19	<0.27	<0.12			<0.12
Campbeltown	*Fucus vesiculosus*	1[S]		<0.10	0.17	<0.39	<0.20			<0.22
Port William	*Fucus vesiculosus*	4[S]		<0.10	0.56	<0.32	<0.14			0.53
Garlieston	*Fucus vesiculosus*	4[S]		<0.10	2.2	<0.23	<0.12			4.4
Auchencairn	*Fucus vesiculosus*	4[S]		<0.10	1.6	<0.23	<0.14			1.9
Wales										
Cemaes Bay	Seaweed	2		<0.61	<0.51	<1.9				<0.65
Porthmadog	Seaweed	2		<0.52	<0.45	<1.9				<0.62
Lavernock Point	Seaweed	2		<0.56	<0.46	<1.8	<0.81			<0.55
Fishguard	Seaweed	2		<0.39	<0.31	<1.4				<0.50
Northern Ireland										
Portrush	*Fucus* spp.	4[N]		<0.08	<0.08	<0.37	<0.15			<0.21
Portaferry[a]	*Rhodymenia* spp.	4[N]		<0.06	0.96	<0.27	<0.12	0.12	0.72	1.3
Ardglass	*Fucus vesiculosus*	3[N]		<0.04	0.38	<0.31	<0.13			<0.20
Carlingford Lough	*Ascophyllum nodosum*	1[N]		<0.09	0.36	<0.26	<0.23			<0.12
Carlingford Lough	*Fucus* spp.	3[N]		<0.06	0.25	<0.32	<0.17			<0.15

[a] *The concentrations of ^{242}Cm and $^{243+244}$Cm were not detected by the method used and 0.0020 Bq kg^{-1}, respectively*
[b] *The concentrations of ^{14}C was 21 Bq kg^{-1}*
[c] *The concentrations of ^{14}C was 83 Bq kg^{-1}*
[d] *The concentrations of ^{14}C was 17 Bq kg^{-1}*
[e] *The concentrations of ^{35}S was <6.9 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, 2018

Material and selection[a]		No. of sampling observations[c]	Mean radioactivity concentration (fresh)[b], Bq kg^{-1}											
			Organic ^{3}H	^{3}H	^{14}C	^{60}Co	^{90}Sr	^{95}Nb	^{95}Zr	^{99}Tc	^{106}Ru	^{125}Sb	^{129}I	^{134}Cs
Milk		3		<5.4	18	<0.05	0.036	<0.41	<0.22	<0.0076	<0.42	<0.11	<0.0037	<0.05
Milk	max						0.042	<0.54	<0.25		<0.48	<0.12	<0.0040	<0.06
Beef kidney		1		<5.5	27	<0.03	0.028	<0.30	<0.30	<0.056	<0.28	<0.14	<0.027	<0.03
Beef liver		1		<3.7	30	<0.04	<0.044	<0.58	<0.23	<0.035	<0.33	<0.09	<0.0080	<0.03
Beef muscle		1		<3.5	30	<0.05	<0.043	<0.27	<0.18	<0.035	<0.35	<0.14	<0.019	<0.04
Blackberries		1	<2.2	<2.2	13	<0.03	0.088	<0.03	<0.05		<0.25	<0.08	<0.063	<0.03
Sheep muscle		2		<10	28	<0.06	<0.045	<0.67	<0.36	<0.033	<0.52	<0.12	<0.019	<0.06
Sheep muscle	max			12	32		<0.046	<0.91	<0.42	<0.034	<0.53		<0.021	
Sheep offal		2		<5.3	33	<0.03	<0.044	<0.69	<0.21	<0.033	<0.28	<0.07	<0.017	<0.03
Sheep offal	max			<5.5	36		<0.045	<0.86	<0.23		<0.29			

Material and selection[a]		No. of sampling observations[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		<0.33				<0.000038	<0.000035	<0.18	<0.000026
Milk	max		<0.12		<0.34							
Beef kidney		1	0.94	0.94	<0.26	0.0034	0.00058	0.0022	<0.000020	0.00011	<0.25	0.00025
Beef liver		1	0.39	0.39	<0.24				0.000036	0.00055	<0.26	0.00041
Beef muscle		1	2.2	2.2	<0.24				<0.000029	0.000072	<0.21	0.000090
Blackberries		1	<0.05	0.054	<0.17				0.000023	0.00034	<0.22	0.00049
Sheep muscle		2	0.52	0.52	<0.38				0.000032	0.000067	<0.23	0.00010
Sheep muscle	max		0.56	0.56	<0.39				0.000033	0.000077	<0.24	0.00014
Sheep offal		2	0.53	0.53	<0.25				0.000071	0.00011	<0.24	0.00081
Sheep offal	max		0.60	0.60	<0.26				0.000079	0.00015	<0.27	0.0012

[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, 2018

Location	No. of sampling observations	Mean radioactivity concentration, Bq l^{-1}								
		^{3}H	^{60}Co	^{90}Sr	^{134}Cs	^{137}Cs	^{238}Pu	^{239}Pu + ^{240}Pu	Gross alpha	Gross beta
Ehen Spit beach[a]	4	120	<0.25	<0.028	<0.25	<0.30	<0.0026	<0.0023	<4.2	11
River Ehen (100m downstream of sewer outfall)	4	<5.1	<0.26	<0.037	<0.27	<0.22	<0.00079	<0.0013	<0.044	0.32
River Calder (downstream)	4	<2.8	<0.28	<0.086	<0.30	<0.24	<0.00058	<0.0013	<0.043	0.25
River Calder (upstream)	4	<2.9	<0.25	<0.014	<0.26	<0.22	<0.0036	<0.0021	<0.030	<0.044
River Ehen (upstream of site and tidal confluence)	4	<2.8	<0.25	<0.015	<0.28	<0.22	<0.0031	<0.0014	<0.026	<0.070
Wast Water	1	<2.9	<0.32			<0.26			<0.014	<0.022
Ennerdale Water	1	<3.0	<0.19		<0.20	<0.17			<0.018	<0.023
Sellafield Tarn[b]	1	4.1		0.070		<0.22	<0.0028	<0.0020		
Devoke Water	1	<3.0	<0.12		<0.12	<0.10			<0.018	<0.029
Thirlmere	1	<2.9	<0.24			<0.22			<0.019	<0.033

[a] *The concentration of ^{99}Tc was <0.28 Bq l^{-1}*

[b] *The concentration of ^{99}Tc was <0.21 Bq l^{-1}*

Table 2.15 Concentrations of radionuclides in road drain sediments from Whitehaven and Seascale, 2018

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	<0.99	<1.0	<1.0	130	1.1	12	18
Seascale SS 233	1	<1.2	<0.67	<1.3	68	1.9	12	16
Seascale SS 209	1	<1.1	<0.72	<1.1	12	1.5	9.5	12
Seascale SS 232	1	<1.1	<0.66	<1.2	26	1.8	11	15
Seascale SS 231	1	<0.97	<1.3	<1.2	13	2.9	17	16
Whitehaven SS 201	1	<1.5	<0.86	<1.7	18	<0.64	1.2	<2.3

Table 2.16 Doses from artificial radionuclides in the Irish Sea, 2007-2018

Group	Exposure, mSv per year											
	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Northern Ireland	0.015	0.017	0.012	0.010	0.010	0.011	0.010	0.009	0.009	0.011	0.010	0.011
Dumfries and Galloway	0.060	0.047	0.047	0.040	0.040	0.046	0.044	0.045	0.038	0.044	0.035	0.029
Whitehaven	0.009	0.009	0.011	0.010	0.010	0.013	0.010	0.012	0.017	0.016	0.017	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	0.070
Morecambe Bay	0.037	0.042	0.041	0.046	0.034	0.034	0.036	0.032	0.031	0.024	0.026	0.015
North Wales	0.014	0.018	0.015	0.013	0.014	0.014	0.013	0.018	0.014	0.015	0.014	0.011

Table 2.17 Individual radiation exposures, Sellafield, 2018

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 crustacean consumers	**0.37**[e]	**0.030**	**0.33**	**-**	**<0.005**	**-**	**-**	**-**
***Total dose* – maximum effect of gaseous release and direct radiation sources**								
Infant local inhabitants (0.5–1km)	**0.006**[b]	**-**	**-**	**0.006**	**<0.005**	**-**	**<0.005**	**0.005**
***Total dose* – maximum effect of liquid release source**								
Adult crustacean consumers	**0.37**[e]	**0.030**	**0.33**	**-**	**<0.005**	**-**	**-**	**-**
Source specfic doses								
Seafood consumers								
Local seafood consumers (habits averaged 2014-18)	0.40[f]	0.042	0.33	-	0.028	-	-	-
Local seafood consumers (habits for 2018)	0.44[g]	0.043	0.38	-	0.023	-	-	-
Whitehaven seafood consumers	0.017	0.017	-	-	-	-	-	-
Dumfries and Galloway seafood and wildfowl consumers	0.029	0.023	-	-	0.007	-	-	-
Morecambe Bay seafood consumers	0.015	0.006	-	-	0.008	-	-	-
Northern Ireland seafood consumers	0.011	0.008	-	-	<0.005	-	-	-
North Wales seafood consumers	0.011	0.007	-	-	<0.005	-	-	-
Other groups								
Ravenglass Estuary, marsh users	0.008	-	-	-	0.005	<0.005	-	-
Fishermen handling nets or pots[c]	0.092	-	-	-	0.092	-	-	-
Bait diggers and shellfish collectors[c]	0.064	-	-	-	0.064	-	-	-
Ribble Estuary houseboats	0.034	-	-	-	0.034	-	-	-
Barrow Houseboats	0.045	-	-	-	0.045	-	-	-
Local infant consumers of locally grown food at Ravenglass	0.018[b]	-	-	0.018	-	-	-	-
Local infant consumers of locally grown food at LLWR near Drigg	0.006[b]	-	-	0.006	-	-	-	-
Infant inhabitants and consumers of locally grown food	0.011[b]	-	-	0.011	-	-	<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	0.005	-	-	-	0.005	-	-	-
North Cumbria	0.010	-	-	-	0.010	-	-	-
Sellafield	0.010	-	-	-	0.010	-	-	-
Lancashire	0.005	-	-	-	0.005	-	-	-
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	0.010	-	-	-	0.010	-	-	-
Lancashire	<0.005	-	-	-	<0.005	-	-	-
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 0.034 mSv*

[f] *The dose due to nuclear industry discharges was 0.070 mSv*

[g] *The dose due to nuclear industry discharges was 0.066 mSv*

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

[i] *Enhanced naturally occurring radionuclides from Whitehaven*

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

3. Research establishments

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

The NDA has ownership of 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) became the site licensed companies for Harwell and Winfrith, and Dounreay, respectively. DSRL is the site licensed company responsible for the decommissioning and clean-up of the Dounreay site and is a wholly-owned subsidiary of the Cavendish Dounreay Partnership. In 2015, Harwell and Winfrith sites, previously operated by RSRL, were re-licensed into a single site licensed company and 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 2018, 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 2018 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 annual dose limit, for sites that were assessed

Dounreay, Highland

- *Total dose* for the representative person was 0.035 mSv and increased in 2018
- Gaseous discharges of alpha and non-alpha, and liquid discharges of alpha, decreased in 2018

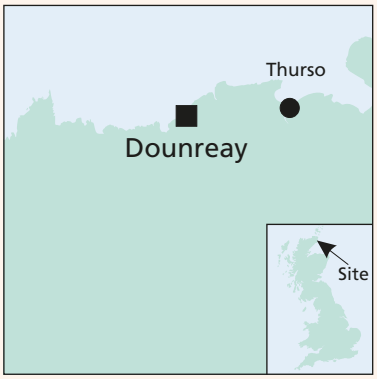
Harwell, Oxfordshire

- *Total dose* for the representative person was 0.028 mSv and decreased in 2018
- Liquid discharges increased (by small amounts) in 2018

Winfrith, Dorset

- *Total dose* for the representative person was 0.027 mSv and decreased in 2018

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 between 2030 and 2033 (NDA, 2019).

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 licensed 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. Throughout 2018, the facility has been closed to acceptance of new waste (whilst DSRL went through a process of revalidating all LLW waste previously disposed) and held in storage on the Dounreay site against the Waste Acceptance Criteria for the facility.

In May 2018, it was identified that High Efficiency Particulate Air filters present within a ventilation system, on the Dounreay site, had exceeded the maximum age specified within the relevant DSRL standard. SEPA investigated DSRL's filter age management arrangements. As a result, SEPA sent a Final Warning Letter to DSRL.

In October 2018, following an application from DSRL, SEPA issued a Notice of Variation to the site authorisation under RSA 93. The variation covered an increase in the gaseous discharge subsidiary limits associated with the stack height group 10 – 30 metres above ground level (to accommodate discharges from a new stack associated with the decommissioning of the Dounreay Materials Test Reactor facility), a reduction in a gaseous discharge subsidiary limit associated with stack height group of 30 metres and above, and the addition of the new stack to the list of authorised gaseous discharge outlets.

In 2018, 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). No solid waste transfers occurred from Dounreay in 2018 (Appendix 2, Table A2.4).

In 2018, a habits survey was conducted to determine the consumption and occupancy rates by members of the public (SEPA, *in press*/c). A large increase in fish and mollusc consumption rates has been observed, together with smaller increases in crustacean consumption rates and occupancy rates over local beaches, in comparison with those of the previous survey in 2013. In addition, the most recent habits survey did not identify Geo occupants, who visit Oigin's Geo, as an external exposure pathway. Revised figures for consumption rates, together with occupancy rates, are provided in Appendix 1 (Table X2.2).

Doses to the public

The *total dose* from all pathways and sources of radiation was 0.035 mSv in 2018 (Table 3.1), or approximately 3 per cent of the dose limit, and up from 0.010 mSv in 2017. In 2018, the representative person was adults consuming game meat at high-rates, and a change from that in 2017 (adults consuming wild fruit and nuts). The increase in *total dose* was mostly due to the inclusion of the caesium-137 concentration in game (venison) in 2018 (not collected in 2017). This activity in 2018 was most likely from historical releases.

The trend in the annual *total dose* over the period 2007 – 2018 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 annual *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 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 collected in 2017).

Source specific assessments for consumers of terrestrial foodstuffs and external pathways for fishermen give exposures that were less than the *total dose* in 2018 (Table 3.1). The dose to a consumer of terrestrial foodstuffs was 0.019 mSv in 2018 or less than 2 per cent of the dose limit for members of the public of 1 mSv. As in previous years, adults were identified as the most exposed age group. The reason for the increase in dose (from 0.011 mSv in 2017) is the same as that contributing to the maximum *total dose*. The annual dose to a consumer of fish and shellfish, including external exposure from occupancy over local beaches, was 0.006 mSv. The small decrease in dose from 0.008 mSv (in 2017) was mostly due to lower gamma dose rates over sand (Dunnet Bay) in 2018. The dose (external pathways only) to members of the public visiting Oigin's Geo, based on previously collected habits data (Papworth *et al.*, 2014), was less than 0.005 mSv.

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 Submarine Delivery Agency. In 2018, discharges of alpha and non-alpha decreased (reported as less than 1 per cent of the annual limit), in comparison to releases in 2017. Monitoring conducted in 2018 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 2018.

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

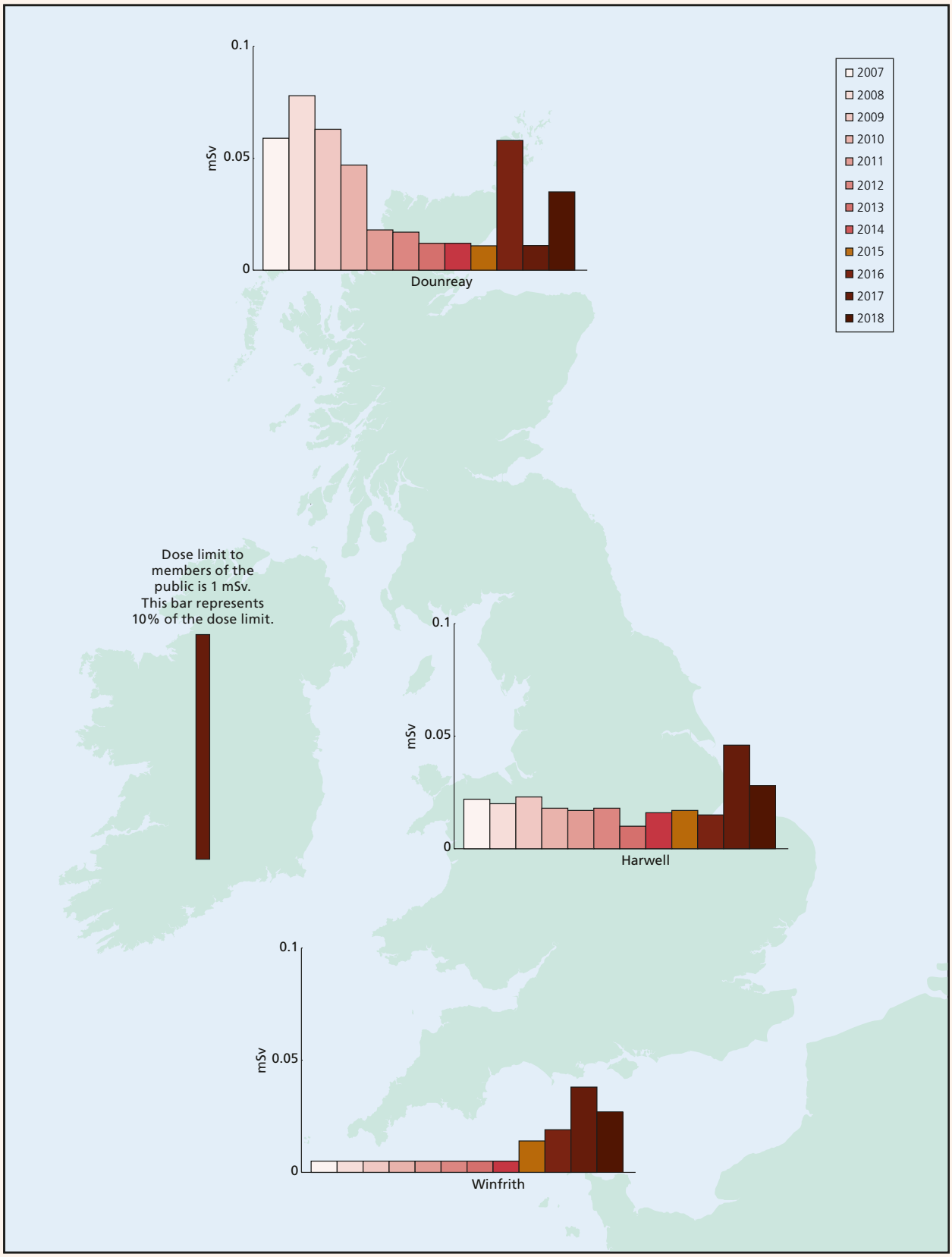


Figure 3.1. *Total dose* at research establishments, 2007–2018
(Small doses less than or equal to 0.005 mSv are recorded as being 0.005 mSv)

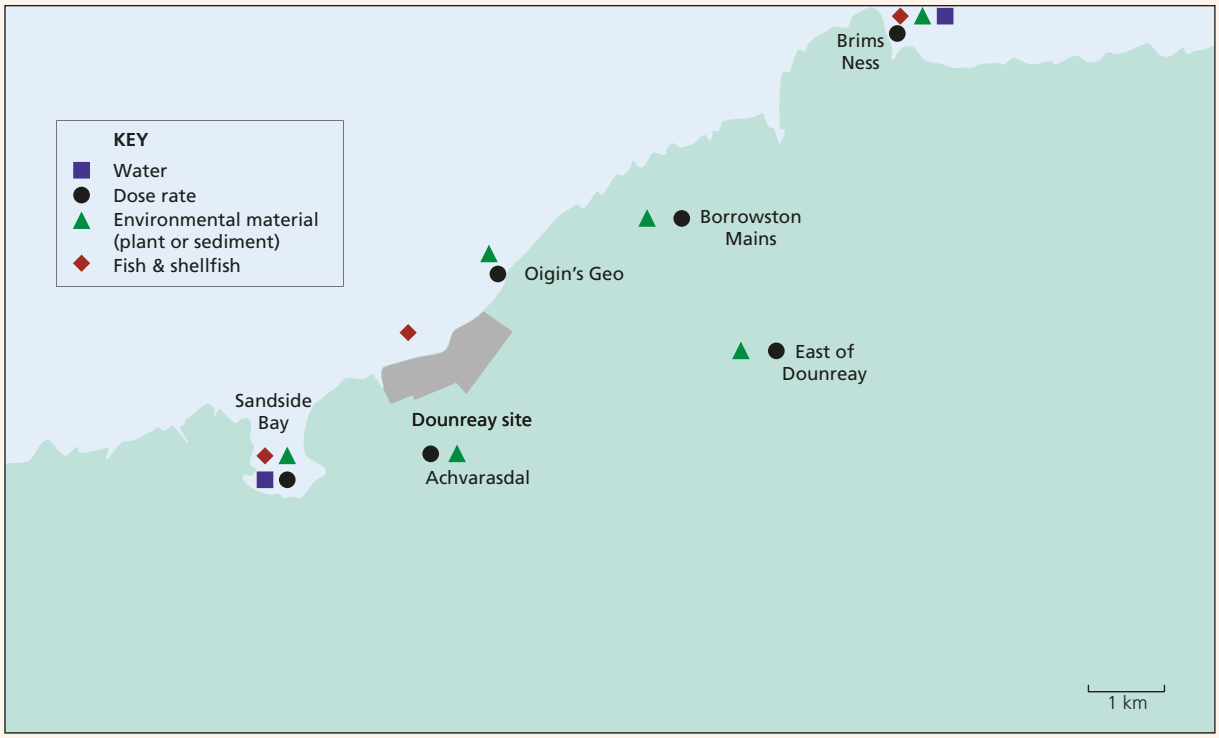


Figure 3.2. Monitoring locations at Dounreay, 2018 (not including farms or air sampling locations)

(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 2018, low concentrations of tritium, strontium-90, caesium-137, antimony-125, iodine-129, plutonium-239+240 and americium-241 are reported in a few food samples (close to the less than values).

Additional monitoring for caesium-137 in a venison sample was carried out in 2018 to re-assess the typical background concentration in the vicinity of the site (sample not collected in 2017). The caesium-137 concentration in venison was 42 Bq kg^{-1} and less elevated than those enhanced concentrations measured in other game in previous years (venison: 160 Bq kg^{-1} and 69 Bq kg^{-1} in 2016 and 2009, respectively; rabbit: 110 Bq kg^{-1} in 2008). The variation of caesium-137 concentrations in the terrestrial environment in the Dounreay area will have been affected by fallout from weapons testing in the 1960s and from the Chernobyl reactor accident in 1986. A honey sample was not collected in 2018. Earlier RIFE reports have provided results and interpretation of honey monitoring (e.g. Environment Agency, FSA, FSS, NIEA, NRW and SEPA, 2018). 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 on-site low level solid waste disposal facility (no longer authorised to receive waste), and a minor contribution from the adjoining reactor site (Vulcan NRTE). Discharges have remained low in 2018, although alpha decreased, and strontium-90 and non-alpha increased (all by small amounts), in comparison to releases 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 FSS (then FSA in Scotland).

Crabs were collected (including samples from the outfall area), together with mussels and winkles from areas along the coastline. Additionally, seawater, sediment and seaweed were sampled as indicator materials. The results for marine samples, and gamma and beta dose rates, are given in Tables 3.2(a) and (b). Activity concentrations were generally low in 2018 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

* *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.*

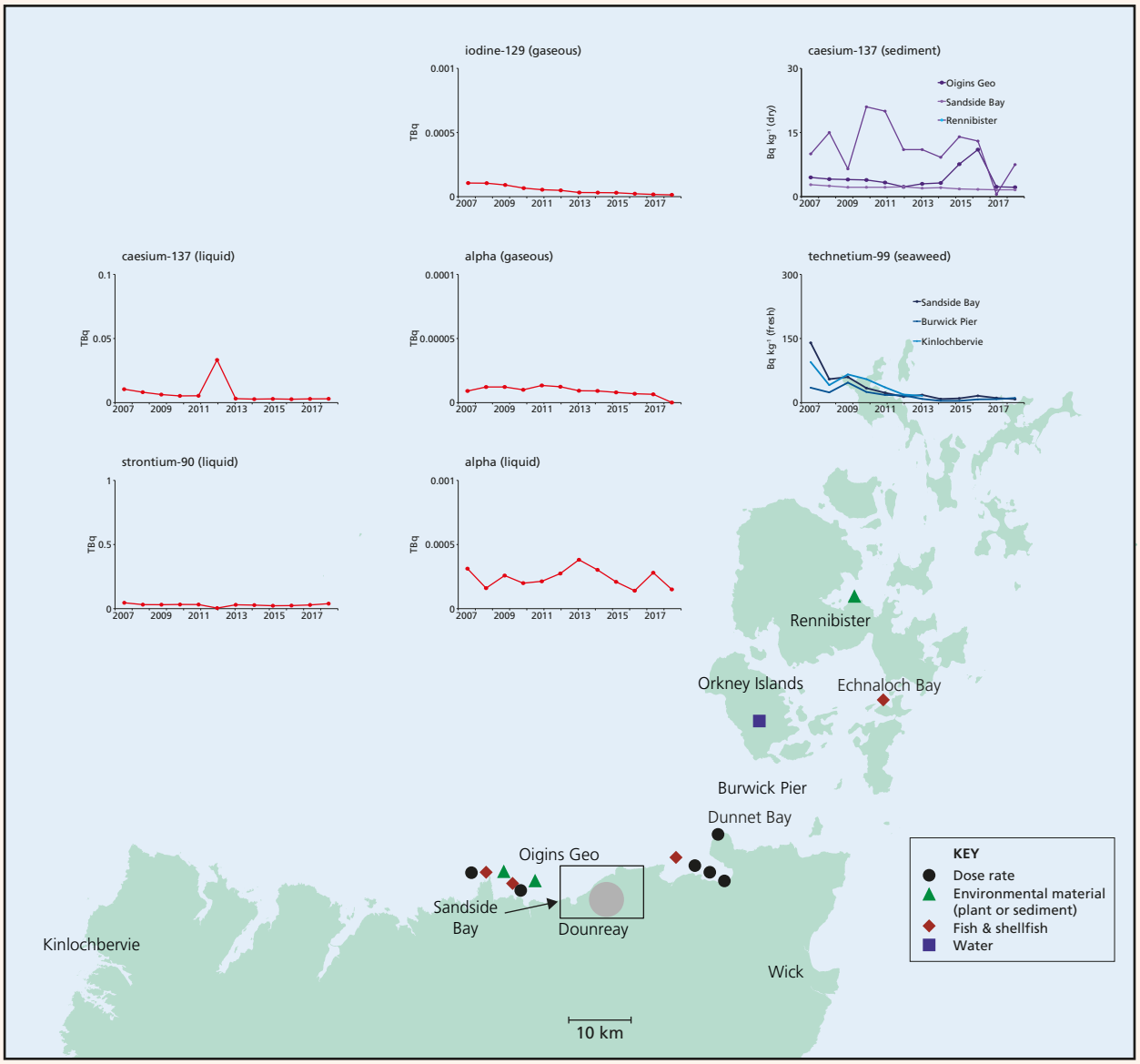


Figure 3.3. Monitoring locations, discharges of gaseous and liquid radioactive wastes and monitoring of the environment in the north of Scotland, 2018 (not including farms or air sampling locations). The rectangle around the Dounreay site is the area presented in Figure 3.2.

Sellafield) in seaweed at Sandside Bay (location shown in Figure 3.2), Kinlochbervie and Burwick. Data indicate a general decline in concentrations over the period at all three locations. Overall, gamma dose rates were similar in 2018 (in comparison to 2017), although lower dose rates were measured over some sands (most noticeably Dunnet Bay). Beta dose rate measurements are reported as less than values (Table 3.2(b)).

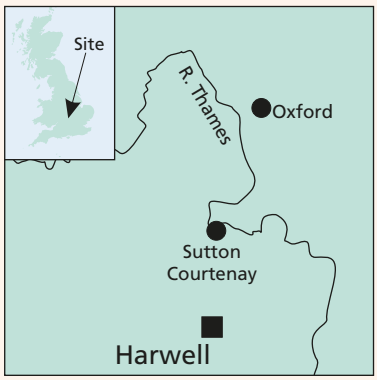
During 2018, DSRL continued vehicle-based monitoring of local public beaches for radioactive fragments in compliance with the requirements of the authorisation granted by SEPA. In 2018, 3 fragments were recovered from Sandside Bay and 12 from the Dounreay foreshore. The caesium-137 activity measured in the fragments recovered from Sandside Bay ranged between 6.3 kBq and 110 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 seepage of radioactively contaminated water offsite at Castle Gate seep.

In December 2016, one fragment was detected and recovered from the Dounreay foreshore due to the measurement of americium-241. Unlike fragments normally detected and removed, the presence of caesium-137 contamination was not detected in this fragment by gamma-ray spectrometry. Simulated digestion analysis was undertaken on the fragment. The results indicated that low quantities of americium-241 were released and as a result the fragment would not represent a risk to public health. 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. Following a recommendation in the 2016 PRAG(D) report FSS agreed that the FEPA Order would remain in place and be reviewed following re-evaluation of particle arrival rates.

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 2015, the Harwell site has been operated by Magnox Limited on behalf of the NDA. The Harwell nuclear licensed site forms part of Harwell Campus, a science, innovation and business campus. The nuclear licensed site originally accommodated five research reactors of various types. Two of the reactors have been completely removed, and the fuel has been removed from the remaining three reactors. Decommissioning at the Harwell site is well underway. It is expected that all primary facilities and reactor decommissioning on the site will be completed by 2027. Final site clearance is expected to be achieved by 2064 (NDA, 2019). The most recent habits survey was conducted in 2015 (Clyne *et al*., 2016b).

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

Doses to the public

The *total dose* from all pathways and sources of radiation was 0.028 mSv in 2018 (Table 3.1), which was less than 3 per cent of the dose limit, and down from 0.046 mSv 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 decrease in *total dose* was mostly attributed to a lower estimate of direct radiation from the site in 2018 (in comparison to that in 2017). The trend in annual *total dose* over the period 2007 – 2018 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* in 2018 (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 (some reported as nil) in 2018. The monitoring programme sampled milk, fruit and wheat. 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 2018 are shown in Table 3.3. As in 2017, the results for tritium and caesium-137 analyses in terrestrial samples are reported as less than values (or close to the less than value).

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 by RSRL. Magnox Limited is now removing the pipeline (as it is no longer required) at Sutton Courtenay. This will allow the permitted authorisation and access rights over the land to be extinguished. Further information is available via: **https://www.gov.uk/government/publications/decommissioning-of-the-harwell-site-discharge-pipeline**.

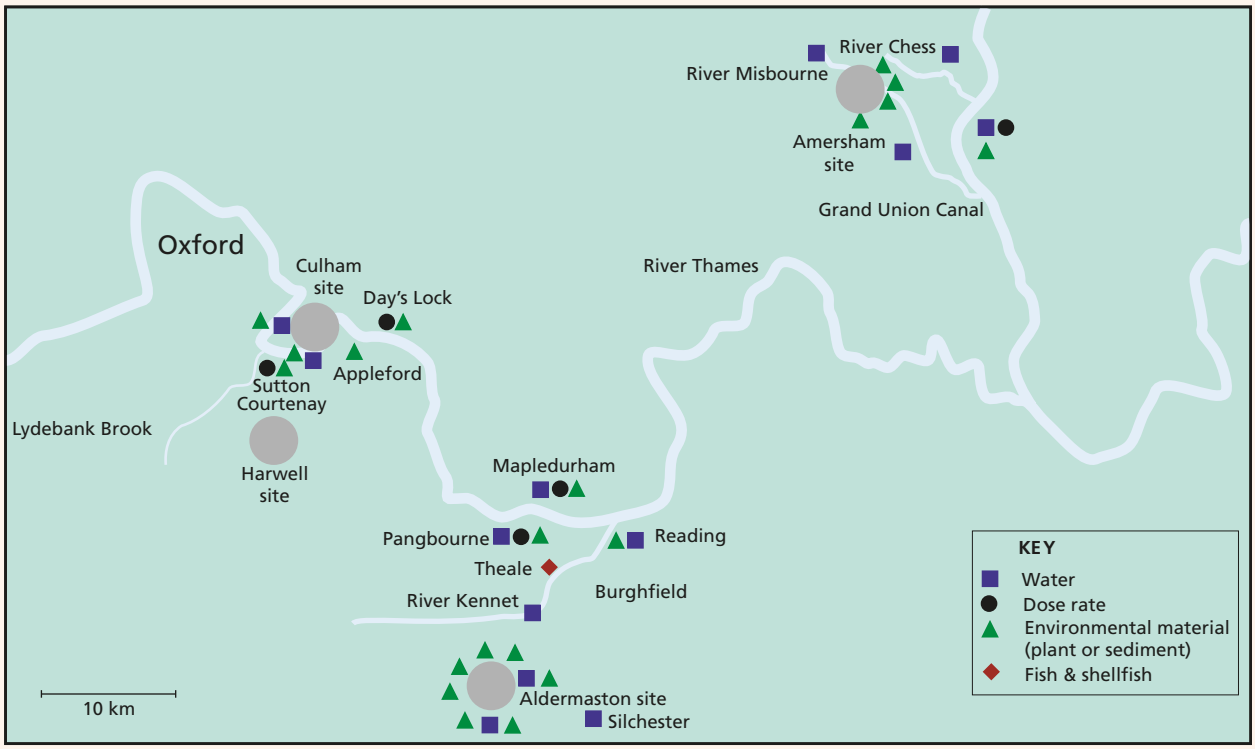
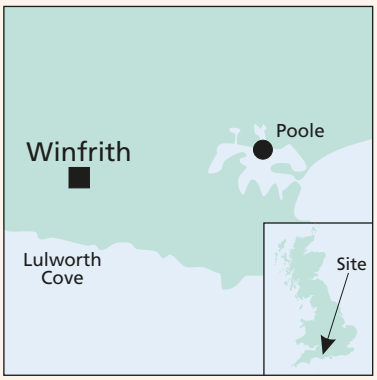


Figure 3.4. Monitoring locations at Thames sites, 2018 (not including farms)

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 increased by small amounts in 2018, in comparison to releases in 2017. However, cobalt-60 and caesium-137 discharges to the sewer in 2016 were the lowest releases for many years. Figure 3.5 shows trends of discharges over time (2007 – 2018) for cobalt-60 and caesium-137. There was an overall reduction in the discharges over the whole period and very low discharges in most recent years.

The aquatic monitoring programme is directed at consumers of freshwater fish and occupancy (sediment and freshwater samples) close to the liquid discharge point. Samples (sediment and freshwater) and measured dose rates were not obtained from Day's Lock in 2018, due to access issues. Concentrations of tritium, cobalt-60 and transuranic elements in all aquatic samples, and caesium-137 in freshwater, are reported as less than values (as in 2017). The concentrations of all radionuclides in flounder from the lower reaches of the Thames are reported as less than values. The caesium-137 concentration in sediment (Sutton Courtenay) continued to be enhanced above background levels in 2018, but is small in terms of any radiological effect. In 2018, gamma dose rates at Sutton Courtenay (footnote, Table 3.3) were unchanged from those measured in 2017.

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 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 2023, at which point the land will be returned to heathland with public access (NDA, 2019).

In December 2017, a variation to the Magnox Winfrith permit was issued by the Environment Agency to reduce liquid discharge limits (through the Winfrith inner pipeline) to the discharge point at Arish Mell. The discharge limits were reduced by an amount equivalent to a permit application (granted at the same time), from Tradebe-Inutec at Fawley, for a permitted route into the English Channel. These changes were effective from the 01 January 2018.

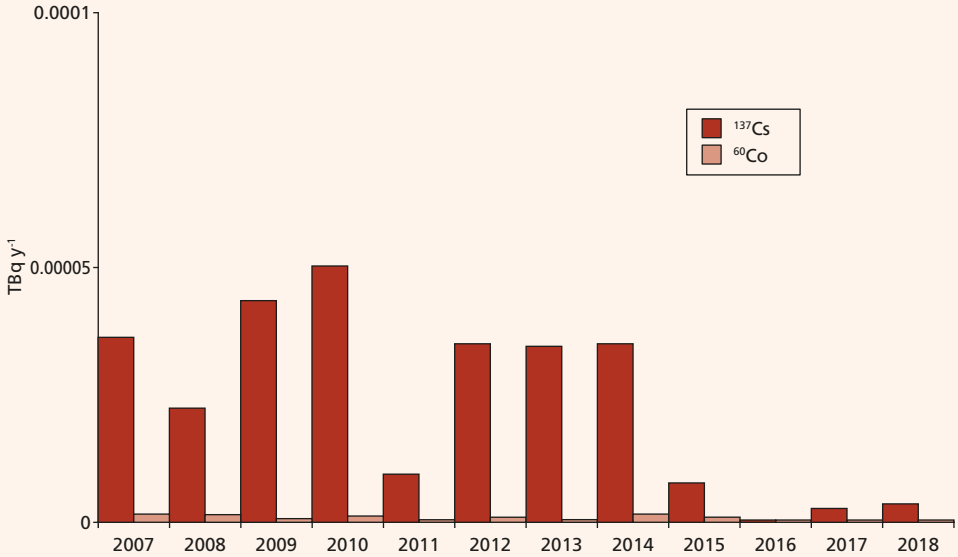


Figure 3.5. Trends in liquid discharges of caesium-137 and cobalt-60 from Harwell, Oxfordshire 2007-2018

In February 2019, both ONR and Environment Agency granted a new nuclear site licence and partial transfer (respectively) to Inutec Limited (who trade as Tradebe Inutec), for their operations on part of the former Winfrith site. The new site licence and permit were required following Tradebe Inutec's acquisition of buildings and land on the Winfrith site, obtained from the NDA in February 2019. Prior to this, Tradebe Inutec, had been operating as a tenant of Magnox Limited.

The most recent habits survey undertaken for Winfrith was in 2003 (McTaggart *et al*., 2004b).

Doses to the public

In 2018, the *total dose* from all pathways and sources of radiation was 0.027 mSv (Table 3.1), or less than 3 per cent of the dose limit, and down from 0.038 mSv in 2017. The representative person was adults living near the site (as in previous years). This dose was almost entirely due to direct radiation from the Winfrith site. The decrease in *total dose* was due to a lower estimate of direct radiation from the site in 2018 (in comparison to that in 2017). Trends in annual *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 2018 (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 were very low (some permitted radionuclides reported as nil) in 2018. The focus of the terrestrial sampling was for the analyses of tritium and carbon-14 in milk and crops. Local freshwater and sediment samples were also analysed. Sampling locations at Winfrith are shown in Figure 3.6. Data for 2018 are given in Table 3.4(a). Results from 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 tritium concentrations were measured in surface water to the north of the site, similar to those in previous years. 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

Liquid wastes are disposed via a pipeline to deep water in Weymouth Bay. As in previous years, discharges continued at very low rates in 2018 (most reported as < 1 per cent of the annual limit). Figure 3.7 shows trends of liquid discharges over time (2007 – 2018) for tritium and alpha-emitting radionuclides. In recent years, alpha-emitting radionuclide discharges have decreased since the peak in 2013. Discharges of alpha-emitting radionuclides from Winfrith (inner pipeline) were less than 1 per cent of the annual limit. In comparison, tritium discharges have varied more between years, with periodic peaks in releases, due to operations at Tradebe Inutec, but have also generally declined since 2015.

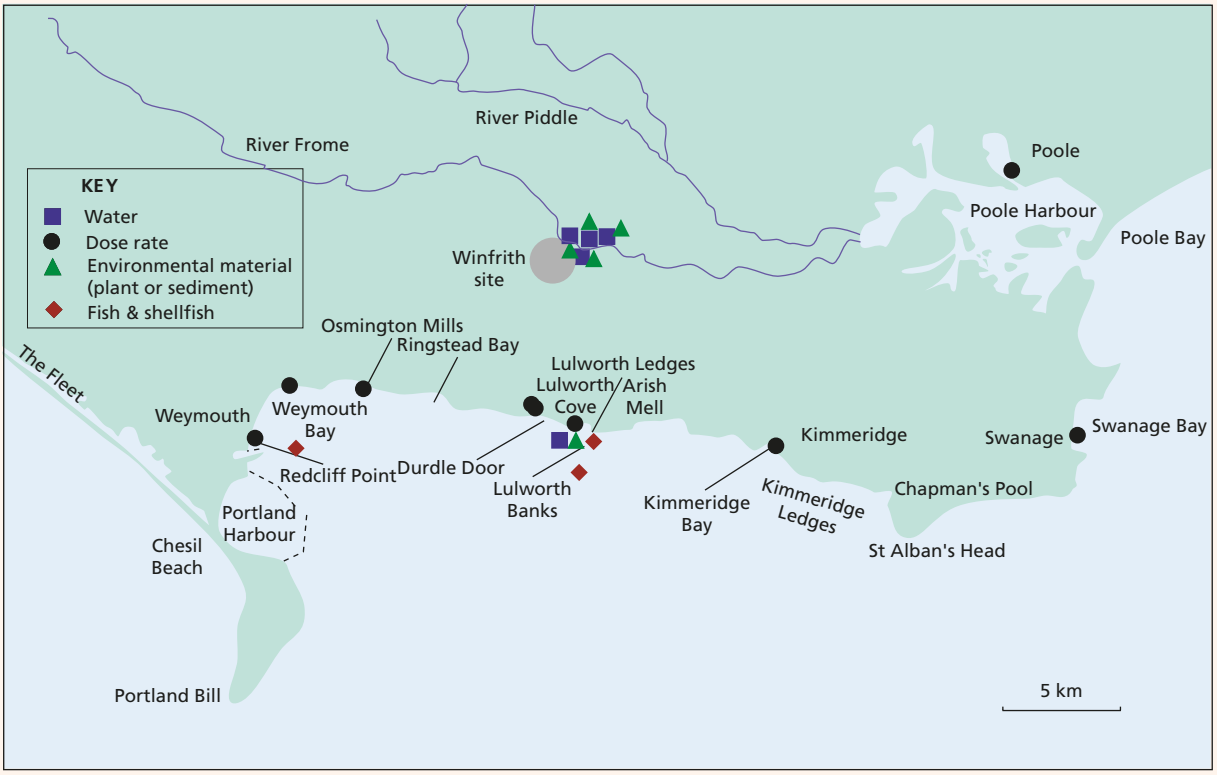


Figure 3.6. Monitoring locations at Winfrith, 2018 (not including farms)

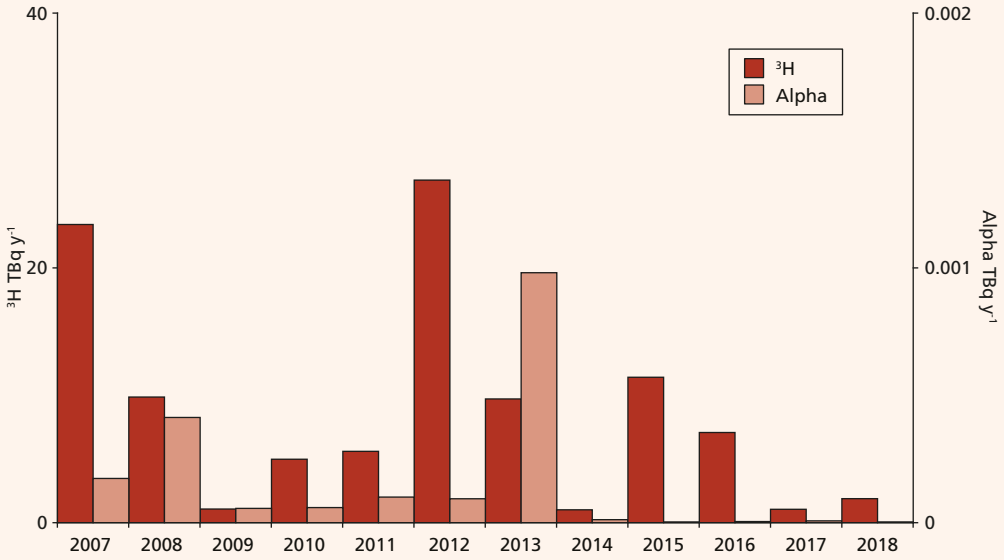


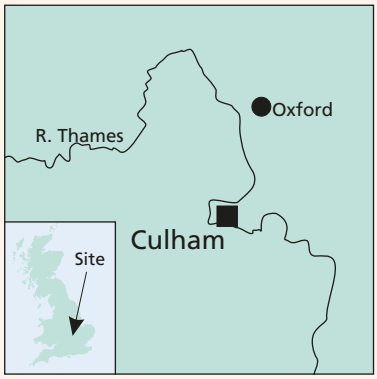
Figure 3.7. Trends in liquid discharges of tritium and alpha emitting radionuclides from Winfrith, Dorset 2007-2018

Analyses of seafood and marine indicator materials and measurements of external radiation over muddy intertidal areas were conducted. Data for 2018 are given in Tables 3.4(a) and (b). Concentrations of radionuclides in the marine environment were low and similar to those in previous years. Caesium-137 and technetium-99 concentrations were all reported as below the less than value. 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 2018 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. The science programme is managed by the EUROfusion consortium (**https://www.euro-fusion.org/programme/**). 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.

An annual *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 2018, was estimated to be much less than 0.005 mSv in 2018 (Table 3.1).

Monitoring of soil and grass around Culham and of sediment and water from the River Thames was undertaken in 2018. 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 were detected due to site operation. The reported caesium-137 concentration in the downstream sediment (28 Bq kg^{-1}) was lower in 2018, in comparison to that in 2017 (60 Bq kg^{-1}). Caesium-137 concentrations in the River Thames sediment are not attributable to Culham but were due to past discharges from Harwell, and fallout from Chernobyl and nuclear weapons testing.

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 and de-fuelled in 2014. Final reactor dismantling will commence shortly, with eventual de-licensing of the site by 2023.

Gaseous and liquid discharges of tritium decreased (both reported as nil) in 2018 in comparison to those in 2017 (Appendix 2, Tables A2.1 and A2.2). These discharges have been infrequent since the reactor shut down. 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, 2018

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[b]	Intakes of sediment and water[c]	Gaseous plume related pathways	Direct radiation from site
Culham								
Source specific dose	Drinkers of river water	<0.005	-	-	-	<0.005	-	-
Dounreay								
***Total dose* – all sources**	**Adult game meat consumers**	**0.035**	**<0.005**	**0.035**	**-**	**-**	**-**	**-**
Source specific doses	Seafood consumers	0.006	<0.005	-	0.005	-	-	-
	Inhabitants and consumers of locally grown food	0.019	-	0.019	-	-	<0.005	-
Harwell								
***Total dose* – all sources**	**Local adult inhabitants (0-0.25km)**	**0.028[d]**	**-**	**-**	**-**	**-**	**<0.005**	**0.028**
Source specific doses	Anglers	<0.005	<0.005	-	<0.005	-	-	-
	Infant inhabitants and consumers of locally grown food	<0.005[d]	-	<0.005	-	-	<0.005	-
Winfrith								
***Total dose* – all sources**	**Local adult inhabitants (0.25–0.5km)**	**0.027**	**<0.005**	**<0.005**	**-**	**-**	**<0.005**	**0.027**
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] *Doses (*total dose *and source specific doses) only include estimates of anthropogenic inputs (by substracting background and cosmic sources from measured gamma dose rates)*

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

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

Table 3.2(a) Concentrations of radionuclides in food and the environment near Dounreay, 2018

Material	Location	No. of sampling observ-ations	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}						
			^{3}H	^{90}Sr	^{95}Nb	^{99}Tc	^{125}Sb	^{137}Cs	^{154}Eu
Marine samples									
Cod	Scrabster	2			<1.3		<0.24	0.31	<0.11
Crabs	Pipeline	1		<0.10	<0.23	0.62	<0.11	<0.10	<0.10
Crabs	Strathy	2			<0.34		<0.17	<0.10	<0.11
Crabs	Melvich Bay	2			<0.30	<0.19	<0.18	<0.10	<0.10
Winkles	Brims Ness	4		<0.10	<0.51		<0.22	<0.11	<0.12
Winkles	Sandside Bay	4		<0.10	<0.75	<0.33	<0.20	<0.12	<0.11
Mussels	Echnaloch Bay	4			<0.41	0.53	<0.19	<0.11	<0.11
Fucus vesiculosus	Brims Ness	4			<1.9		<0.14	<0.10	<0.10
Fucus vesiculosus	Sandside Bay	4			<0.24	8.3	<0.12	<0.11	<0.10
Fucus vesiculosus	Burwick Pier	4			<0.47	11	<0.15	<0.10	<0.10
Sediment	Oigin's Geo	4			<0.15		<0.28	2.2	<0.19
Sediment	Brims Ness	1			<0.10		<0.17	0.93	<0.11
Sediment	Sandside Bay	1			<0.11		<0.14	1.6	<0.10
Sediment	Melvich Bay	1			<0.25		<0.11	1.5	<0.10
Sediment	Strathy	1			<0.30		<0.14	0.81	<0.10
Sediment	Rennibister	1			<0.10		<0.10	7.5	<0.10
Seawater	Brims Ness	2	<1.0		<0.10		<0.14	<0.10	<0.10
Seawater	Sandside Bay	2	<1.0		<0.10		<0.11	<0.10	<0.10

Material	Location	No. of sampling observ-ations	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	Scrabster	2	<0.19	0.0025	0.0025	0.0025		
Crabs	Pipeline	1	<0.10	0.0089	0.0086	0.082	0.67	140
Crabs	Strathy	2	<0.14	0.0027	0.019	0.0095		
Crabs	Melvich Bay	2	<0.11	0.0023	0.013	0.0087		
Winkles	Brims Ness	4	<0.15	0.10	0.43	0.084		
Winkles	Sandside Bay	4	<0.16	0.018	0.090	0.12		
Mussels	Echnaloch Bay	4	<0.16	0.0096	0.043	0.020		
Fucus vesiculosus	Brims Ness	4	<0.13			<0.11	3.4	330
Fucus vesiculosus	Sandside Bay	4	<0.13			<0.14	3.0	430
Fucus vesiculosus	Burwick Pier	4	<0.17			<0.15		
Sediment	Oigin's Geo	4	<0.96	0.72	3.5	0.71		
Sediment	Brims Ness	1	<0.16	2.5	9.2	17		
Sediment	Sandside Bay	1	<0.16	2.6	12	12		
Sediment	Melvich Bay	1	<0.15	0.16	1.2	2.5		
Sediment	Strathy	1	<0.19	0.089	0.74	2.8		
Sediment	Rennibister	1	0.98	0.30	0.91	1.9		
Seawater	Brims Ness	2	<0.13			<0.10		
Seawater	Sandside Bay	2	<0.10			<0.10		

Table 3.2(a) continued

Material	Location or selection[b]	No. of sampling observ-ations	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}						
			^{3}H	^{90}Sr	^{95}Nb	^{125}Sb	^{129}I	^{137}Cs	^{155}Eu
Terrestrial samples									
Beef muscle		1	<5.0	<0.10	<0.22	<0.05	<0.14	0.10	<0.06
Beef offal		1	<5.0	<0.10	<0.13	<0.09	<0.083	<0.05	<0.09
Cabbage		1	<5.0	0.12	<0.05	<0.06	<0.050	<0.05	<0.05
Carrots		1	<5.0	<0.10	<0.16	<0.11		<0.05	<0.10
Eggs		1	7.5	<0.10	<0.19	<0.08	<0.050	<0.05	<0.08
Lamb muscle		1	<5.0	<0.10	<0.27	<0.08	<0.055	0.20	<0.10
Leeks		1	7.9	0.17	<0.23	<0.12		<0.05	<0.09
Pheasant		1	5.5	<0.10	<0.27	<0.13	<0.050	0.24	<0.10
Pork		1	<5.0	<0.10	<0.19	<0.08	<0.050	0.16	<0.10
Potatoes		1	<5.0	<0.10	<0.18	<0.11		0.11	<0.09
Rosehips		1	<5.0	0.25	<0.06	<0.05	<0.050	0.08	<0.06
Turnips		1	<5.0	0.16	<0.08	<0.05	<0.050	<0.05	<0.06
Venison		1	14	<0.10	<0.62	<0.19	<0.050	42	<0.17
Wild mushrooms		1	<5.0	0.18	<0.13		<0.050	1.3	<0.05
Grass		6	<5.0	0.17	<0.15		<0.063	0.10	<0.08
Grass	max			0.26	<0.23		<0.065	0.13	<0.14
Soil		6	<5.0	0.78	<0.32		<0.17	19	1.9
Soil	max			0.80	0.33		<0.20	22	2.1
Freshwater	Loch Calder	1	<1.0		<0.01			<0.01	
Freshwater	Loch Shurrery	1	<1.0		<0.01			<0.01	
Freshwater	Loch Baligill	1	<1.0		<0.01			<0.01	
Freshwater	Heldale Water	1	<1.0		<0.01			<0.01	

Material	Location or selection[b]	No. of sampling observ-ations	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}						
			^{234}U	^{235}U	^{238}U	^{238}Pu	^{239}Pu + ^{240}Pu	^{241}Am	Gross alpha
Terrestrial samples									
Beef muscle		1	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	
Beef offal		1	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	
Cabbage		1				<0.050	<0.050	<0.050	
Carrots		1				<0.050	<0.050	0.050	
Eggs		1				<0.050	<0.050	0.050	
Lamb muscle		1	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	
Leeks		1				<0.050	<0.050	0.050	
Pheasant		1				<0.050	<0.050	<0.050	
Pork		1				<0.050	<0.050	0.32	
Potatoes		1				<0.050	<0.050	0.050	
Rosehips		1				<0.050	<0.050	<0.050	
Turnips		1				<0.050	<0.050	<0.050	
Venison		1				<0.050	<0.050	0.13	
Wild mushrooms		1				<0.050	0.050	0.050	
Grass		6	<0.070	<0.050	<0.070	<0.050	<0.050	<0.050	
Grass	max		0.13		0.13				
Soil		6	42	1.2	38	<0.050	0.43	0.33	
Soil	max		46	1.8	42	<3.7	0.48	0.34	
Freshwater	Loch Calder	1						<0.01	0.013
Freshwater	Loch Shurrery	1						<0.01	<0.010
Freshwater	Loch Baligill	1						<0.01	0.16
Freshwater	Heldale Water	1						<0.01	<0.010

[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, 2018

Location	Material or ground type	No. of sampling observations	µGy h^{-1}
Mean gamma dose rates at 1m over substrate			
Sandside Bay	Sand	2	0.057
Sandside Bay	Winkle Bed	2	0.098
Oigin's Geo	Rocks	1	0.16
Oigin's Geo	Sediment	1	0.14
Brims Ness	Sediment	2	0.084
Melvich	Salt marsh	2	0.061
Melvich Sands	Sand	2	0.053
Strathy Sands	Sand	2	0.052
Thurso riverbank	Sediment	2	0.089
Achvarasdal	Grass	2	0.077
Thurso Park	Grass	2	0.067
Borrowston Mains	Grass	2	0.076
Castletown Harbour	Sand	2	0.063
Dunnet Bay	Sand	2	<0.054
Hallam	Grass	2	0.079
Mean beta dose rates			µSv h^{-1}
Sandside Bay	Sediment	2	<1.0
Oigin's Geo	Sediment	2	<1.0
Thurso riverbank	Sediment	2	<1.0
Castletown Harbour	Sand	1	<1.0

Table 3.2(c) Radioactivity in air near Dounreay, 2018

Location	No. of sampling observations	Mean radioactivity concentration, mBq m^{-3}			
		^{131}I	^{137}Cs	Gross alpha	Gross beta
Shebster	12	<0.030	<0.010	<0.0092	<0.20
Reay	12	<0.033	<0.010	<0.0081	<0.20
Balmore	12	<0.036	<0.010	<0.0094	<0.20

Table 3.3 Concentrations of radionuclides in food and the environment near Harwell, 2018[d]

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	<0.09	<1.2	<0.10			<0.22		
Sediment	Bank of River Thames (Sutton Courtenay)	1[E]		<0.44	5.0	13	<0.44	<0.49	<0.41	260	430
Freshwater	River Thames (Long Wittenham)	4[E]	<2.7	<0.32		<0.27				<0.055	0.27

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	<4.3	<4.3	<0.05
Milk	max		<4.8	<4.8	
Strawberries		1	<7.8	<7.8	<0.04
Wheat		1	<11	<11	<0.04

* *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*

[d] *The gamma dose rate in air at 1m over grass and mud at Sutton Courtney was 0.072 μGy h^{-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(a) Concentrations of radionuclides in food and the environment near Winfrith, 2018

Material	Location	No. of sampling observ-ations	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}									
			^{14}C	^{99}Tc	^{137}Cs	^{238}Pu	^{239}Pu + ^{240}Pu	^{241}Am	^{242}Cm	^{243}Cm + ^{244}Cm	Gross alpha	Gross beta
Marine samples												
Brill	Weymouth Bay	1			<0.14			<0.18				
Crabs	Lulworth Banks	1	33		<0.05			<0.05				
Scallops	Lulworth Ledges	1			<0.06	0.00044	0.0033	0.00085	*	*		
Seaweed	Lulworth Cove	1[E]		<0.86	<0.47			<0.53				
Seawater	Lulworth Cove	1[E]			<0.27			<0.33			<3.0	16

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	<3.8	<3.8	17	<0.04		
Milk	max		<4.7	<4.7	18			
Beetroot		1	<2.5	<2.5	12	<0.06		
Wheat		1	<4.5	<4.5	58	0.07		
Grass	Near Newburgh Farm Cottages	2[E]		<15	21	<1.1	<3.5	240
Grass	Adjacent to railway	2[E]		<19	<13	<2.4	6.2	210
Sediment	North of site	1[E]				5.7	<110	<130
Sediment	R Frome (upstream)	1[E]				2.1	210	290
Sediment	R Frome (downstream)	1[E]				7.0	280	410
Sediment	R Win, East of site	1[E]				1.6	350	460
Freshwater	North of site	2[E]		8.7		<0.23	0.070	0.18
Freshwater	R Frome (upstream)	2[E]		<2.7		<0.26	<0.030	0.090
Freshwater	R Frome (downstream)	2[E]		<2.7		<0.26	<0.030	<0.10
Freshwater	R Win, East of site	2[E]		<2.9		<0.29	<0.050	0.19

* *Not detected by the method used*

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

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

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

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

Table 3.4(b) Monitoring of radiation dose rates near Winfrith, 2018

Location	Ground type	No. of sampling observations	µGy h^{-1}
Mean gamma dose rates at 1m over substrate			
Weymouth Bay	Sand	1	0.052
Osmington Mills	Rock and sand	1	0.056
Durdle Door	Shingle	1	0.049
Lulworth Cove	Shingle	1	0.060
Kimmeridge Bay	Shingle and rock	1	0.084
Swanage Bay	Sand	1	0.054
Poole Harbour	Sand	1	0.050

Table 3.5 Concentrations of radionuclides in the environment near Culham, 2018

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	<2.7		<0.30	<0.049	0.30
Freshwater	River Thames (downstream)	2	<6.3		<0.25	<0.064	0.33
Grass	0.6 km East of site perimeter	1	<14	<5.3	<0.75		220
Sediment	River Thames (upstream)	2			4.4		
Sediment	River Thames (downstream)	2			28		
Soil	1 km East of site perimeter	1	<14	<6.9	2.9		350

[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 5 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 unchanged in 2018
- Gaseous discharges of tritium and carbon-14 decreased from Berkeley, and liquid discharges of tritium and "other radionuclides" increased from Oldbury, in 2018

Bradwell, Essex

- *Total dose* for the representative person was 0.011 mSv and unchanged in 2018
- Gaseous discharges decreased in 2018

Chapelcross, Dumfries and Galloway

- *Total dose* for the representative person was 0.019 mSv and decreased in 2018
- Gaseous discharges of "all other radionuclides" decreased in 2018

Dungeness, Kent

- *Total dose* for the representative person was 0.022 mSv and increased in 2018
- Gaseous discharges of tritium and carbon-14 decreased, and liquid discharges of tritium increased and carbon-14 decreased, from Dungeness B in 2018

Hartlepool, County Durham

- *Total dose* for the representative person was 0.012 mSv and decreased in 2018
- Gaseous discharges of carbon-14 decreased, liquid discharges of tritium and sulphur-35 decreased, in 2018

Heysham, Lancashire

- *Total dose* for the representative person was 0.010 mSv and decreased in 2018
- Liquid discharges of tritium decreased from both Heysham 1 and 2 in 2018

Hinkley Point, Somerset

- *Total dose* for the representative person was 0.041 mSv and increased in 2018
- Gaseous discharges of carbon-14 and sulphur-35 decreased from Hinkley Point B in 2018

Hunterston, North Ayrshire

- *Total dose* for the representative person was less than 0.005 mSv and decreased in 2018
- Gaseous discharges of "all other radionuclides" from Hunterston A and carbon-14 from Hunterston B decreased in 2018
- Liquid discharges of tritium decreased from Hunterston B in 2018

Sizewell, Suffolk

- *Total dose* for the representative person was 0.026 mSv and increased in 2018
- Gaseous and liquid discharges of tritium decreased from Sizewell B in 2018

Torness, East Lothian

- *Total dose* for the representative person was less than 0.005 mSv and decreased in 2018
- Liquid discharges of sulphur-35 decreased in 2018

Trawsfynydd, Gwynedd

- *Total dose* for the representative person was 0.017 mSv and decreased in 2018

Wylfa, Isle of Anglesey

- *Total dose* for the representative person was 0.006 mSv and increased in 2018

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 2019, the NDA published a business plan (2019 – 2022) which summarises the programme of work at each of the sites (NDA, 2019). Of the eleven sites that have Magnox reactors, only two have yet to complete de-fuelling (Wylfa

in Wales and Calder Hall on the Sellafield site, scheduled to complete in 2019/2020).

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 re-license the ten Magnox sites into a single site licensed company alongside the Harwell and Winfrith sites. In 2015, Harwell and Winfrith sites, previously operated by RSRL, merged to be part of Magnox Limited. In July 2018, the NDA announced that Magnox Limited will become a nuclear decommissioning subsidiary of the NDA from 1 September 2019 (replacing the previous PBO management model of ownership by the private sector).

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 PWR power station were owned and operated by EDF Energy Nuclear Generation Limited in 2018; 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 2018.

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 2018, 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 2018 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. Electricity generation started in 1962 and ceased in 1989. 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. Final site clearance is expected to commence in 2070 and achieved by 2079 (NDA, 2019).

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. Final site clearance is expected to commence in 2092 and achieved by 2103 (NDA, 2019).

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

In 2018, the *total dose* from all pathways and sources of radiation was less than 0.005 mSv (Table 4.1), or less than 0.5 per cent of the dose limit, and unchanged from 2017. The representative person was infants (1 year-old) consuming milk at high-rates and was a change from that in 2017 (adults spending time over sediments). The trend in the *total dose* over the period 2007 – 2018 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

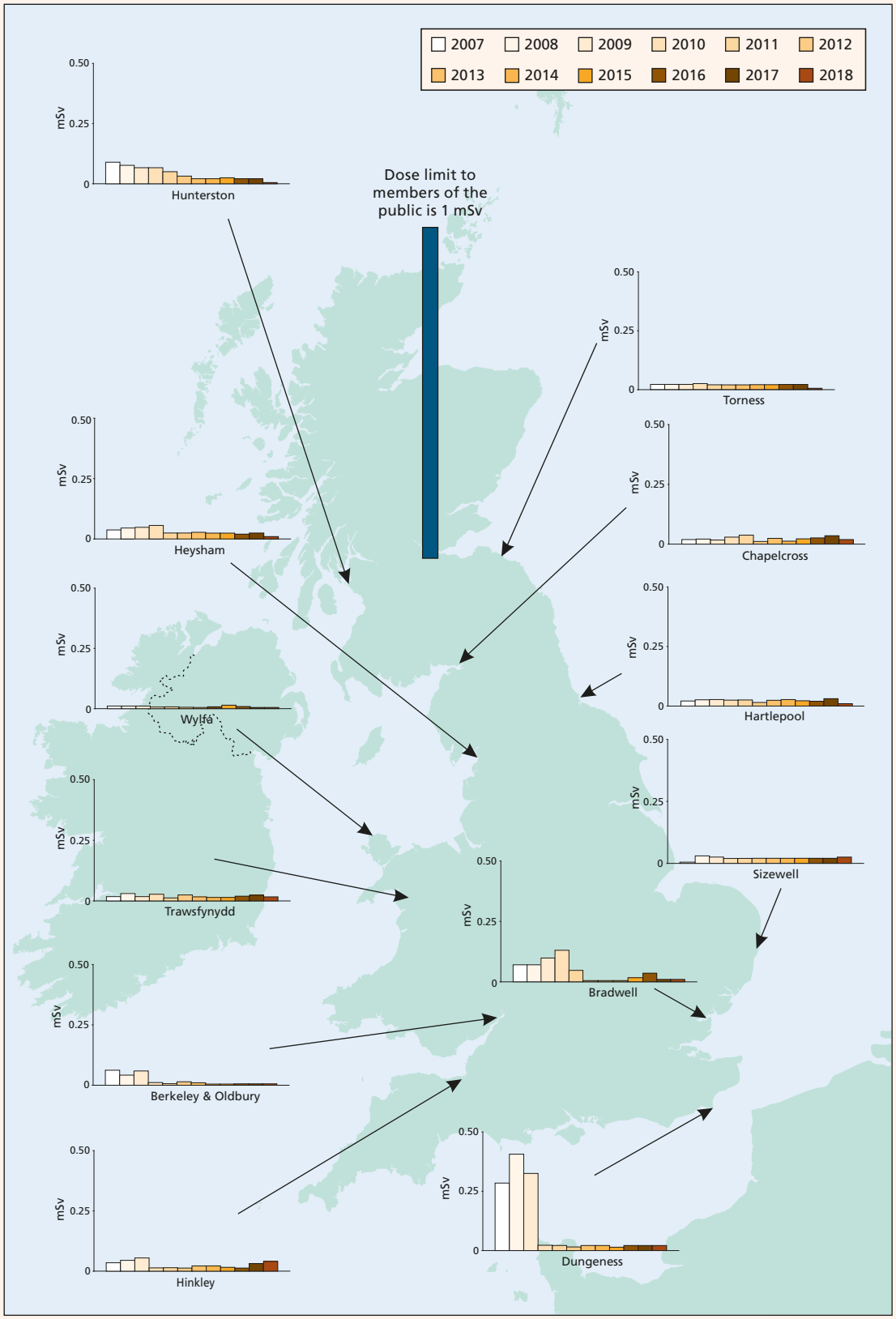


Figure 4.1. *Total dose* at nuclear power stations, 2007-2018
(Small doses less than or equal to 0.005 mSv are recorded as being 0.005 mSv)

that were also less than 0.005 mSv in 2018 (Table 4.1). The dose to a consumer of fish and shellfish includes external gamma radiation, a component due to the tritium historically originating from the GE Healthcare Limited plant at Cardiff, and a component of the dose resulting from an increased tritium dose coefficient (see Appendix 1). The dose for houseboat dwellers was 0.013 mSv in 2018. The reason for the small decrease in estimated dose for houseboat dwellers (from 0.016 mSv in 2017) was due to lower gamma dose rates over mud and saltmarsh (at Sharpness), in comparison to those in 2017. 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

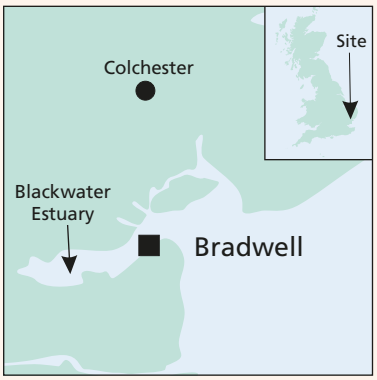
The Berkeley and Oldbury sites discharge gaseous radioactive wastes via separate stacks to the atmosphere. Discharges of tritium and carbon-14 decreased from Berkeley in 2018, in comparison to releases in 2017. The focus of the terrestrial sampling was for the analyses of tritium, carbon-14 and sulphur-35 in milk and crops. Local freshwater samples were also analysed. Data for 2018 are given in Table 4.2(a). Sulphur-35 was detected at a very low concentration in one terrestrial sample (grass) in 2018, as in recent years. Carbon-14 concentrations in foodstuffs (including milk) increased in 2018 (by small amounts) in comparison to those in 2017. Tritium, gross alpha and gross beta concentrations in surface water were below the investigation levels for drinking water in the European Directive 2013/51.

Liquid waste discharges and aquatic monitoring

Liquid radioactive wastes are discharged to the Severn Estuary. Discharges of tritium and "other radionuclides" increased from Oldbury in 2018, in comparison to releases in 2017. For a six month period (November 2018 to April 2019), liquid discharges increased as a result of the draining of their pond and associated operations. The discharges were controlled and part of planned decommissioning activities, and remained well below annual discharge limits.

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. Data for 2018 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 fallout from nuclear 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 recent years, the tritium concentrations in fish, shellfish and seawater are reported as less than values in 2018. In earlier decades, concentrations 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 2017.

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 site followed an accelerated decommissioning programme, which is now complete. At the end of 2018, Bradwell became the UK's first Magnox site to reach the stage of passive Care and Maintenance. The plan is for final site clearance to commence in 2083 and achieved by 2092 (NDA, 2019). In November 2017, Magnox Limited applied to the Environment Agency to vary its environmental permit. The revised permit, effective from May 2019, provides reduced discharge limits and strengthened conditions in the use of best available techniques (to protect people and the environment).

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.

Following the cessation of Intermediate Level Waste (Fuel Element Debris) treatment at Bradwell, the enhanced environmental monitoring reverted to the baseline monitoring programme in 2018. The results of the enhanced monitoring programme (2015 – 2017) are described in earlier RIFE reports (e.g. Environment Agency, FSA, FSS, NIEA, NRW and SEPA, 2018).

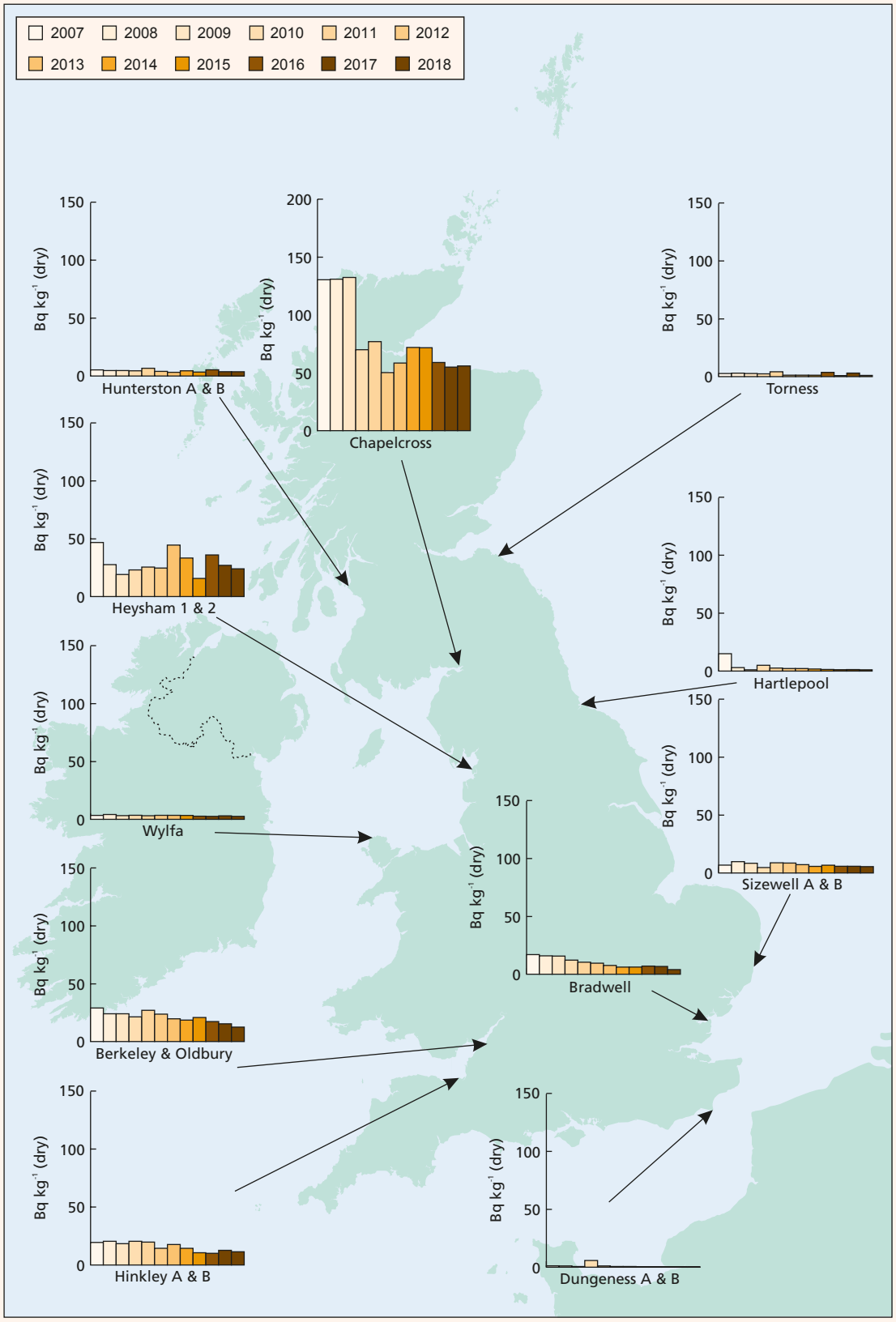


Figure 4.2. Caesium-137 concentration in marine sediments near nuclear power stations between 2007-2018

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 2018 (Table 4.1), or approximately 1 per cent of the dose limit for members of the public of 1 mSv, and unchanged from 2017. The representative person was prenatal children of local inhabitants. The trend in *total dose* over the period 2007 – 2018 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 2018 (Table 4.1). The doses to these high-rate consumers were both less than 0.005 mSv.

Gaseous discharges and terrestrial monitoring

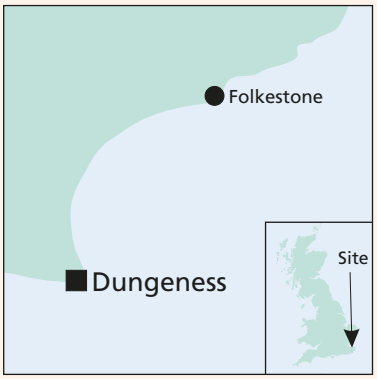
This power station is permitted to discharge gaseous wastes to the local environment via stacks to the atmosphere. Discharges of tritium and carbon-14 decreased by small amounts in 2018, in comparison to releases in 2017. Terrestrial sampling (baseline monitoring programme) is similar to that for other power stations including analyses of milk and crop samples. Samples of water are also taken from a coastal ditch. 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. Tritium and caesium-137 concentrations in food, grass and freshwater samples are reported as less than values (or just above the less than value). As in recent years, strontium-90 was detected at a low concentration in one coastal ditch sample in 2018. As in previous years, the gross beta activities (and gross alpha in 2018) in water from the coastal ditch continued to be enhanced above background concentrations, 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. There were no discharges to the estuary via the site's active effluent discharge system in 2018 (the last discharge via this route took place in September 2017). Rainfall is the only remaining source of liquid effluent discharges to the estuary. This is discharged via the main drain pit at Bradwell and is sampled at quarterly intervals.

Aquatic sampling (baseline monitoring programme) 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. Data for 2018 are given in Tables 4.3(a) and (b). Low concentrations of artificial radionuclides were detected in marine samples as a result of discharges from the station, discharges from Sellafield and fallout from nuclear weapons testing. Due to the low concentrations detected, it is generally difficult to attribute the results to a particular source; however, concentrations (including those from enhanced sediment monitoring in 2017) were generally similar to those reported in recent years. There is an overall decline in caesium-137 concentrations in sediments over the last decade (Figure 4.2). The caesium-137 concentration in sediments in 2018 is lowest reported value in recent years. Gamma dose rates on beaches were difficult to distinguish from natural background and generally similar to those in 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, 2019). Dungeness B is expected to continue electricity generation until 2028. The most recent habits survey was undertaken in 2010 (Clyne *et al*., 2011).

Doses to the public

In 2018, the *total dose* from all pathways and sources of radiation was 0.022 mSv (Table 4.1), or approximately 2 per cent of the dose limit of 1 mSv, and up from 0.021 mSv (in 2017). As in recent years, this was almost entirely due to direct radiation from the site. The representative person was adults living near to the site. The small

increase in *total dose* (from 2017) was mostly attributable to a slightly higher estimate of direct radiation in 2018 (Table 1.1). For the 2018 calendar year (and beyond), EDF Energy have revised their method of direct dose assessment based on readings at the site boundary, distances and occupancy data (see Section 1.2.1). The trend in *total dose* over the period 2007 – 2018 is given in Figure 4.1. *Total doses* ranged between 0.014 and 0.40 mSv over this time period and were dominated by direct radiation. Over a longer time series, this dose has declined more significantly from the peak value of 0.63 mSv, following the shut-down of the Magnox reactors in 2006 (Figure 4.1, Environment Agency, FSA, FSS, NIEA, NRW and SEPA, 2018).

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 (from external exposure), give exposures that were less than the *total dose* in 2018 (Table 4.1) and all source specific doses were less than 0.005 mSv. The decreases in dose for a local bait digger (from 0.006 mSv in 2017) and to a houseboat dweller (from 0.014 mSv in 2017) were because gamma dose rates were measured on different types of ground type (at Pilot Sands and Rye Bay, respectively) in 2018.

Gaseous discharges and terrestrial monitoring

Gaseous wastes are discharged via separate stacks to the local environment. Discharges of tritium and carbon-14 decreased from Dungeness B in 2018, in comparison to releases in 2017. 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 2018 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 very low concentrations in local food samples (potato and wheat). 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 from both power stations are made via separate outfalls to the English Channel. Discharges of tritium increased and carbon-14 decreased (both by small amounts) from Dungeness B in 2018, in comparison to releases in 2017. Marine monitoring included gamma dose rate measurements, and analysis of seafood and sediments. The results of monitoring for 2018 are given in Tables 4.4(a) and (b). The caesium-137 concentrations in seafood is attributable to discharges from the stations, to the fallout from nuclear weapons testing and 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 values expected at sites remote from Sellafield. Tritium (in seafood) and strontium-90 (in sediment) are reported as less than values in 2018. Caesium-137 concentrations in sediment have remained low over the last decade (Figure 4.2) and reported as less than values in 2018; 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. 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 0.012 mSv in 2018 (Table 4.1), which was approximately 1 per cent of the dose limit, and down from 0.031 mSv in 2017. The decrease in *total dose* was mostly attributed to a lower estimate of direct radiation from the site in 2018 (in comparison to that in 2017). 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. For the 2018 calendar year (and beyond), EDF Energy have revised their method of direct dose assessment based on readings at the site boundary, distances and occupancy data (see Section 1.2.1). The trend in *total dose* over the period 2007 – 2018 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* in 2018 (Table 4.1). The dose to a local fish and shellfish consumer (including external radiation but excluding naturally occurring radionuclides) was 0.011 mSv in 2018,

and down from 0.019 mSv in 2017. The reason for the decrease in dose was mostly attributable to lower gamma dose rates over sand and sea coal in 2018, in comparison to those in 2017.

Since 2012, a source specific assessment has been undertaken to determine the exposure from naturally occurring radionuclides, as a consequence of reported polonium-210 concentrations in mollusc samples. As in previous years, winkle samples collected in 2018 for South Gare (inside the Tees Estuary entrance) consisted of a mixture, including some winkles from the estuary entrance near Paddy's Hole. The area in close proximity to Paddy's Hole is polluted with oil and other wastes and therefore unlikely to support a high-rate consumption of winkles. 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 was considered for naturally occurring radionuclides. In 2018, the polonium-210 (and lead-210) concentrations were not enhanced above background, and therefore no additional exposure contributed to the dose, in additional to that from artificial radionuclides. This estimate assumes that the median concentrations for naturally occurring radionuclides at background (Appendix 1, Table X4.1) be subtracted from the total concentrations as measured in 2018.

Gaseous discharges and terrestrial monitoring

Gaseous radioactive waste is discharged via stacks to the local environment. Discharges of carbon-14 decreased in 2018, in comparison to those in 2017. 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 2018 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 close to or just above the less than values) were measured in food (potatoes and barley) and grass samples in 2018. The maximum tritium concentration in locally produced milk was positively detected just above the less than value. 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.

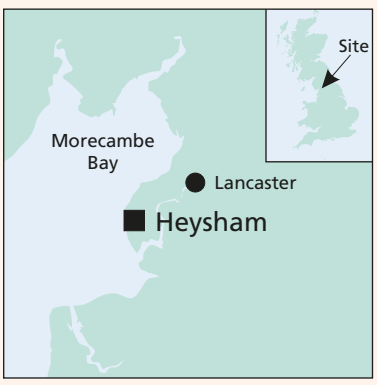
Liquid waste discharges and aquatic monitoring

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 decreased in 2018 in comparison to those in 2017. The decrease in sulphur-35 was associated with reduced Carbonyl Sulphide (COS) injection in 2018. Results of the aquatic monitoring programme conducted in 2018 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 generally similar in 2018, in comparison to those in 2017.

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 Figure 2.11, Environment Agency, FSA, FSS, NIEA, NRW and SEPA, 2018). 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 2018. 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 fallout from nuclear weapons testing. However, caesium-137 concentrations in sediment have remained low for a number of years (Figure 4.2). Overall, gamma dose rates were generally similar over sediment in 2018, although the dose rates over sand and sea coal (Carr House) and over sand (North Gare) decreased by small amounts, in comparison to those in 2017.

In 2018, the reported polonium-210 and lead-210 concentrations in winkles from South Gare are values expected due to natural sources (given in Table X4.1). The polonium-210 concentration (12 Bq kg^{-1}) was lower in 2018, in comparison to that concentration reported in 2017 (enhanced above background). These winkle samples (collected inside the Tees Estuary entrance) consisted of a mixture including some winkles collected from the estuary entrance near 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, commencing operations in 1983 and the second station following in 1984. 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 and adjacent 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 0.010 mSv in 2018 (Table 4.1), or 1 per cent of the dose limit for members of the public, and down from 0.025 mSv in 2017. In 2018, the representative person was adults spending time over sediments, and was a change from that in 2017 (adults living near the site). The decrease in *total dose*, and change in the representative person (from 2017), was mostly attributed to a lower estimate of direct radiation from the site in 2018 (Table 1.1). For the 2018 calendar year (and beyond), EDF Energy have revised their method of direct dose assessment based on readings at the site boundary, distances and occupancy data (see Section 1.2.1).

The trend in *total dose* over the period 2007 – 2018 is given in Figure 4.1. Any changes in *total doses* from 2007 – 2010 were attributed 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. More recently (in 2017), the increase in *total dose* was mostly attributed to a higher estimate of direct radiation from the site.

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* in 2018 (Table 4.1). The estimated doses for terrestrial food consumption and from turf cutting were 0.005 mSv and less than 0.005 mSv, respectively, in 2018. The reason for the small decrease in dose from turf cutting in 2018 (from 0.008 mSv in 2017) was because gamma dose rates were measured over different ground types from one year to the next. 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 0.015 mSv in 2018, which was less than 2 per cent of the dose limit for members of the public of 1 mSv (Table 4.1). The dose in 2017 was 0.026 mSv. The decrease in dose was mostly attributed to lower gamma dose rates over sand in 2018 (in comparison to those in 2017).

Gaseous discharges and terrestrial monitoring

Both stations discharge gaseous radioactive waste via stacks to the atmosphere. The monitoring programme for the effects of gaseous disposals was similar to that for other power stations. Data for 2018 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 grass and silage samples in 2018. Carbon-14 concentrations in milk in 2018 were similar to those in 2017. 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 via outfalls into Morecambe Bay. Discharges of tritium decreased from both Heysham 1 and 2 in 2018, in comparison to those in 2017. 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 2018 are given in Tables 4.6(a) and (b). In general, activity concentrations in 2018 were similar (in comparison to those in 2017) and the effect of liquid disposals from Heysham was difficult to detect above the Sellafield background. Concentrations of tritium in flounder, shrimps and mussels were not sufficiently high to demonstrate that any originated as a result of discharges from Heysham, although tritium concentrations were enhanced in winkles (in comparison to those in recent years). Iodine-129 was positively detected in seaweed (reported as just above the less than value) in 2018 (reported in the footnote). Plutonium radionuclides and americium-241 concentrations in mussels were slightly lower in 2018 (in comparison to those in 2017). Concentrations of technetium-99 in marine samples remained at values typical of recent years, caused by discharges from Sellafield. In 2018, strontium-90 was detected at low concentrations (reported as just above, or close to, the less than value) in food samples. Gamma dose rates over intertidal sediment in 2018 were generally lower (where comparisons can be made from similar ground types and locations) to those in 2017.

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, 2019). 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. The most recent habits survey was conducted in 2017 (Greenhill *et al.*, 2018).

Construction of the Hinkley Point C station, to be powered by twin EPR™ reactors, is continuing at pace. In 2017, ONR granted its first consent for the start of nuclear safety construction at the site. The consent covers the placement of the structural concrete for the first nuclear safety-related structure. In November 2018, ONR provided NNB GenCo with consent to commence the unit 1 Nuclear Island concrete pour at Hinkley Point C. Summary details of earlier environmental permits issued (by the Environment Agency), the pre-construction safety case (published by ONR), the planning consents granted and other approvals, are available in earlier RIFE reports (e.g. Environment Agency, FSA, FSS, NIEA, NRW and SEPA, 2018). Latest information can be found at: **https://www.gov.uk/government/collections/hinkley-point**.

Doses to the public

In 2018, the *total dose* from all pathways and sources of radiation was 0.041 mSv (Table 4.1), or approximately 4 per cent of the dose limit, and up from 0.032 mSv in 2017. The representative person was adults spending time over sediments, and a change from that in 2017 (prenatal children of occupants over sediment). The increase in *total dose* was mostly due to higher gamma dose rates (over mud) in 2018, in comparison to those in 2017.

The trend in *total dose* over the period 2007 – 2018 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. The increase in *total dose* in 2017 was mostly due to the increase in occupancy rates (over sand) reported in the most recent habits survey.

Source specific assessments for a high-rate consumer of locally grown food, and a local fisherman who consumed a large amount of seafood and was exposed to external radiation over intertidal area, give exposures that were less than the *total dose* in 2018 (Table 4.1). The dose to this consumer of locally grown food was 0.005 mSv in 2018. The decrease in dose (from 0.007 mSv in 2017) was mostly due to lower carbon-14 concentrations in milk in 2018. The dose to the local fisherman was 0.025 mSv in 2018, or less than 3 per cent of the dose limit for members of the public of 1 mSv. The reason for the increase in dose from 0.019 mSv (in 2017) is the same as that contributing to the maximum *total* dose. This dose estimate also includes the effects of discharges (historical) of tritium and carbon-14 from the GE Healthcare Limited plant at Cardiff and uses an increased tritium dose coefficient (see Appendix 1, Annex 3). An additional source specific assessment was undertaken to determine the external exposure to a houseboat dweller (identified in the habits survey) in 2018. The estimated dose was 0.012 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.

For the 2018 calendar year (and beyond), EDF Energy have revised their method of direct dose assessment based on readings at the site boundary, distances and occupancy data (see Section 1.2.1). The estimated dose from direct radiation is lower in 2018 than in previous years (Table 1.1).

Gaseous discharges and terrestrial monitoring

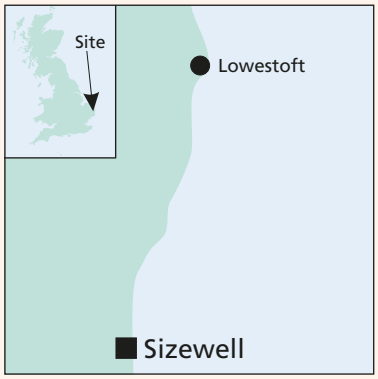
Gaseous radioactive waste is discharged via separate stacks to the local environment. Discharges of carbon-14 and sulphur-35 decreased (by small amounts) from Hinkley Point B in 2018, in comparison to releases in 2017. Analyses of milk, fruit, honey and crops were undertaken to measure activity concentrations of tritium, carbon-14, sulphur-35 and gamma emitters. Local reservoir water samples were also taken and analysed. Data for 2018 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 2017. Carbon-14 was also detected in blackberries (as in 2017) above the expected background value in 2018. 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.

The environmental results for 2018 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 2018, tritium concentrations in shellfish (shrimps) were higher by small amounts, in comparison to those in 2017, 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, and fallout from Chernobyl and nuclear weapons testing. 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 2018 were generally similar (where comparisons can be made), although the dose rates over mud (at Stolford) increased (by small amounts), in comparison to those in 2017.

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 that 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, 2019). Sizewell B, powered by one reactor, is the only commercial PWR power station in the UK. The B power station began operation in 1995 and it is estimated that it will end power generation by 2035. In November 2018, a permit variation was issued for Sizewell B. The variation incorporated improvements to the existing routes of disposal. The most recent habits survey was conducted in 2015 (Garrod *et al.*, 2016).

NNB GenCo is developing its plans for a twin EPR™ reactor based station at the site (Sizewell C) and has undertaken initial consultations relating to its intended application to the Planning Inspectorate for a Development Consent Order (DCO). The application for the DCO is due to be submitted in late 2019.

Doses to the public

The *total dose* from all pathways and sources of radiation was 0.026 mSv in 2018 (Table 4.1) or less than 3 per cent of the dose limit, and up from 0.021 mSv in 2017. 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. The increase in *total dose* (from 2017) was mostly attributed to a higher estimate of direct radiation in 2018 (Table 1.1). For the 2018 calendar year (and beyond), EDF Energy have revised their method of direct dose assessment based on readings at the site boundary, distances and occupancy data (see Section 1.2.1). The trend in *total dose* over the period 2007 – 2018 is given in Figure 4.1. Any variation in *total dose* from year to year was due to a change in the contribution from direct radiation from the site. The *total dose* has declined (reduced by a factor of three), following the closure of the Magnox reactors at Sizewell A in 2006 (Figure 4.1, Environment Agency, FSA, FSS, NIEA, NRW and SEPA, 2018).

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 2018 (Table 4.1).

Gaseous discharges and terrestrial monitoring

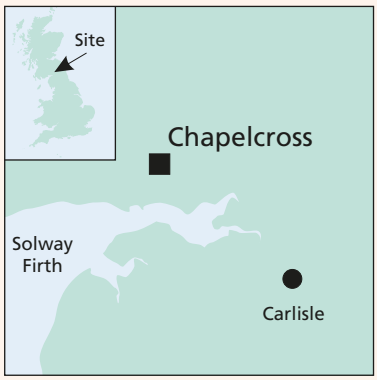
Gaseous wastes are discharged via separate stacks to the local environment. Discharges of tritium decreased from Sizewell B in 2018, in comparison to releases in 2017. The results of the terrestrial monitoring in 2018 are shown in Table 4.8(a). Gamma-ray spectrometry and radiochemical analysis of tritium, 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 concentrations in milk increased in 2018 (by small amounts) in comparison to those in 2017. Sulphur-35 was positively detected at a very low concentration in food samples (potatoes and barley) in 2018. Tritium was positively detected at a low concentration in one local foodstuff (barley) in 2018. 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 decreased from Sizewell B in 2018, in comparison to those in 2017. 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 2018 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 fallout from Chernobyl and nuclear weapons testing. Tritium concentrations in seafood, and strontium-90 in sediment, 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 were generally lower in comparison to those in 2017 (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 are being addressed during the decommissioning phase. 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, 2019).

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 was 0.019 mSv in 2018 (Table 4.1), which was less than 2 per cent of the dose limit, and down from 0.035 mSv in 2017. As in recent years, the representative person was infants consuming milk at high rates. The decrease in *total dose* (from 2017) was mostly due to a lower strontium-90 concentration in milk in 2018 (reported as a less than value), in comparison to the positively detected maximum value in 2017. The trend in *total dose* over the period 2007 – 2018 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 2018 (Table 4.1). The dose for the terrestrial food consumer was estimated to be 0.014 mSv in 2018. The reason for the decrease in dose from 0.023 mSv (in 2017) is the same as that contributing to the maximum *total dose*. The dose for the salmon, mollusc and wildfowl consumer was 0.011 mSv in 2018, and down from 0.014 mSv in 2017. The decrease in dose was mostly due to lower concentrations of americium-241 in molluscs (mostly cockles), and to a much lesser extent to lower gamma dose rates measured over salt marsh, in 2018.

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" decreased in 2018, in comparison to releases in 2017. 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 2018 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 were similar to those values used to represent background concentrations, whilst the strontium-90 concentration in milk was reported as a less than value in 2018 (the maximum strontium-90 was positively detected as 0.38 Bq l^{-1} in 2017). Sulphur-35 and americium-241 concentrations in all terrestrial food and grass samples are reported as less than values, the maximum concentrations in soil were just above these values.

In previous years, the tritium results in terrestrial samples have shown the effects of discharges from Chapelcross. In 2018, tritium concentrations over the range of food samples, and most other samples, are reported as less than values and the effects of discharges are only apparent in the maximum concentrations in milk, grass and soil. 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 2018 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 measurement of gamma dose rates. Data for 2018 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 and europium-155 were positively detected (reported as just above the less than value) in sediment samples. Cobalt-60 was also detected in one food sample (cockles) just above the less than value in 2018 (as in 2017).

As in previous years, concentrations of caesium-137, plutonium radionuclides and americium-241 were enhanced in sediment samples taken close to the pipeline in 2018. Technetium-99 concentrations in seaweed and mussels were generally similar, in comparison to those in 2017, whilst concentrations in crustaceans (shrimps) are reported as less than values in 2018. Concentrations of caesium-137 in sediments, largely due to Sellafield, are generally in decline over the last decade (Figure 4.2). In 2018, gamma dose rates (where comparisons can be made) were generally lower at locations over salt marsh (at Priestside Bank and the pipeline), in comparison to those in 2017. Measurements of the contact beta dose rate on stake nets and sediment are reported as less than values in 2018.

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 2018 (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 in 2024. 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, 2019).

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, there is still a need 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.

Reactors 3 and 4 at Hunterston B were taken off-line (in March 2018 and October 2018, respectively) for planned graphite inspection outages. Following the results of the inspections, the reactors were kept off-line for the rest of 2018 whilst work was carried out on a new safety case.

Environmental monitoring in the area considers the effects of both Hunterston A and Hunterston B sites together. The most recent habits survey was conducted in 2017 (SEPA, *in press*/b).

Doses to the public

The *total dose* from all pathways and sources of radiation was less than 0.005 mSv in 2018 (Table 4.1), which was less than 0.5 per cent of the dose limit, and down from 0.023 mSv in 2017. In 2018, the representative person was prenatal children of local inhabitants and a change from that in 2017 (adults consuming root vegetables, direct radiation being the dominant contributor to the dose). The decrease in *total dose* and change in the representative person (from 2017) was mostly due to a lower estimate of direct radiation from the site in 2018 (Table 1.1). For the 2018 calendar year (and beyond), EDF Energy have revised their method of direct dose assessment based on readings at the site boundary, distances and occupancy data (see Section 1.2.1). The trend in *total dose* over the period 2007 – 2018 is given in Figure 4.1. The decrease in *total dose* in recent years has reflected a downward trend in the reported direct radiation.

A source specific assessment for a high-rate consumer of local seafood gives an exposure that was the same as the *total dose* in 2018 (Table 4.1). The estimated dose to a terrestrial food consumer was 0.013 mSv in 2018 which was approximately 1 per cent of the dose limit for members of the public of 1 mSv. The reason for the decrease in dose from 0.016 mSv (in 2017) was mostly due to a lower modelled concentration of carbon-14 in the gaseous plume. The dose to a fish and shellfish consumer was 0.005 mSv, and unchanged from 2017.

Gaseous discharges and terrestrial monitoring

Gaseous discharges are made via separate discharge points from the Hunterston A and Hunterston B stations. Discharges of "all other radionuclides" decreased from Hunterston A, in comparison to those releases in 2017. Due to reactor shutdowns, carbon-14 discharges also decreased from Hunterston B in 2018. 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 2018 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). Positively detected values were measured in the maximum concentration of sulphur-35 in grass and for europium-155 in soil samples (reported as just above the less than value) in 2018. However, europium-155 was not detected in grass samples (not analysed in recent years). Carbon-14 concentrations in a number of foodstuffs were higher than those values used to represent background values (apples, carrots, sprouts, rosehips and honey and the maximum value in milk). Furthermore, the maximum concentration in milk was higher in 2018, in comparison to that in 2017. In 2018, americium-241 concentrations in all terrestrial samples, measured by gamma–ray spectrometry, are reported as less than values. 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 (Table 4.10(c)) are reported as less than values (or close to the less than value). Solid waste transfers in 2018 are also given in Appendix 2 (Table A2.4).

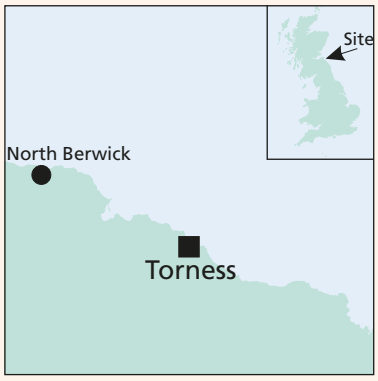
Liquid waste discharges and aquatic monitoring

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 tritium decreased from Hunterston B in 2018, in comparison to those releases in 2017. 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 2018 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 2018 and were generally similar to those reported in previous years. Small concentrations (reported as just above the less than value) of activation products (manganese-54 and cobalt-60) were detected in seaweed and in some mollusc samples (silver-110m). These activation products are likely to have originated from the site, but continued to be of negligible radiological significance (as in previous years). Gamma dose rates were generally similar in 2018, in comparison to

those in 2017. Measurements of the beta dose rates over sand are reported as less than values in 2018. 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.

The IAEA Operational Safety Review Team (OSART), an independent team of industry experts, led a mission to review the operational safety at Torness nuclear power station from 22 January to 8 February 2018. The OSART report (published in October 2018) includes operational safety recommendations and highlights good practices found at Torness, for consideration by the relevant UK authorities and EDF Energy. More information is available via: **https://www.gov.uk/government/publications/operational-safety-review-torness-nuclear-power-station-2018-independent-report-and-government-response**.

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 2018. 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). Solid waste transfers in 2018 are also given in Appendix 2 (Table A2.4).

The most recent habits survey, to determine the consumption and occupancy rates by members of the public, was undertaken in 2016 (Dale *et al.*, 2019a).

Doses to the public

In 2018, the *total dose* from all pathways and sources of radiation was less than 0.005 mSv (Table 4.1) or less than 0.5 per cent of the dose limit, and down from 2017. In 2018, the representative person was prenatal children of local inhabitants who consumed wild fruits and nuts at high rates and a change from that in 2017 (adults living in the vicinity of the site). The decrease in *total dose* and change in the representative person (from 2017) was mostly attributed to a lower estimate of direct radiation from the site in 2018 (Table 1.1). For the 2018 calendar year (and beyond), EDF Energy have revised their method of direct dose assessment based on readings at the site boundary, distances and occupancy data (see Section 1.2.1). The trend in *total dose* over the period 2007 – 2018 is given in Figure 4.1. The decrease in *total dose* in the earlier years reflected a downward trend in the reported direct radiation, thereafter *total doses* have remained broadly similar, from year to year, and were low.

A source specific assessment for a high-rate consumer of local fish and shellfish gives an exposure that was also less than 0.005 mSv in 2018 (Table 4.1). The estimated dose to a terrestrial food consumer was 0.007 mSv in 2018, which was less than 1 per cent of the dose limit for members of the public of 1 mSv. The apparent decrease in dose (from 0.013 mSv in 2017) was mostly due to the exclusion of americium-241 concentrations in food in the 2018 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).

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 2018 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). The maximum carbon-14 concentration in locally produced milk was close to those values used to represent background levels in 2018. The effects of sulphur-35 discharges from the power station were only detected in concentrations in one terrestrial food (eggs) and in the maximum concentration in an environmental indicator material (soil), but these were low (close to the less than values). Caesium-137 in honey was positively detected at a low concentration (2.0 Bq kg^{-1}) in 2018, but similar to the value reported in 2017 (4.9 Bq kg^{-1}). Americium-241 concentrations in all terrestrial food and soil samples (measured by gamma–ray spectrometry) are reported as less than values in 2018. 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 in air, at locations near to the site, are reported as less than values (or close to the less than value) in 2018 (Table 4.11(c)). It was previously reported that cobalt-60 was positively detected at a very low concentration in one air sample (Innerwick) in 2016 (but not in 2017 and 2018). Solid waste transfers in 2018 are also given in Appendix 2 (Table A2.4).

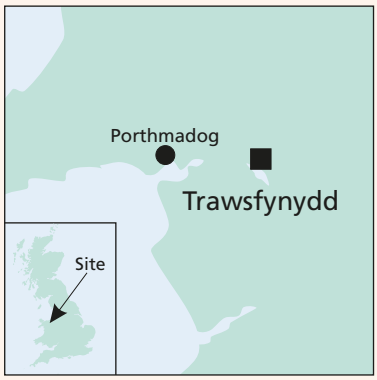
Liquid waste discharges and aquatic monitoring

Discharges of authorised liquid radioactive wastes are made to the Firth of Forth. Discharges of sulphur-35 decreased in 2018, in comparison to those releases in 2017 (due to general operational variability between years). Seafood, seaweed, sediment, and seawater samples were collected in 2018. 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 2018 are shown in Tables 4.11(a) and (b). Concentrations of artificial radionuclides were mainly due to the distant effects of Sellafield discharges, and fallout from Chernobyl and nuclear weapons testing. As in recent years, a few activation products (manganese-54, cobalt-60 and silver-110m) were detected at low concentrations in environmental indicator samples. In 2018, these radionuclides were also detected in one food sample (winkles) at low concentrations. These activation products were likely to have originated from the station. 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 and nets are reported as less than values in 2018.

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 in 2029 (NDA, 2019). Thereafter, final site clearance is expected to commence in 2074 and achieved by 2083.

In July 2018, a habits survey was conducted to determine the consumption and occupancy rates by members of the public (Greenhill *et al.*, 2019). A large increase in the fish consumption rates (brown trout) has been observed, together with a small increase in the occupancy rate over the lake shore, in comparison with those of the previous survey in 2005. Revised figures for consumption rates of fish, together with occupancy rates, are provided in Appendix 1 (Table X2.2).

Doses to the public

The *total dose* from all pathways and sources of radiation was 0.017 mSv in 2018 (Table 4.1), which was less than 2 per cent of the dose limit, and down from 0.024 mSv in 2017. The representative person in 2018 was adults exposed to external radiation over lake sediments (as in 2017). The decrease in *total dose* was attributed to revised habits information (assessing occupancy on different locations) and resulting in lower concentrations (caesium-137) in lake sediments included in the assessment in 2018 (in comparison to those in 2017). The trend in *total dose* over the period 2007 – 2018 is given in Figure 4.1. *Total doses* remained broadly similar, from year to year, and were low.

The dose to an angler (who consumes large quantities of fish and spends long periods of time in the location being assessed) was 0.018 mSv in 2018 (Table 4.1), which was less than 2 per cent of the dose limit for members of the public of 1 mSv. The decrease in dose (from 0.026 mSv in 2017) 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 rates. The dose to infants (1 year-old) consuming terrestrial food was 0.025 mSv, or approximately 2 per cent of the dose limit. The dose in 2017 was 0.028 mSv, and the decrease was mostly due to a lower reported less than value for americium-241 in milk in 2018.

Gaseous discharges and terrestrial monitoring

The results of the terrestrial programme, for local food (including milk) and silage samples in 2018, 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 generally similar in 2018 (in comparison to those in 2017) and just above those values used to represent background concentrations. Measured activities for caesium-137 are reported as less than values (or close to the less than value) in 2018. The most likely source of small amounts of caesium-137 is fallout from Chernobyl and nuclear weapons testing, 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 2018, detected activities in potatoes were low and generally similar to observations in other areas of England and Wales, where activity was attributable to fallout from nuclear weapons testing. There was no evidence of re-suspension of activity in sediment from the lake shore contributing to increased exposure from transuranic radionuclides in 2018.

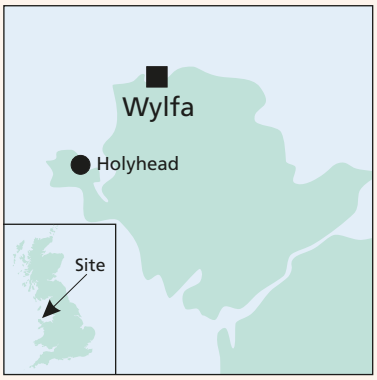
Liquid waste discharges and aquatic monitoring

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. Due to the limited period that they spend in the lake, introduced fish generally exhibit lower radiocaesium concentrations than indigenous fish.

Data for 2018 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 (in comparison to previous annual surveys). A brown trout sample was not collected in 2018. As in previous years, caesium-137 concentrations in water samples are reported as less than values in 2018. Concentrations in the water column are predominantly maintained by processes that release activity (such as remobilisation) from near surface sediments. Caesium-137 concentrations in lake sediments were generally similar (where comparisons can be made), in comparison to those in 2017 (but higher than those in 2016). In 2018, the highest caesium-137 concentration was in a sediment sample collected near the footbridge (640 Bq kg^{-1}), enhanced above those values reported in recent years at this location. 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 2018 were similar to those in recent years. Strontium-90 and transuranic concentrations in fish continued to be very low in 2018 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 dose rates in 2018 and were generally similar (with some small variations) to those in 2017. The predominant radionuclide was caesium-137. The time trends of concentrations of caesium-137 in sediments and discharges are shown in Figure 4.3. A substantial decline in concentrations 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. By October 2018, three-quarters of the used nuclear fuel had been emptied from its twin reactors. De-fuelling is expected to be completed between 2019 and 2020 (NDA, 2019). The Wylfa site will enter the Care and Maintenance phase by the year 2026. Final site clearance is expected to commence in 2097 and achieved by 2105. The most recent habits survey was undertaken in 2013 (Garrod *et al.*, 2014).

Doses to the public

The *total dose* from all pathways and sources of radiation was 0.006 mSv in 2018 (Table 4.1), which was approximately 0.5 per cent of the dose limit, and up from less than 0.005 mSv in 2017. In 2018, the representative person was adults spending time over sediments. The apparent small increase in *total dose* (from 2017) was because gamma dose rates were measured over different ground types from one year to next. The trend in *total dose* over the period 2007 – 2018 is given in Figure 4.1. *Total doses* remained broadly similar, from year to year, and were generally very low.

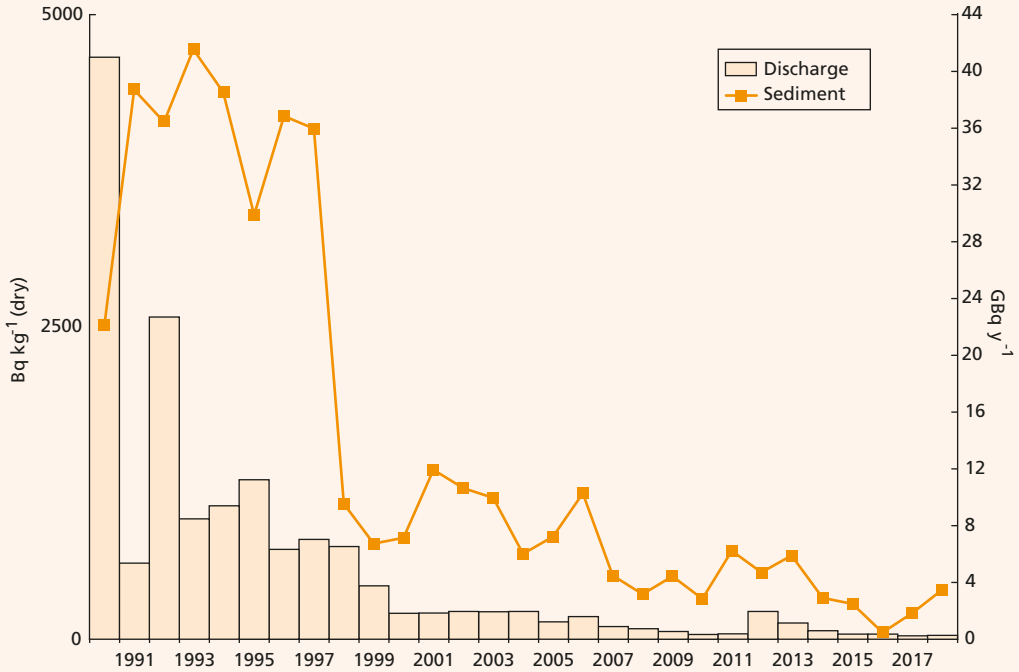


Figure 4.3. Caesium-137 liquid discharge from Trawsfynydd and concentration in sediment in Trawsfynydd lake, 1990-2018

A source specific assessment for a high-rate consumer of locally grown foods gives an exposure that was the same as the *total dose* (Table 4.1). The dose to a high-rate consumer of fish and shellfish (including external radiation) was 0.008 mSv. The reason for the small increase in dose from 0.007 mSv (in 2017) is the same as that contributing to the maximum *total dose*.

Gaseous discharges and terrestrial monitoring

The focus of the terrestrial sampling was for the analyses of tritium, carbon-14 and sulphur-35 in milk and crops. Data for 2018 are given in Table 4.13(a). Sulphur-35 concentrations were detected at low concentrations (reported as close to, or just above, the less than value) in food (potatoes) and silage samples. Carbon-14 was detected in locally produced milk at concentrations above the expected background concentration and increased by small amounts in comparison to those in 2017.

Liquid waste discharges and aquatic monitoring

The aquatic monitoring programme consists of sampling of fish and shellfish, and the measurement of gamma dose rates. Samples of sediment, seawater and seaweed are analysed as environmental indicator materials. The results of the programme in 2018 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 2018 were similar to those in recent years. The reported concentration of technetium-99 in seaweed in 2018 (due to the distant effects of discharges to sea from Sellafield) was similar to those reported in recent 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, 2018

Site	Representative person[a]	Exposure, mSv per year					
		Total	Fish and shellfish	Other local food	External radiation from intertidal areas or the shoreline[c]	Gaseous plume related pathways	Direct radiation from site
England							
Berkeley and Oldbury							
***Total dose* – all sources**	**Infant milk consumers**	**<0.005**	**-**	**<0.005**	**-**	**-**	**-**
Source specific doses	Seafood consumers	<0.005	<0.005	-	<0.005	-	-
	Houseboat occupants	0.013	-	-	0.013	-	-
	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)**	**0.022**	**<0.005**	**<0.005**	**<0.005**	**<0.005**	**0.021**
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	-
Hartlepool							
***Total dose* – all sources**	**Local adult inhabitants (0–0.25km)**	**0.012**	**<0.005**	**-**	**0.006**	**<0.005**	**0.006**
Source specific doses	Seafood consumers[b]	0.011	<0.005	-	0.008	-	-
	Infant inhabitants and consumers of locally grown food	<0.005	-	<0.005	-	<0.005	-
Heysham							
***Total dose* – all sources**	**Adult occupants over sediment**	**0.010**	**<0.005**	**<0.005**	**0.010**	**<0.005**	**<0.005**
Source specific doses	Seafood consumers	0.015	0.006	-	0.010	-	-
	Turf cutters	<0.005	-	-	<0.005	-	-
	Infant inhabitants and consumers of locally grown food	0.005	-	<0.005	-	<0.005	-
Hinkley Point							
***Total dose* – all sources**	**Adult occupants over sediment**	**0.041**	**<0.005**	**<0.005**	**0.041**	**-**	**-**
Source specific doses	Seafood consumers	0.025	<0.005	-	0.023	-	-
	Infant inhabitants and consumers of locally grown food	0.005	-	0.007	-	<0.005	-
Sizewell							
***Total dose* – all sources**	**Local adult inhabitants (0–0.25km)**	**0.026**	**<0.005**	**<0.005**	**<0.005**	**<0.005**	**0.025**
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**	**0.019**	**<0.005**	**0.019**	**<0.005**	**-**	**-**
Source specific doses	Salmon, mollusc and wildfowl consumers	0.011	0.008	-	<0.005	-	-
	Crustacean consumers	<0.005	<0.005	-	-	-	-
	Infant inhabitants and consumers of locally grown food	0.014	-	0.014	-	<0.005	-
Hunterston							
***Total dose* – all sources**	**Prenatal children of local inhabitants (0.5–1 km)**	**<0.005**	**-**	**<0.005**	**<0.005**	**<0.005**	**-**
Source specific doses	Seafood consumers	0.005	<0.005	-	<0.005	-	-
	Infant inhabitants and consumers of locally grown food	0.013	-	0.012	-	<0.005	-
Torness							
***Total dose* – all sources**	**Prenatal children of wild fruit and nut consumers**	**<0.005**	**<0.005**	**<0.005**	**<0.005**	**-**	**-**
Source specific doses	Seafood consumers	<0.005	<0.005	-	<0.005	-	-
	Infant inhabitants and consumers of locally grown food	0.007	-	0.007	-	<0.005	-
Wales							
Trawsfynydd							
***Total dose* – all sources**	**Adult occupants over sediment**	**0.017**	**<0.005**	**0.016**	**-**	**<0.005**	**-**
Source specific doses	Anglers	0.018	<0.005	-	0.016	-	-
	Infant inhabitants and consumers of locally grown food	0.025	-	0.025	-	<0.005	-
Wylfa							
***Total dose* – all sources**	**Adult occupants over sediment**	**0.006**	**<0.005**	**<0.005**	**0.006**	**-**	**-**
Source specific doses	Seafood consumers	0.008	<0.005	-	0.006	-	-
	Infant inhabitants and consumers of locally grown food	0.006	-	0.006	-	<0.005	-

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

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

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

Table 4.2(a) Concentrations of radionuclides in food and the environment near Berkeley and Oldbury nuclear power stations, 2018

Material	Location	No. of sampling observations	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}					
			^{3}H	^{14}C	^{99}Tc	^{137}Cs	^{238}Pu	^{239}Pu + ^{240}Pu
Marine samples								
Salmon	Beachley	1				0.10		
Elvers	River Severn	1				<0.10		
Mullet	Guscar	1	<25			0.23		
Salmon	Severn Beach	1				0.10		
Shrimps	Guscar	2	<25	14		0.21	0.00018	0.0017
Seaweed	2 km south west of Berkeley	2[E]			<1.4	<1.4		
Sediment	0.5 km south of Oldbury	2[E]				13		
Sediment	2 km south west of Berkeley	2[E]				16		
Sediment	Sharpness	2[E]				11		
Sediment	Ledges	2[E]				11		
Seawater	2 km south west of Berkeley	2[E]	<3.0			<0.24		

Material	Location	No. of sampling observations	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}				
			^{241}Am	^{242}Cm	^{243}Cm + ^{244}Cm	Gross alpha	Gross beta
Marine samples							
Salmon	Beachley	1	<0.22				
Elvers	River Severn	1	<0.11				
Mullet	Guscar	1	<0.21				
Salmon	Severn Beach	1	<0.22				
Shrimps	Guscar	2	0.0018	*	*		
Seaweed	2 km south west of Berkeley	2[E]	<0.70				
Sediment	0.5 km south of Oldbury	2[E]	<1.4				
Sediment	2 km south west of Berkeley	2[E]	<1.1				
Sediment	Sharpness	2[E]	<1.0				
Sediment	Ledges	2[E]	<1.2				
Seawater	2 km south west of Berkeley	2[E]	<0.32			<2.1	6.9

Material	Location or selection[b]	No. of sampling observations[c]	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}					
			^{3}H	^{14}C	^{35}S	^{137}Cs	Gross alpha	Gross beta
Terrestrial samples								
Milk		4	<4.5	18	<0.22	<0.04		
Milk	max		<5.5	21	<0.23	<0.05		
Potato		1	<6.3	21	0.40	<0.05		
Barley		1	<16	64	2.7	<0.08		
Freshwater	Gloucester and Sharpness Canal	2[E]	<2.8		<0.39	<0.23	<0.052	0.34

* *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, 2018

Location	Ground type	No. of sampling observations	μGy h^{-1}
Mean gamma dose rates at 1m over substrate			
0.5 km south of Oldbury	Mud and salt marsh	2	0.076
2 km south west of Berkeley	Mud and salt marsh	1	0.075
2 km south west of Berkeley	Mud	1	0.079
Guscar Rocks	Mud	1	0.082
Guscar Rocks	Mud and salt marsh	1	0.084
Lydney Rocks	Mud	1	0.097
Lydney Rocks	Mud and silt	1	0.098
Sharpness	Salt marsh	1	0.072
Sharpness	Mud and salt marsh	1	0.076
Ledges	Salt marsh	1	0.070
Ledges	Mud and salt marsh	1	0.082

Table 4.3(a) Concentrations of radionuclides in food and the environment near Bradwell nuclear power station, 2018

Material	Location	No. of sampling observations	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}				
			^{3}H	^{99}Tc	^{137}Cs	^{238}Pu	^{239}Pu + ^{240}Pu
Marine samples							
Skate	Pipeline	1			0.14		
Lobster	West Mersea	1			0.07		
Native oysters	Blackwater Estuary	1			<0.13	0.00028	0.0018
Samphire	Tollesbury	1		<0.061	<0.04		
Seaweed	Waterside	2[E]		<6.5	<0.62		
Seaweed	West Mersea	1[E]		<0.77	<1.3		
Sediment	Bradwell Pipeline	2[E]			3.2		
Sediment	Waterside	2[E]			3.6		
Sediment	N side Blackwater Estuary	2[E]			5.8		
Sediment	Maldon Harbour	2[E]			8.7		
Sediment	West Mersea Beach Huts	2[E]			<0.66		
Sediment	West Mersea Boatyard	2[E]			2.1		
Seawater	Bradwell Pipeline	2[E]	<2.8		<0.31		

Material	Location	No. of sampling observations	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}				
			^{241}Am	^{242}Cm	^{243}Cm + ^{244}Cm	Gross alpha	Gross beta
Marine samples							
Skate	Pipeline	1	<0.18				
Lobster	West Mersea	1	<0.15				
Native oysters	Blackwater Estuary	1	0.00085	*	0.0000093		
Samphire	Tollesbury	1	<0.15				
Seaweed	Waterside	2[E]	<0.78				
Seaweed	West Mersea	1[E]	<1.4				
Sediment	Bradwell Pipeline	2[E]	<0.86				
Sediment	Waterside	2[E]	<0.72				
Sediment	N side Blackwater Estuary	2[E]	<1.3				
Sediment	Maldon Harbour	2[E]	<0.69				
Sediment	West Mersea Beach Huts	2[E]	<0.61				
Sediment	West Mersea Boatyard	2[E]	<0.51				
Seawater	Bradwell Pipeline	2[E]	<0.36			<3.1	12

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		3	<3.9	14		<0.04	<0.24		
Milk	max		<6.0	19		<0.05	<0.44		
Cabbage		1	7.9	10		<0.04	<0.46		
Grass		1	<8.5	23		<0.11	<0.20		
Freshwater	Coastal ditch, between power station and shore	1[E]	<2.8		<0.022	<0.21		<0.59	4.3
Freshwater	Coastal ditch, east face of sector building	1[E]	5.4			<0.28		0.17	2.0
Freshwater	Coastal ditch, east face of turbine hall	1[E]	4.8		0.38	<0.21		0.45	3.1
Freshwater	Coastal ditch, drain pit overflow	2[E]	4.5			<0.20		<0.74	8.6

* *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, 2018

Location	Ground type	No. of sampling observations	μGy h^{-1}
Mean gamma dose rates at 1m over substrate			
Bradwell Beach	Mud and sand	1	0.064
Bradwell Beach	Sand and shingle	1	0.064
Bradwell Beach opposite power station N side of estuary	Mud and salt marsh	2	0.067
Waterside	Mud and pebbles	1	0.060
Waterside	Mud and silt	1	0.064
Maldon Harbour	Mud and salt marsh	2	0.061
West Mersea Beach Huts	Mud and pebbles	1	0.057
West Mersea Beach Huts	Pebbles and sand	1	0.051
SE of West Mersea boatyard	Mud	1	0.063
SE of West Mersea boatyard	Mud and shale	1	0.058

Table 4.4(a) Concentrations of radionuclides in food and the environment near Dungeness nuclear power stations, 2018

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		<0.06			0.13
Sole	Pipeline	1	<25	<25		<0.06			<0.05
Spiny Spider Crab	Pipeline	1	<25	<25		<0.11			<0.09
Scallop	Pipeline	1	<25	<25	21	<0.10	<0.018		<0.07
Sea kale	Dungeness Beach	1				<0.07			<0.04
Seaweed	Folkestone Harbour	2[E]				<0.62		<1.2	<0.45
Sediment	Rye Harbour	2[E]				<0.49	<2.0		<0.40
Sediment	Camber Sands	2[E]				<0.34	<1.9		<0.28
Sediment	Pilot Sands	2[E]				<0.34	<1.9		<0.26
Seawater	Dungeness South	2[E]		<3.5		<0.30			<0.25

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			<0.13				
Sole	Pipeline	1			<0.11				
Spiny Spider Crab	Pipeline	1			<0.14				
Scallop	Pipeline	1	0.00061	0.0032	0.0017	*	0.000090		
Sea kale	Dungeness Beach	1			<0.12				
Seaweed	Folkestone Harbour	2[E]			<0.56				
Sediment	Rye Harbour	2[E]	<0.45	<0.40	<0.83				570
Sediment	Camber Sands	2[E]			<0.46				
Sediment	Pilot Sands	2[E]			<0.42				
Seawater	Dungeness South	2[E]			<0.32			<3.2	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	^{60}Co	^{137}Cs	^{241}Am	Gross alpha	Gross beta
Terrestrial samples										
Milk		2	<5.0	16	<0.16	<0.05	<0.04	<0.13		
Milk	max		<7.0	17	<0.18			<0.15		
Potato		1	12	22	0.70	<0.05	<0.04	<0.10		
Wheat		1	<10	57	1.7	<0.07	<0.06	<0.14		
Grass	Lydd	2[E]	<15	<18		<2.3	<1.8			
Grass	Denge Marsh	2[E]	<17	<28		<1.4	<1.1			
Freshwater	Long Pits	2[E]	<2.8		<0.77	<0.29	<0.23		<0.022	0.095
Freshwater	Pumping station Well number 1	1[E]	<2.4		<0.40	<0.30	<0.30		<0.035	0.10

* *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, 2018

Location	Ground type	No. of sampling observations	μGy h^{-1}
Mean gamma dose rates at 1m over substrate			
Littlestone on Sea	Sand and silt	1	0.055
Littlestone on Sea	Sand and shingle	1	0.047
Greatstone on Sea	Mud	1	0.065
Greatstone on Sea	Sand and silt	1	0.051
Pilot Sands	Sand and silt	2	0.054
Dungeness West	Sand and shingle	1	0.047
Dungeness West	Shingle	1	0.049
Jury's Gap	Sand and silt	1	0.064
Jury's Gap	Pebbles and sand	1	0.057
Rye Bay	Sand and silt	1	0.061
Rye Bay	Pebbles and sand	1	0.055

Table 4.5(a) Concentrations of radionuclides in food and the environment near Hartlepool nuclear power station, 2018

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	23	<0.08		*	0.15	
Crabs	Pipeline	1	<25	<25	24	<0.04		*	<0.05	
Winkles	South Gare	2	<25	<25	25	<0.06		*	0.18	1.4
Seaweed	Pilot Station	2[E]				<0.63	2.6	6.7	<0.44	
Sediment	Old Town Basin	2[E]				<0.36			0.99	
Sediment	Seaton Carew	2[E]				<0.25			<0.30	
Sediment	Paddy's Hole	2[E]				<0.38			1.1	
Sediment	North Gare	2[E]				<0.23			<0.18	
Sediment	Greatham Creek	2[E]				<0.48			2.8	
Sediment	Redcar Sands	2[E]				<0.23			0.54	
Sea coal	Old Town Basin	2[E]				<0.45			<0.61	
Sea coal	Carr House Sands	2[E]				<0.44			<0.94	
Seawater[d]	North Gare	2[E]		<2.6		<0.34			<0.29	

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				<0.17				
Winkles	South Gare	2	12	0.0031	0.021	0.0093	0.000053	0.000043		
Seaweed	Pilot Station	2[E]				<0.56				
Sediment	Old Town Basin	2[E]				<0.50				
Sediment	Seaton Carew	2[E]				<0.39				
Sediment	Paddy's Hole	2[E]				<0.71				
Sediment	North Gare	2[E]				<0.36				
Sediment	Greatham Creek	2[E]				<0.78				
Sediment	Redcar Sands	2[E]				<0.39				
Sea coal	Old Town Basin	2[E]				<0.58				
Sea coal	Carr House Sands	2[E]				<0.61				
Seawater[d]	North Gare	2[E]				<0.35			<5.7	13

Material	Location or selection[b]	No. of sampling observations[c]	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}							
			^{3}H	^{14}C	^{35}S	^{60}Co	^{131}I	^{137}Cs	Gross alpha	Gross beta
Terrestrial samples										
Milk		2	<4.6	19	<0.19	<0.05	<0.91	<0.04		
Milk	max		5.0	20	<0.20	<0.06	<1.1	<0.05		
Potatoes		1	<4.0	23	0.50	<0.08	<0.10	<0.06		
Barley		1	<4.4	57	2.2	<0.07	<0.09	<0.04		
Grass	0.8 km NW of site	2[E]	<10	<6.2	3.1	<1.2		<0.96		
Grass	0.6 km NE of site	2[E]	<12	<3.6	5.4	<1.1		<0.87		
Freshwater	Boreholes, Dalton Piercy	2[E]	<2.6		<0.68	<0.28		<0.25	0.090	0.13

* *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 <0.45 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, 2018

Location	Ground type	No. of sampling observations	µGy h^{-1}
Mean gamma dose rates at 1m over substrate			
Fish Sands	Sand	2	0.063
Old Town Basin	Sand	1	0.069
Old Town Basin	Sand and seacoal	1	0.065
Carr House	Sand	1	0.064
Carr House	Sand and seacoal	1	0.060
Seaton Carew	Sand	2	0.060
North Gare	Sand	2	0.062
Paddy's Hole	Sand and pebbles	2	0.17
Greatham Creek nature reserve	Mud	2	0.079
Redcar Sands	Sand	1	0.064
Redcar Sands	Sand and pebbles	1	0.077

Table 4.6(a) Concentrations of radionuclides in food and the environment near Heysham nuclear power stations, 2018

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	<29	40	44	<0.08	0.033	<0.23	<0.67	3.0	<0.14
Shrimps[b]	Morecambe	2	<25	<25	54	<0.07	<0.038	0.53	<0.63	3.6	<0.16
Winkles[c]	Middleton Sands	2	340	370	46	<0.13	0.16	11	<0.99	2.1	<0.24
Mussels[d]	Morecambe	2	71	68	55	<0.06	0.14	6.9	<0.55	1.3	<0.20
Wildfowl	Morecambe	1				<0.08			<0.80	0.67	<0.17
Seaweed[e]	Half Moon Bay	2[E]				<0.73		250	<4.1	3.5	
Sediment	Half Moon Bay	2[E]				<0.58				54	
Sediment	Potts' Corner	2[E]				<0.39				13	
Sediment	Morecambe central beach	2[E]				<0.30				5.6	
Sediment	Red Nab Point	1[E]				<0.49				15	
Sediment	Shore adjacent to Northern Outfall	1[E]				<0.46				34	
Seawater[f]	Shore adjacent to Northern Outfall	2[E]		36		<0.44			<2.9	<0.36	

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	0.00084	0.0051		0.010	0.000045	0.000015		
Shrimps[b]	Morecambe	2	0.0054	0.035		0.058	*	*		
Winkles[c]	Middleton Sands	2	0.24	1.5	6.6	2.9	*	0.0030		150
Mussels[d]	Morecambe	2	0.17	1.0	4.6	1.8	*	0.0025		130
Wildfowl	Morecambe	1				<0.16				
Seaweed[e]	Half Moon Bay	2[E]				<2.1				
Sediment	Half Moon Bay	2[E]	6.5	43		88				
Sediment	Potts' Corner	2[E]				15				
Sediment	Morecambe central beach	2[E]				5.4				
Sediment	Red Nab Point	1[E]				14				
Sediment	Shore adjacent to Northern Outfall	1[E]				60				
Seawater[f]	Shore adjacent to Northern Outfall	2[E]				<0.38			<4.5	12

Table 4.6(a) continued

Material	Location or selection[g]	No. of sampling observ-ations[h]	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	<4.0	18	<0.25	<0.05	<0.48	<0.07		
Milk	max		<4.5		<0.35			<0.10		
Beetroot		1	<3.0	15	<0.10	<0.07	<0.67	<0.05		
Silage		1	<3.4	29	1.9	<0.06	<0.48	0.25		
Grass	Half Moon Bay, recreation ground	2[E]	<18	20	3.2	<1.1		<0.81		
Grass	Overton	2[E]	<18	13	<2.3	<1.1		<0.87		
Freshwater	Damas Gill reservoir	2[E]	<2.6	<5.3	<0.32	<0.24		<0.21	<0.028	<0.065
Freshwater	Lower Halton Weir	2[E]	<2.7	<2.8	<0.44	<0.34		<0.28	<0.021	0.058

* *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 4.7 Bq kg^{-1}*

[c] *The concentration of ^{210}Po was 13 Bq kg^{-1}*

[d] *The concentration of ^{210}Po was 35 Bq kg^{-1}*

[e] *The concentrations of ^{35}S was <6.9 Bq kg^{-1} and ^{129}I was 2.1 Bq kg^{-1}*

[f] *The concentrations of ^{35}S was <0.64 Bq kg^{-1}*

[g] *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*

[h] *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, 2018

Location	Ground type	No. of sampling observations	µGy h^{-1}
Mean gamma dose rates at 1m over substrate			
Sand Gate Marsh	Salt marsh	2	0.071
Arnside 2	Salt marsh	2	0.076
Morecambe central beach	Sand	2	0.060
Half Moon Bay	Sand	2	0.070
Pipeline	Sand	1	0.072
Red Nab Point	Sand and pebbles	1	0.060
Middleton sands	Sand	2	0.069
Sunderland Point	Mud and sand	1	0.078
Sunderland Point	Sand	1	0.082
Colloway Marsh	Salt marsh	2	0.10
Lancaster	Grass	1	0.072
Aldcliffe Marsh	Salt marsh	2	0.079
Conder Green	Salt marsh	2	0.078

Table 4.7(a) Concentrations of radionuclides in food and the environment near Hinkley Point nuclear power stations, 2018

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									
Mullet	Stolford	1	<25	<25	19	<0.08			0.25
Shrimps	Stolford	1	56	55	31	<0.07			0.15
Limpets	Stolford	1	<25	47	18	<0.14			<0.18
European Oyster	Stolford	1	<25	<25	6.4	<0.04			<0.03
Seaweed	Pipeline	2[E]				<0.88		<1.8	<0.64
Sediment	Pipeline	2[E]				<0.57	<1.9		4.0
Sediment	Stolford	2[E]				<1.7	<1.2		16
Sediment	Steart Flats	2[E]				<0.71	<1.6		10
Sediment	River Parrett	2[E]				<1.0	<1.2		17
Sediment	River Parrett Central 2	2[E]				<0.99	<1.1		8.6
Sediment	Weston-Super-Mare	2[E]				<0.41	<1.2		0.89
Sediment	Burnham-On-Sea	2[E]				<0.34	<1.0		0.95
Sediment	Kilve	2[E]				<0.31	<1.4		0.78
Sediment	Helwell Bay	2[E]				<0.46	<1.4		4.7
Sediment	Blue Anchor Bay	2[E]				<0.29	<0.98		0.79
Seawater	Pipeline	1[E]		15		<0.24	<0.045		<0.22

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									
Mullet	Stolford	1			<0.12				
Shrimps	Stolford	1	0.000082	0.00020	0.00024	*	*		
Limpets	Stolford	1			<0.17				
European Oyster	Stolford	1			<0.05				
Seaweed	Pipeline	2[E]			<0.82				
Sediment	Pipeline	2[E]			<0.78				
Sediment	Stolford	2[E]			<2.0				
Sediment	Steart Flats	2[E]			<0.88				
Sediment	River Parrett	2[E]			<2.0				
Sediment	River Parrett Central 2	2[E]			<1.6				
Sediment	Weston-Super-Mare	2[E]			<0.47				
Sediment	Burnham-On-Sea	2[E]			<0.54				
Sediment	Kilve	2[E]			<0.65				
Sediment	Helwell Bay	2[E]			<0.95				
Sediment	Blue Anchor Bay	2[E]			<0.57				
Seawater	Pipeline	1[E]			<0.31			<3.0	13

Table 4.7(a) continued

Material	Location or selection[b]	No. of sampling observ-ations[c]	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}							
			^{3}H	^{14}C	^{35}S	^{60}Co	^{137}Cs	^{241}Am	Gross alpha	Gross beta
Terrestrial samples										
Milk		2	<4.5	19	<0.35	<0.05	<0.04	<0.15		
Milk	max		<4.8	20	<0.38		<0.05	<0.17		
Blackberries		1	<3.7	25	0.90	<0.03	<0.02	<0.06		
Honey		1	<4.5	45	<0.20	<0.05	<0.06	<0.73		
Wheat		1	<5.5	53	1.0	<0.05	<0.04	<0.15		
Grass	Gunter's Grove	2[E]	<16	22		<1.4	<1.2			
Grass	Wall Common	2[E]	<13	22		<1.4	<1.2			
Freshwater	Durleigh Reservoir	2[E]	<2.7		<0.54	<0.30	<0.25		<0.046	0.16
Freshwater	Ashford Reservoir	2[E]	<2.6		<0.39	<0.29	<0.25		<0.023	0.089

* *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, 2018

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	0.064
Weston-super-Mare	Sand	1	0.067
Burnham-on-Sea	Sand	2	0.063
River Parrett	Mud	2	0.083
River Parrett Bridgwater Central 2	Mud	2	0.084
Steart Flats	Mud	2	0.078
Stolford	Mud	2	0.10
Hinkley Point	Mud and rock	1	0.093
Hinkley Point	Rock and shingle	1	0.10
Kilve	Rock and sand	2	0.094
Helwell Bay	Mud and rock	2	0.097
Blue Anchor Bay	Mud and sand	2	0.071

Table 4.8(a) Concentrations of radionuclides in food and the environment near Sizewell nuclear power stations, 2018

Material	Location	No. of sampling observations	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			<0.12	
Dover Sole	Sizewell	1	<25	<25			0.16	
Crabs	Sizewell	1	<25	<25			<0.07	
Mussels	River Alde	1	<25	<25	19		<0.15	0.00034
Sediment	Aldeburgh	2[E]				<1.8	<0.20	
Sediment	Southwold harbour	2[E]				<2.2	5.5	
Sediment	Minsmere river outfall	2[E]				<1.9	5.9	
Seawater	Sizewell beach	2[E]		<2.7	<3.3		<0.31	

Material	Location	No. of sampling observations	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		<0.14				
Dover Sole	Sizewell	1		<0.19				
Crabs	Sizewell	1		<0.23				
Mussels	River Alde	1	0.0022	0.0018	0.000024	0.000029		
Sediment	Aldeburgh	2[E]		<0.34				
Sediment	Southwold harbour	2[E]		<1.1				960
Sediment	Minsmere river outfall	2[E]		<0.53				
Seawater	Sizewell beach	2[E]		<0.36			<4.2	15

Material	Location or selection[b]	No. of sampling observations[c]	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}					
			^{3}H	^{14}C	^{35}S	^{137}Cs	Gross alpha	Gross beta
Terrestrial samples								
Milk		2	<3.6	20	<0.29	<0.05		
Milk	max		<4.4	21	<0.38			
Potatoes		1	<2.7	16	0.90	<0.06		
Barley		1	21	54	2.9	<0.05		
Grass	Sizewell belts	2[E]	<14	<9.2		<0.87		
Grass	Sizewell common	2[E]	<13	<14		<1.1		
Freshwater	Minsmere nature reserve	2[E]	<2.7		<0.76	<0.24	<0.066	0.20
Freshwater	The Meare	2[E]	<2.7		<0.81	<0.28	<0.055	0.29
Freshwater	Leisure Park	2[E]	<2.6		<0.81	<0.31	<0.046	0.36

[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, 2018

Location	Ground type	No. of sampling observations	μGy h^{-1}
Mean gamma dose rates at 1m over substrate			
Sizewell Beach	Sand and shingle	1	0.054
Sizewell Beach	Shingle and stones	1	0.048
Dunwich	Sand and shingle	1	0.051
Dunwich	Shingle	1	0.050
Aldeburgh	Sand and shingle	2	0.049
Southwold Harbour	Mud and silt	2	0.068

Table 4.9(a) Concentrations of radionuclides in food and the environment near Chapelcross nuclear power station, 2018

Material	Location	No. of sampling observ-ations	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											
Flounder	Inner Solway	2		21	<0.10	<0.10	0.28	0.17	<0.72	<0.11	<0.20
Salmon	Inner Solway	1	<5.0		<0.10		<0.35		<0.84	<0.12	<0.26
Sea trout	Inner Solway	1	<5.0		<0.10		<0.36		<0.83	<0.12	<0.24
Shrimps	Inner Solway	2	<5.7		<0.10	<0.10	<0.19	<0.40	<0.36	<0.10	<0.12
Cockles	North Solway	1			0.17		<0.46		<0.80	<0.16	<0.24
Mussels	North Solway	1	<5.0	19	<0.10	0.46	<0.31	25	<0.81	<0.16	<0.23
Fucus vesiculosus	Pipeline	4			<0.10		<0.15	48	<0.50	<0.10	<0.14
Fucus vesiculosus	Browhouses	2			<0.10		<0.15	31	<0.41	<0.10	<0.13
Fucus vesiculosus	Dornoch Brow	2			<0.10		<0.14	54	<0.36	<0.10	<0.13
Sediment	Priestside Bank	1			<0.10		<0.21		<0.70	<0.14	<0.23
Sediment	Pipeline	4	<5.0		<0.24		<0.23		<0.83	<0.12	<0.36
Sediment	Dornoch Brow	1			0.15		<0.25		<0.72	<0.12	<0.25
Sediment	Powfoot	1			<0.10		<0.20		<0.75	<0.14	<0.24
Sediment	Redkirk	1			<0.10		<0.27		<0.69	<0.13	<0.23
Sediment	Stormont	1			<0.10		<0.33		<0.79	<0.14	<0.28
Seawater	Pipeline	2	<1.7		<0.10		<0.10		<0.30	<0.10	<0.11

Material	Location	No. of sampling observ-ations	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										
Flounder	Inner Solway	2	<0.18	<0.12	<0.19	0.0026	0.0042	0.020		
Salmon	Inner Solway	1	0.13	<0.12	<0.22			<0.13		
Sea trout	Inner Solway	1	<0.10	<0.12	<0.20			<0.12		
Shrimps	Inner Solway	2	<0.10	<0.10	<0.11	<0.0035	0.0051	0.011		
Cockles	North Solway	1	3.5	<0.12	<0.21	0.76	4.6	12		
Mussels	North Solway	1	2.3	<0.12	<0.21	0.58	3.5	5.4		
Fucus vesiculosus	Pipeline	4	5.1	<0.10	<0.27	0.54	2.6	6.4	11	330
Fucus vesiculosus	Browhouses	2	2.9	<0.10	<0.12	0.42	2.3	5.1	5.9	230
Fucus vesiculosus	Dornoch Brow	2	5.8	<0.10	0.26	0.58	2.9	3.6	8.5	400
Sediment	Priestside Bank	1	21	<0.19	<0.31	1.8	11	30		
Sediment	Pipeline	4	98	<0.26	<0.57	13	77	150		
Sediment	Dornoch Brow	1	66	<0.20	0.99	9.9	58	110		
Sediment	Powfoot	1	23	<0.23	<0.35	2.3	16	31		
Sediment	Redkirk	1	38	<0.16	<0.22	4.0	21	43		
Sediment	Stormont	1	36	<0.21	<0.41	3.2	19	38		
Seawater	Pipeline	2	<0.10	<0.10	<0.10			<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	^{90}Sr	^{95}Nb	^{106}Ru	^{137}Cs	^{155}Eu	^{241}Am	Gross alpha	Gross beta
Terrestrial samples													
Milk		10	<6.7	<15	<0.50	<0.10	<0.12	<0.22	<0.05		<0.05		
Milk	max		27		<0.60		<0.31	<0.41					
Apples		1	<5.0	16	<0.50	<0.10	<0.06	<0.14	<0.05		<0.05		
Beef		1	<5.0	<15	<0.73	<0.10	<0.47	<0.38	<0.05		<0.09		
Cabbage		1	<5.0	<15	<0.50		<0.35	<0.22	<0.05		<0.05		
Carrots		1	<5.0	16	<0.50	0.13	<0.47	<0.29	0.06		<0.05		
Cauliflower		1	<5.0	26	<0.50	<0.10	<0.12	<0.28	<0.05		<0.05		
Duck		2	<5.0	25	<0.50	<0.10	<0.19	<0.31	0.21				
Duck	max			27			<0.31	<0.46	0.29		<0.06		
Goose		1	<5.0	31	<0.61	<0.10	<0.28	<0.37	0.28		<0.09		
Leeks		1	<5.0	17	<0.50	0.10	<0.34	<0.36	<0.05		<0.05		
Onion		1	<5.0	<15	<0.50	<0.10	<0.09	<0.23	<0.05		<0.05		
Pork		1	<5.0	38	<0.50	<0.10	<0.08	<0.19	<0.05		<0.05		
Potatoes		1	<5.0	<15	<0.50	<0.10	<0.10	<0.26	0.05		<0.05		
Rosehips		1	<5.0	18	<0.50	0.40	<0.13	<0.27	<0.05		<0.10		
Turnip		1	<5.0	<15	<0.50	0.16	<0.32	<0.35	<0.05		<0.05		
Grass		4	<11	<15	<0.50	0.21	<0.08	<0.23	<0.07	<0.07	<0.07	2.2	340
Grass	max		28			0.30	<0.12	<0.29	0.09	<0.092	<0.09	2.8	470
Soil		3	<8.0	15	<1.6	1.1	<0.27	<0.51	7.9	1.7	<0.28	210	1600
Soil	max		15		2.3	1.9	<0.33	<0.60	12	2.0	0.36		1800
Freshwater	Purdomstone	1	<1.0				<0.01	<0.03	<0.01		<0.01	<0.010	0.050
Freshwater	Winterhope	1	<1.0				<0.01	<0.04	<0.01		<0.01	<0.010	0.049
Freshwater	Black Esk	1	<1.0				<0.01	<0.03	<0.01		<0.01	<0.010	0.018
Freshwater	Gullielands Burn	1	14				<0.01	<0.03	<0.01		<0.01	<0.011	0.22

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

Table 4.9(b) Monitoring of radiation dose rates near Chapelcross, 2018

Location	Material or ground type	No. of sampling observations	μGy h^{-1}
Mean gamma dose rates at 1m over substrate			
Glencaple Harbour	Sand	2	0.062
Priestside Bank	Salt marsh	2	0.055
Powfoot Merse	Sand	2	0.061
Gullielands	Grass	1	0.056
Seafield	Sand	2	0.080
Woodhead	Grass	1	0.059
East Bretton	Grass	1	0.057
Pipeline	Salt marsh	2	0.066
Pipeline	Sediment	2	0.073
Dumbretton	Grass	1	0.057
Battlehill	Sand	2	0.066
Dornoch Brow	Sand	2	0.082
Dornoch Brow	Salt marsh	2	0.070
Browhouses	Sand	2	0.077
Redkirk	Sediment	2	0.065
Stormont	Sand	2	0.063
Mean beta dose rates			μSv h^{-1}
Pipeline	Skate nets	3	<1.0
500 m East of pipeline	Sediment	1	<1.0
500 m West of pipeline	Sediment	1	<1.0

Table 4.9(c) Radioactivity in air near Chapelcross, 2018

Location	No. of sampling observations	Mean radioactivity concentration, mBq m^{-3}			
		^{131}I	^{137}Cs	Gross alpha	Gross beta
Eastriggs	10	<0.042	<0.010	<0.014	<0.20
Kirtlebridge	9	<0.032	<0.010	<0.012	<0.20
Brydekirk	9	<0.020	<0.010	0.013	<0.20

Table 4.10(a) Concentrations of radionuclides in food and the environment near Hunterston nuclear power station, 2018

Material	Location	No. of sampling observations	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}						
			^{3}H	^{35}S	^{54}Mn	^{60}Co	^{95}Nb	^{99}Tc	^{110m}Ag
Marine samples									
Cod	Millport	2			<0.10	<0.10	<0.13		<0.10
Hake	Millport	2			<0.10	<0.10	<0.33		<0.10
Crabs	Millport	2			<0.10	<0.10	<0.28	<0.3	<0.10
Nephrops	Millport	2			<0.10	<0.10	<0.26		<0.10
Lobsters	Largs	1			<0.10	<0.10	<0.10	16	<0.10
Mussels	Pipeline	1			<0.10	<0.10	<0.21		<0.10
Squat lobsters	Largs	2			<0.11	<0.10	<1.1	5.0	<0.13
Winkles	Pipeline	2			<0.14	<0.12	<0.87		0.80
Scallops	Largs	2			<0.10	<0.10	<0.46		<0.11
Oysters	Hunterston	1			<0.10	<0.10	<0.21		0.17
Fucus vesiculosus	N of pipeline	2			<0.24	0.25	<0.51		<0.10
Fucus vesiculosus	S of pipeline	2			0.25	0.15	<0.65		<0.11
Sediment	Largs	1			<0.10	<0.10	<0.10		<0.10
Sediment	Millport	1			<0.10	<0.10	<0.11		<0.10
Sediment	Gull's Walk	1			<0.10	<0.10	<0.54		<0.10
Sediment	Ardneil Bay	1			<0.10	<0.10	<0.10		<0.10
Sediment	Fairlie	1			<0.10	<0.10	<0.19		<0.10
Sediment	Pipeline	1			<0.10	<0.10	<0.36		<0.10
Sediment	Ardrossan North Bay	1			<0.10	<0.10	<0.20		<0.10
Sediment	Ardrossan South Bay	1			<0.10	<0.10	<0.16		<0.10
Seawater	Pipeline	2	3.6	<0.57	<0.10	<0.10	<0.10		<0.10

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
Marine samples								
Cod	Millport	2	0.85	<0.10	<0.11			<0.10
Hake	Millport	2	0.63	<0.10	<0.12			<0.12
Crabs	Millport	2	0.15	<0.10	<0.10	0.012	0.049	0.047
Nephrops	Millport	2	0.39	<0.10	<0.10			<0.10
Lobsters	Largs	1	0.25	<0.10	<0.10			<0.10
Mussels	Pipeline	1	<0.10	<0.10	<0.17			<0.11
Squat lobsters	Largs	2	0.17	<0.11	<0.16	0.0072	0.030	0.029
Winkles	Pipeline	2	0.19	<0.10	<0.14	0.072	0.23	0.082
Scallops	Largs	2	0.18	<0.10	<0.14	0.038	0.089	0.15
Oysters	Hunterston	1	<0.10	<0.10	<0.10			<0.10
Fucus vesiculosus	N of pipeline	2	0.50	<0.10	<0.17			<0.21
Fucus vesiculosus	S of pipeline	2	0.28	<0.10	<0.16			<0.14
Sediment	Largs	1	7.7	<0.10	<0.11			<0.12
Sediment	Millport	1	3.6	<0.10	<0.10			0.45
Sediment	Gull's Walk	1	6.4	<0.12	<0.22			0.81
Sediment	Ardneil Bay	1	2.0	<0.10	<0.15			<0.17
Sediment	Fairlie	1	4.9	<0.10	<0.13			<0.17
Sediment	Pipeline	1	2.5	<0.15	<0.30			0.38
Sediment	Ardrossan North Bay	1	2.1	<0.10	<0.19			0.26
Sediment	Ardrossan South Bay	1	2.4	<0.10	<0.11			0.66
Seawater	Pipeline	2	<0.10	<0.10	<0.11			<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	^{90}Sr	^{95}Nb	^{137}Cs	^{155}Eu	^{241}Am	Gross alpha	Gross beta
Terrestrial samples													
Milk			2	<5.0	<16	<0.50	<0.10	<0.11	<0.05		<0.05		
Milk		max			26			<0.15	0.07				
Apples			2	<5.0	21	<0.50	<0.10	<0.25	<0.05		<0.07		
Apples		max			23			<0.32			<0.08		
Beef			1	<5.0	36	<0.50	<0.10	<0.20	0.25		<0.08		
Beetroot			1	<5.0	<15	<0.50	<0.10	<0.08	<0.05		<0.05		
Brussel Sprouts			1	5.9	<15	<0.50	0.10	<0.05	<0.05		<0.05		
Cabbage			1	<5.0	<15	<0.50	<0.10	<0.08	<0.05		<0.05		
Carrots			1	<5.0	17	<0.50	<0.10	<0.05	<0.05		<0.05		
Eggs			1	<5.0	28	<0.50	<0.10	<0.30	<0.05		<0.06		
Honey			1	<5.0	97	<0.62	<0.10	<0.05	1.8		<0.06		
Lamb			1	<5.0	37	<0.50	<0.10	<0.19	0.89		<0.08		
Pheasant			1	<5.0	18	<0.50	<0.10	<0.09	0.44		<0.09		
Potatoes			1	<5.0	<15	<0.50	<0.10	<0.10	0.06		<0.05		
Rosehips			1	<5.0	29	<0.50	0.44	<0.07	0.09		<0.06		
Turnips			1	<5.0	<15	<0.50	0.24	<0.08	<0.05		<0.05		
Grass			3	<5.0	<20	<0.64	0.49	<0.13	0.15	<0.11	<0.11	2.7	270
Grass		max			23	0.78	1.0	<0.16	0.27	<0.12	<0.13	3.5	300
Grass[d]			3	<5.0	<20	<0.50	<0.24	<0.24	<0.59	<0.11	<0.10	1.8	250
Grass		max			33		0.50	<0.37	3.0		<0.13	4.3	410
Soil			3	<5.0	<15	<0.62	0.70	<0.17	9.5	0.64	<0.18	130	890
Soil		max				<0.85	1.0	<0.27	12	0.82	<0.21	170	1200
Freshwater	Knockenden Reservoir		1	<1.0				<0.01	<0.01		<0.01	<0.01	0.025
Freshwater	Loch Ascog		1	<1.0				<0.01	<0.01		<0.01	<0.01	0.10
Freshwater	Munnoch Reservoir		1	<1.0				<0.01	<0.01		<0.01	<0.01	0.095
Freshwater	Camphill		1	<1.0				<0.01	<0.01		<0.01	<0.01	0.05
Freshwater	Outerwards		1	<1.0				<0.01	<0.01		<0.01	<0.01	0.038

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

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

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

[d] *Substitute samples taken in lieu of unavailable milk samples*

Table 4.10(b) Monitoring of radiation dose rates near Hunterston nuclear power station, 2018

Location	Ground type	No. of sampling observations	µGy h^{-1}
Mean gamma dose rates at 1m over substrate			
Meigle Bay	Sand	2	0.054
Largs Bay	Pebbles	2	0.063
Kilchatten Bay	Sand	2	<0.048
Millport	Sand	2	<0.047
Gull's Walk	Sand	2	0.051
Hunterston	Sand	2	<0.052
0.5 km north of pipeline	Sand	2	<0.055
0.5 km south of pipeline	Sand	2	<0.056
Portencross	Grass	1	<0.047
Ardneil Bay	Sand	2	<0.047
Ardrossan North Bay	Sand	2	<0.047
Ardrossan South Bay	Sand	2	<0.047
Milstonford	Grass	1	0.052
Biglies	Grass	1	<0.057
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, 2018

Location	No. of sampling observations	Mean radioactivity concentration, mBq m^{-3}			
		^{131}I	^{137}Cs	Gross alpha	Gross beta
Fairlie	10	<0.031	<0.010	0.012	<0.20
West Kilbride	10	<0.017	<0.010	<0.015	<0.20
Low Ballees	11	<0.029	<0.010	0.010	<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	^{99}Tc	^{110m}Ag	^{137}Cs
Marine samples								
Cod	White Sands	2	<0.10	<0.10	<0.16		<0.10	0.18
Mackerel	Pipeline	2	<0.10	<0.10	<0.18		<0.10	<0.11
Crabs[d]	Torness	1	<0.10	<0.10	<0.10	<0.24	<0.10	<0.10
Lobsters	Torness	1	<0.10	<0.10	<0.10	<0.46	<0.10	<0.10
Nephrops	Dunbar	2	<0.10	<0.10	<0.19		<0.10	<0.12
Winkles	Pipeline	2	0.60	0.35	<0.27		7.5	<0.18
Fucus vesiculosus	Pipeline	2	2.7	0.62	<0.15		1.1	<0.11
Fucus vesiculosus	Thorntonloch	2	1.0	0.24	<0.16	11	0.49	<0.10
Fucus vesiculosus	White Sands	2	<0.10	<0.10	<0.16		<0.10	<0.10
Fucus vesiculosus	Coldingham Bay	2	<0.10	<0.10	<0.17		<0.10	<0.10
Fucus vesiculosus	Pease Bay	2	<0.10	<0.10	<0.13		<0.10	<0.10
Sediment	Dunbar	1	<0.10	<0.10	<0.35		<0.16	1.9
Sediment	Barns Ness	1	<0.10	<0.10	<0.25		<0.12	1.5
Sediment	Thorntonloch	1	<0.10	<0.10	<0.17		<0.10	0.58
Sediment	Heckies Hole	1	<0.10	<0.10	<0.24		<0.12	1.1
Sediment	Belhaven Bay	1	<0.10	<0.10	<0.20		<0.10	0.30
Sediment	Coldingham Bay	1	<0.10	<0.10	<0.18		<0.10	0.71
Sediment	Pease Bay	1	<0.10	<0.10	<0.25		<0.12	1.4
Seawater[e]	Pipeline	2	<0.10	<0.10	<0.11		<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	<0.14			<0.10		
Mackerel	Pipeline	2	<0.14			<0.11		
Crabs[d]	Torness	1	<0.10			<0.10		
Lobsters	Torness	1	<0.10			<0.10		
Nephrops	Dunbar	2	<0.16	0.00080	0.0040	0.013		
Winkles	Pipeline	2	<0.19			<0.11	3.7	110
Fucus vesiculosus	Pipeline	2	<0.12			<0.11		
Fucus vesiculosus	Thorntonloch	2	<0.14			<0.15		
Fucus vesiculosus	White Sands	2	<0.13			<0.13		
Fucus vesiculosus	Coldingham Bay	2	<0.13			<0.12		
Fucus vesiculosus	Pease Bay	2	<0.10			<0.10		
Sediment	Dunbar	1	<0.31			<0.34		
Sediment	Barns Ness	1	<0.24			<0.28		
Sediment	Thorntonloch	1	<0.19			<0.18		
Sediment	Heckies Hole	1	<0.24			<0.26		
Sediment	Belhaven Bay	1	<0.18			<0.18		
Sediment	Coldingham Bay	1	<0.25			<0.25		
Sediment	Pease Bay	1	<0.20			<0.23		
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	<16	<0.50	<0.05	<0.10	<0.11
Milk	max			<17				<0.13
Beetroot		1	<5.0	16	<0.50	<0.05	0.18	<0.11
Carrots		1	<5.0	18	<0.50	<0.05	0.18	<0.06
Eggs		1	<5.0	27	0.58	<0.05	<0.10	<0.06
Honey		1	<5.0	62	<0.73	<0.05	<0.10	<0.06
Parsnips		1	<5.0	31	<0.50	<0.06	0.20	<0.14
Partridge		1	<5.0	22	<0.50	<0.05	<0.10	<0.05
Pheasant		1	<5.0	23	<0.50	<0.05	<0.10	<0.07
Pigeon		1	<5.0	24	<0.50	<0.05	<0.10	<0.05
Pork		1	<5.0	<15	<0.59	<0.05	<0.10	<0.53
Potatoes		1	<5.0	19	<0.50	<0.05	<0.10	<0.05
Rosehips		1	<5.0	25	<0.50	<0.05	0.30	<0.12
Turnip		1	5.4	18	<0.50	<0.05	0.26	<0.07
Venison		1	<5.0	25	<0.50	<0.05	<0.10	<0.05
Wild mushrooms		1	<5.0	15	<0.50	<0.05	<0.10	<0.29
Grass		3	<5.0	27	<0.74	<0.05	0.27	<0.16
Grass	max			44	<0.94		0.40	<0.20
Soil		3	<6.3	<21	<2.7	<0.05	0.75	<0.29
Soil	max		9.0	34	5.6		0.99	<0.30
Freshwater	Hopes Reservoir	1	<1.0			<0.01		<0.01
Freshwater	Thorter's Reservoir	1	<1.0			<0.01		<0.01
Freshwater	Whiteadder	1	<1.1			<0.01		<0.01
Freshwater	Thornton Loch Burn	1	<1.0			<0.01		<0.01

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		
Milk	max							
Beetroot		1	<0.05	<0.05		<0.05		
Carrots		1	<0.05	<0.05		<0.05		
Eggs		1	<0.05	<0.05		<0.07		
Honey		1	<0.05	2.0		<0.09		
Parsnips		1	<0.07	0.07		<0.07		
Partridge		1	<0.05	<0.05		<0.05		
Pheasant		1	<0.05	<0.05		<0.06		
Pigeon		1	<0.05	<0.05		<0.08		
Pork		1	<0.05	<0.05		<0.05		
Potatoes		1	<0.05	<0.05		<0.05		
Rosehips		1	<0.05	<0.05		<0.08		
Turnip		1	<0.05	<0.05		<0.05		
Venison		1	<0.05	0.30		<0.05		
Wild mushrooms		1	<0.06	0.10		<0.07		
Grass		3	<0.05	<0.06	<0.10	<0.11	2.7	390
Grass	max		<0.06	<0.08	<0.13	<0.16	4.1	440
Soil		3	<0.09	6.6	1.7	<0.18	240	1400
Soil	max		<0.10	8.2	1.9	<0.19	260	1500
Freshwater	Hopes Reservoir	1	<0.01	<0.01		<0.01	<0.010	0.034
Freshwater	Thorter's Reservoir	1	<0.01	<0.01		<0.01	<0.010	0.031
Freshwater	Whiteadder	1	<0.01	<0.01		<0.01	<0.010	0.045
Freshwater	Thornton Loch Burn	1	<0.01	<0.01		<0.01	0.011	0.071

[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 19 Bq kg^{-1}*
[e] *The concentrations of ^{3}H and ^{35}S were <1.0 and <0.5 Bq l^{-1}, respectively*

Table 4.11(b) Monitoring of radiation dose rates near Torness nuclear power station, 2018

Location	Ground type	No. of sampling observations	μGy h^{-1}
Mean gamma dose rates at 1m over substrate			
Heckies Hole	Sand	2	0.062
Dunbar Inner Harbour	Sand	2	0.073
Belhaven Bay	Salt marsh	2	<0.048
Barns Ness	Sediment	2	<0.047
Skateraw	Sediment	2	<0.049
Thorntonloch	Grass	1	0.064
Thorntonloch beach	Sand	2	<0.047
Ferneylea	Grass	1	0.065
Pease Bay	Sand	2	0.057
St Abbs Head	Sand	2	0.092
Coldingham Bay	Sand	2	0.051
West Meikle Pinkerton	Grass	1	0.063
Mean beta dose rates on fishing gear			μSv h^{-1}
Torness	Lobster Pots	1	<1.0
Torness	Nets	1	<1.0

Table 4.11(c) Radioactivity in air near Torness, 2018

Location	No. of sampling observations	Mean radioactivity concentration, mBq m^{-3}				
		^{60}Co	^{131}I	^{137}Cs	Gross alpha	Gross beta
Innerwick	12	<0.010	<0.033	<0.010	<0.010	<0.20
Cockburnspath	12	<0.010	<0.028	<0.010	<0.011	<0.20
West Barns	10	<0.010	<0.032	<0.010	0.016	<0.20

Table 4.12(a) Concentrations of radionuclides in food and the environment near Trawsfynydd nuclear power station, 2018

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		24	<0.13	0.30	<0.09	1.5	<0.31
Sediment	Pipeline	2[E]			<1.1	<0.90	<0.98	500	
Sediment	Lake shore near café	2[E]			<0.57	<0.84	<0.64	410	
Sediment	1.5 km SE of power station	1[E]			<0.56	<1.1	<0.48	300	
Sediment	SE of footbridge	1[E]			<1.8	<1.1	<1.8	640	
Sediment	Cae Adda	2[E]			<0.48	<0.83	<0.54	240	
Freshwater	Pipeline	2[E]	<2.7		<0.34		<0.34	<0.28	
Freshwater	Gwylan Stream	1[E]	<2.4		<0.24		<0.24	<0.22	
Freshwater	Afon Prysor	2[E]	<2.7		<0.32		<0.37	<0.28	
Freshwater	1.5 km SE of power station	2[E]	<2.7		<0.11		<0.12	<0.10	
Freshwater	Afon Tafarn-helyg	2[E]	<2.6		<0.33		<0.34	<0.28	

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	0.000021	0.00011	0.00024	*	*		
Sediment	Pipeline	2[E]	2.2	6.7	12				
Sediment	Lake shore near café	2[E]	<0.67	1.8	<2.4				
Sediment	1.5 km SE of power station	1[E]	0.41	0.96	2.2				
Sediment	SE of footbridge	1[E]	0.83	4.4	11				
Sediment	Cae Adda	2[E]	<0.33	<0.57	<1.6				
Freshwater	Pipeline	2[E]						<0.040	0.045
Freshwater	Gwylan Stream	1[E]						<0.029	0.11
Freshwater	Afon Prysor	2[E]						<0.038	<0.12
Freshwater	1.5 km SE of power station	2[E]						<0.041	<0.046
Freshwater	Afon Tafarn-helyg	2[E]						<0.060	0.055

Material	Selection[c]	No. of sampling observ-ations[d]	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}							
			^{3}H	^{14}C	^{90}Sr	^{137}Cs	Total Cs	^{238}Pu	^{239}Pu + ^{240}Pu	^{241}Am
Terrestrial samples										
Milk		2	<3.6	17	<0.038	<0.09	<0.092			<0.13
Milk	max		4.6	19	0.057	0.10	<0.14			<0.17
Potatoes		1	<2.6	24		<0.09		0.000034	0.00045	0.00032
Silage		1	<2.5	76		0.77		0.000030	0.00028	0.00036

* *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, 2018

Location	Ground type	No. of sampling observations	μGy h^{-1}
Mean gamma dose rates at 1m over substrate			
Lake shore (pipeline)	Rock	1	0.094
Lake shore (pipeline)	Stones	1	0.089
Lake shore (SE of footbridge)	Rock	1	0.10
Lake shore (SE of footbridge)	Stones	1	0.10
Lake shore (1.5 km SE)	Rock	1	0.085
Lake shore (1.5 km SE)	Stones	1	0.083
Cae Adda	Rock	1	0.088
Cae Adda	Stones	1	0.080
Lake shore	Stones	2	0.096

Table 4.13(a) Concentrations of radionuclides in food and the environment near Wylfa nuclear power station, 2018

Material	Location	No. of sampling observations	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}						
			Organic ^{3}H	^{3}H	^{14}C	^{99}Tc	^{137}Cs	^{238}Pu	^{239}Pu + ^{240}Pu
Marine samples									
Plaice	Pipeline	1	<25	<25	26		0.59		
Crabs	Pipeline[d]	1	<25	<25	40		0.31		
Lobsters	Pipeline[d]	1	<25	<25	29	7.2	0.22	0.00030	0.0025
Winkles	Cemaes Bay	1	<25	<25	28	8.2	0.36	0.021	0.15
Seaweed	Cemaes Bay	2[E]				22	<0.51		
Sediment	Cemaes Bay	2[E]					3.3		
Sediment	Cemlyn Bay West	1[E]					1.8		
Seawater	Cemaes Bay	2[E]		<2.8			<0.28		

Material	Location	No. of sampling observations	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}					
			^{241}Pu	^{241}Am	^{242}Cm	^{243}Cm + ^{244}Cm	Gross alpha	Gross beta
Marine samples								
Plaice	Pipeline	1		<0.17				
Crabs	Pipeline[d]	1		<0.19				
Lobsters	Pipeline[d]	1	<0.42	0.0068	*	*		96
Winkles	Cemaes Bay	1	0.37	0.17	*	*		110
Seaweed	Cemaes Bay	2[E]		<0.65				
Sediment	Cemaes Bay	2[E]		1.2				
Sediment	Cemlyn Bay West	1[E]		<0.42				
Seawater	Cemaes Bay	2[E]		<0.34			<2.7	11

Material	Location or selection[b]	No. of sampling observations[c]	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}				
			^{3}H	^{14}C	^{35}S	^{137}Cs	^{241}Am
Terrestrial samples							
Milk		2	<3.0	18	<0.23	<0.05	<0.18
Milk	max		<5.6	24	<0.60		<0.23
Potatoes		1	<3.1	22	0.50	<0.07	<0.17
Silage		1	<2.9	46	7.4	0.23	<0.42
Grass	Foel Fawr	1[E]	<12	<2.6		<0.78	
Grass	Wylfa Head Nature Reserve	2[E]	<18	<23		<0.88	

* *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*

[d] *Data for natural radionuclides for some of these samples may be available in Table 7.6*

[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, 2018

Location	Ground type	No. of sampling observations	µGy h^{-1}
Mean gamma dose rates at 1m over substrate			
Cemaes Bay	Sand	2	0.073
Cemlyn Bay East	Pebbles	1	0.075
Cemlyn Bay West	Sand and pebbles	1	0.066
Porth Yr Ogof	Sand	1	0.089
Porth Yr Ogof	Sand and pebbles	1	0.070

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 discharges at its sites (including low level gaseous discharges from Burghfield, Berkshire). Monitoring at nuclear submarine berths is also conducted by the MoD (e.g. Dstl, 2019).

In 2018, 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 2018 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 5 per cent of the dose limit for all sites assessed

Aldermaston, Berkshire

- *Total dose* for the representative person was 0.010 mSv and unchanged in 2018

Barrow, Cumbria

- *Total dose* for the representative person was 0.046 mSv and decreased in 2018

Derby, Derbyshire

- *Total dose* for the representative person was less than 0.005 mSv and unchanged in 2018

Devonport, Devon

- *Total dose* for the representative person was less than 0.005 mSv and unchanged in 2018

Faslane and Coulport, Argyll and Bute

- *Total dose* for the representative person was 0.008 mSv in 2018

Rosyth, Fife

- *Total dose* for the representative person was 0.010 mSv and decreased in 2018

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).

Gaseous and liquid discharges are regulated by the Environment Agency, permitting discharges of low concentrations of radioactive waste to the environment. In June 2018, the Environment Agency granted a variation in the site permit. The permit variation increased the annual permitted limit for gaseous volatile beta discharges from 4.4E+06 Bq to 1.0E+08 Bq.

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 2018, the *total dose* from all pathways and sources of radiation was 0.010 mSv (Table 5.1), or 1 per cent of the dose limit, and unchanged from 2017. The representative person was adults living near to the site.

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 2018 (Table 5.1). Estimates of activity concentrations in fish have been based on shellfish samples from the aquatic monitoring programme for the dose determination. A low consumption rate of 1 kg per year for fish has been included in the dose assessment for anglers.

Gaseous discharges and terrestrial monitoring

Gaseous radioactive waste is discharged via stacks on the site. In 2018, carbon-14 discharges were reported as nil (as in 2017). 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 2018 are given in Table 5.2(a). In 2018, tritium concentrations and other radionuclides in foodstuffs (including milk) were very low or reported as less than values. Tritium is considered in the dose assessment and is of very low significance. In 2018, caesium-137 concentrations were positively detected in soil samples and were generally similar, in comparison to those in 2017 (where comparisons can be drawn at the same location). Caesium-137 concentrations in all food and grass samples are reported as less than values in 2018. Concentrations of uranium isotopes in 2018 were generally similar to those values in 2017. Natural background or fallout concentrations from nuclear weapons testing would have made a significant contribution to the detected values.

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. A time-series trend of generally decreasing tritium discharges from Aldermaston (2007– 2018) is shown in Figure 5.1. Tritium discharges have declined more significantly, over a longer period in comparison to the last decade (Figure 5.1, Environment Agency, FSA, FSS, NIEA, NRW and SEPA, 2018). The longer-term decline in discharges is due to the replacement of the original tritium facility (the replacement facility uses sophisticated abatement technology that has 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 in order 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). The Environment Agency continued their enhanced environmental monitoring of sediments and freshwater samples in 2018 (as in 2017 and 2016). The concentrations of artificial radioactivity detected in the Thames catchment were very low and generally similar to those in 2017. In 2018, tritium concentrations in freshwater and terrestrial samples were all reported as less than values. As in recent years, iodine-131 was not positively detected in food samples in 2018, but was positively detected at a very low concentration in a sediment sample (at Mapledurham). Prior to 2017, iodine-131 has been routinely 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 very low in 2018 and similar to those reported in 2017. Analyses of caesium-137 and uranium activity concentrations in River Kennet sediments were broadly consistent with those in recent years. In 2018, caesium-137 concentrations in gully pot samples were reported as less than values (or just above the less than value). Tritium concentrations in freshwater samples were all reported as less than values. 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 discharges were reported as nil and liquid discharges were reported well below permitted limits in 2018. The FSA's terrestrial monitoring is limited to vegetable and grass (or silage) 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 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 cover the disposals of liquid radioactive waste arising from the flushing of the primary circuit from submarines which contain refurbished main coolant pumps. The first disposal of the flush water occurred in 2017.

The *total dose* from all pathways and sources of radiation was 0.046 mSv (Table 5.1) in 2018, or less than 5 per cent of the dose limit, and down from 0.074 mSv in 2017. The representative person was adults living on a local houseboat. The decrease in *total dose* was mostly due to lower gamma dose rate over sand (Roa Island) in 2018. Virtually all of this dose was due to the effects of Sellafield discharges.

Source specific assessments for a high-rate consumer of locally grown food and a person living on a local

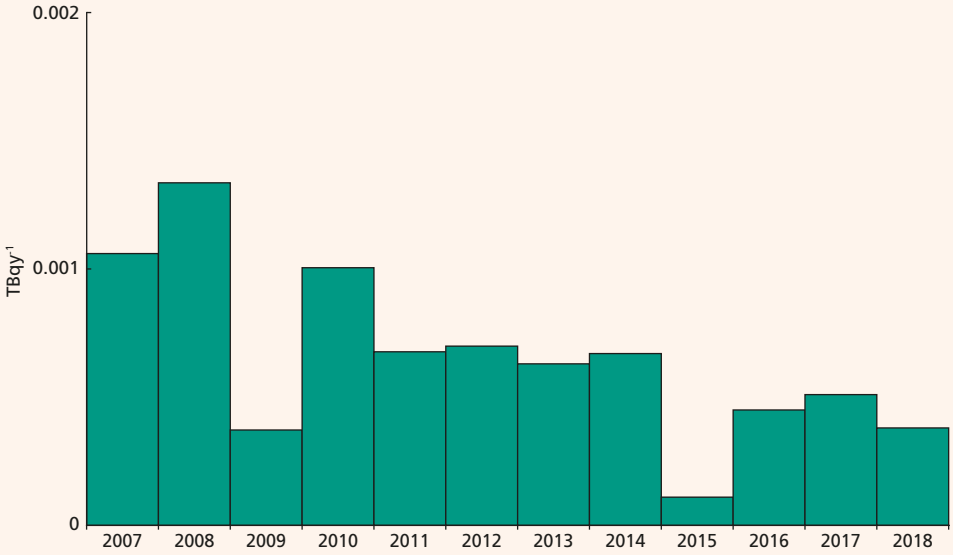


Figure 5.1. Trends in liquid discharges of tritium from Aldermaston, Berkshire 2007-2018
(including discharges to River Thames at Pangbourne, Silchester sewer and Aldermaston Stream)

houseboat give exposures that were less than the *total dose* in 2018 (Table 5.1). No assessment of seafood consumption was undertaken in 2018 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 (Environment Agency, FSA, NIEA, NRW and SEPA, 2014).

In 2018, the reported gross beta concentration in sediment (in the vicinity of the discharge point) was higher in 2018, in comparison to those in previous years (Table 5.3(a)). Dose rates in intertidal areas near Barrow were lower in 2018, but enhanced above those expected due to natural background (Table 5.3(b) and Table 2.9). Any enhancement above natural background is most likely due to the far-field effects of historical discharges from Sellafield. No effects of discharges from Barrow were apparent in the concentrations of radioactivity in vegetables and grass, most 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 at Raynesway. 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

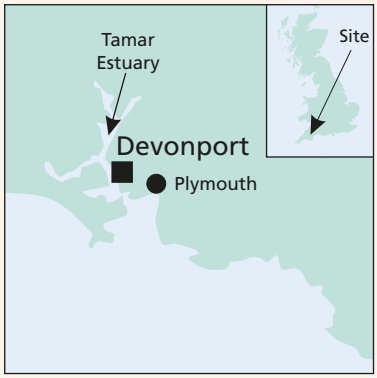
The *total dose* from all pathways and sources of radiation was less than 0.005 mSv in 2018 (Table 5.1), which is less than 0.5 per cent of the dose limit, and unchanged from 2017. Source specific assessments for consumption of vegetables, fish and drinking river water at high-rates, and for a local resident exposed to external and inhalation pathways from gaseous discharges, give exposures that were also less than 0.005 mSv in 2018 (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 2018 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 nuclear weapons testing).

Table 5.3(a) also includes analytical results for a water sample taken from Fritchley Brook, downstream of Hilts Quarry, near Crich in Derbyshire. RRMPOL formerly used the quarry for the controlled burial of solid low level

radioactive waste. Concentrations of uranium isotopes detected in the sample in 2018 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.

The most recent habits survey to determine the consumption and occupancy rates by members of the public was undertaken in 2017 (Moore *et al.*, 2018b). The routine monitoring programme in 2018 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 in 2018 (Table 5.1), which was less than 0.5 per cent of the dose limit, and unchanged from 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 annual *total doses* (2007 – 2018) 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 in 2018 (Table 5.1) which was less than 0.5 per cent of the dose limit for members of the public of 1 mSv.

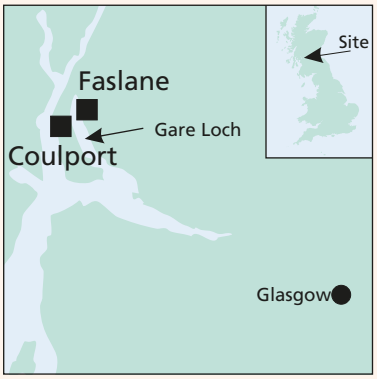
Gaseous discharges and terrestrial monitoring

Discharges of carbon-14 decreased in 2018, in comparison to those releases in 2017, probably due to the periodic nature of routine submarine refit operations. Samples of grass and vegetables were analysed for a number of radionuclides, and most activity concentrations in terrestrial samples are reported as less than values in 2018.

Liquid waste discharges and marine monitoring

Discharges to the Hamoaze in 2018 were similar to those releases in 2017. The trends of tritium and cobalt-60 discharges with time (2007 – 2018) 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. Cobalt-60 discharges have declined more significantly than tritium, since the early 2000s (Figure 5.2, Environment Agency, FSA, FSS, NIEA, NRW and SEPA, 2018). The underlying reason for the overall decrease in cobalt-60 discharges over nearly three decades has been 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. Low caesium-137 concentrations, likely to originate from other sources (such as nuclear weapons testing), were measured in sediment samples. Carbon-14 concentrations in seafood species were generally similar to those in recent years. Iodine-131 was not detected in fish and shellfish samples in 2018. Gamma dose rates in the vicinity of Devonport in 2018, were similar to those in 2017, 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

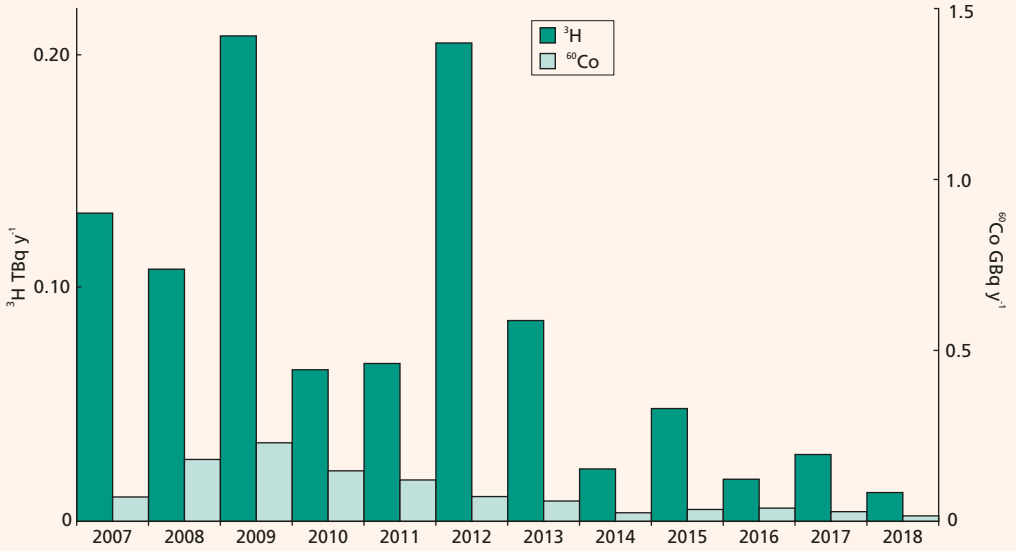


Figure 5.2. Trends in liquid discharges of tritium and cobalt-60 from Devonport, Devon 2007-2018

undertaking, through the Naval Base Commander, Clyde (NBC Clyde) in relation to radioactive waste disposal. MoD through NBC Clyde also remains in control of the undertaking at Coulport although many of the activities undertaken at Coulport have been outsourced to an industrial alliance comprising of AWE plc, Babcock and Lockheed Martin UK (known as ABL).

The construction of a new radioactive waste treatment facility at Faslane continued this year and is expected to be completed in 2021.

Discharges of liquid radioactive waste, into the Gare Loch from Faslane and the discharge of gaseous radioactive waste in the form of tritium to the atmosphere from Coulport, are made under a Letter of Agreement (LoA) between SEPA and the MoD. During 2018, SEPA received an application to include the disposal of general effluents in the current LoA, containing very low levels of tritium, for liquid discharges from Faslane. In 2018, gaseous tritium discharges (from Coulport) were similar, and liquid tritium discharges (from Faslane) were lower, in comparison to those releases in 2017. (Appendix 2, Tables A2.1 and A2.2, respectively).

The disposal of solid radioactive waste from each site is made under a separate LoA between SEPA and the MoD. There were no solid waste transfers from Faslane in 2018 (see Appendix 2, Table A2.4). A small amount of waste was transferred between Coulport and Faslane.

The most recent habits survey to determine the consumption and occupancy rates by members of the public was undertaken in 2016 (Dale *et al.*, 2019b).

The *total dose* from all pathways and sources of radiation was 0.008 mSv in 2018 (Table 5.1), which is less than 1 per cent of the dose limit, compared with less than 0.005 mSv in 2017. The representative person was adults consuming fish at high-rates. Activity concentrations in fish (not collected in 2018) were estimated using reported environmental fish data, sampled outside the aquatic habits survey area of this site (but within the Firth of Clyde). The change in *total dose* was mostly due to the inclusion of a less than value of americium-241 concentrations in fish. Therefore, the assessment of the *total dose* in 2018 is conservative. In 2018, 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 0.010 mSv and less than 0.005 mSv, respectively. The reason for the change in dose (from 0.005 mSv in 2017) 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, wild blackberries, water, grass and soil sampling. The results in 2018 are given in Tables 5.3(a) and (b) and were generally similar to those in 2017. Caesium-137 was positively detected at a low concentration in honey (as in 2017). Radionuclide concentrations were generally reported as less than values in 2018. The amercium-241 concentration was higher (by small amounts) in mollusc samples (winkles) in 2018, in comparison to that in 2017. Caesium-137 concentrations in sediment are consistent with the distant effects of discharges from Sellafield, fallout from Chernobyl and nuclear weapons testing.

Gamma dose rates measured in the surrounding area were difficult to distinguish from natural background. Tritium, gross alpha and gross beta concentrations in freshwater were much lower than the investigation levels in the European Directive 2013/51.

5.6 Holy Loch, Argyll and Bute

A small programme of monitoring at Holy Loch continued during 2018 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 similar to those values reported in 2017. The most recent habits survey to determine the consumption and occupancy rates by members of the public was undertaken in 1989 (Thurston and Gough, 1992).

The external radiation dose to a person spending time on the loch shore was 0.009 mSv in 2018, which was less than 1 per cent of the dose limit for members of the public of 1 mSv (Table 5.1), and unchanged from 2017.

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, 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 at the dockyard site. A LoA (effective from 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 LoA and new authorisation to RRDL has permitted 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 both the Rosyth and Devonport naval sites.

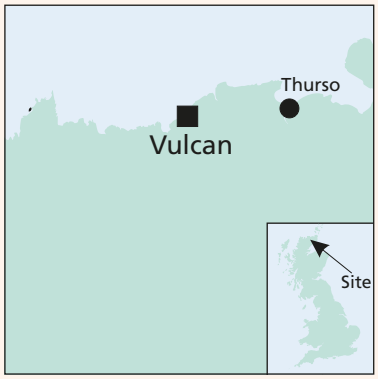
The *total dose* from all pathways and sources of radiation was 0.010 mSv in 2018 (Table 5.1), which was 1 per cent of the dose limit, and down from 0.026 mSv in 2017. In 2018, the representative person was adults who spend a large amount of time over marine sediments. The decrease in *total dose* from 2017 was mostly due to lower gamma dose rates over sand observed in 2018. The source specific assessment for marine pathways (fishermen and beach users) was estimated to be 0.013 mSv in 2018 (from 0.026 mSv in 2017). The reason for the decrease in dose is the same as that contributing to the maximum *total dose*.

The gaseous and liquid discharges from the site in 2018 are given in Appendix 2 (Tables A2.1 and A2.2, respectively), and solid waste transfers in Table A2.4. Gaseous discharges from Rosyth are reported as nil (as in 2017). 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 2017, and in most part due to the combined effects of Sellafield, weapon testing and Chernobyl. Gamma dose rates were lower, in comparison to those in 2017, and difficult to distinguish from natural background in 2018. The most recent habits survey was undertaken in 2015 and the results were incorporated in the dose assessments given above (Tyler *et al.*, 2016*).*

5.8 Vulcan NRTE, Highland



The Vulcan Naval Reactor Test Establishment is operated by the Submarine Delivery Agency, 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 2018 are given in Appendix 2 (Table A2.1 and Table A2.4, respectively).

Table 5.1 Individual doses – defence sites, 2018

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**	**-**	**<0.005**	**-**	**-**	**<0.005**	**0.010**
Source specific doses	Anglers	<0.005	<0.005	-	<0.005	-	-	-
	Infant inhabitants and consumers of locally grown food	<0.005	-	<0.005	-	-	<0.005	-
	Workers at Silchester STW	<0.005	-	-	<0.005	<0.005	-	-
Barrow								
***Total dose* – all sources**	**Adult occupants on houseboats[g]**	**0.046**	**-**	**-**	**0.046**	**-**	**-**	**-**
Source specific doses	Houseboat occupants	0.045	-	-	0.045	-	-	-
	Consumers of locally grown food	<0.005	-	<0.005	-	-	-	-
Derby								
***Total dose* – all sources**	**Adult consumers of locally sourced water**	**<0.005**	**<0.005**	**-**	**<0.005**	**<0.005**	**-**	**-**
Source specific doses	Anglers consuming fish and drinking water[f]	<0.005	<0.005	-	<0.005	<0.005	-	-
	Children Inhabitants and consumers of locally grown food	<0.005	-	<0.005	-	-	<0.005	-
Devonport								
***Total dose* – all sources**	**Adult 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**	**0.008**	**0.006**	**-**	**<0.005**	**-**	**-**	**-**
Source specific doses	Seafood consumers	0.010	0.007	-	<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**	**0.010**	**<0.005**	**-**	**0.010**	**-**	**-**	**-**
Source specific doses	Fishermen and beach users	0.013	<0.005	-	0.010	-	-	-

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

Table 5.2(a) Concentrations of radionuclides in food and the environment near Aldermaston, 2018

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	<1.2	<0.10			
Signal crayfish	Ufton Bridge - Theale	1	<25	<25	*	0.072	0.041	0.0012	0.032
Sediment	Pangbourne	2[E]				<0.72	16	<1.0	18
Sediment	Mapledurham	2[E]			2.3	21	12	<0.63	11
Sediment	Aldermaston	4[E]				4.3	24	<1.2	23
Sediment	Spring Lane	4[E]				<2.8	16	<1.0	16
Sediment	Stream draining south	4[E]				<0.82	32	1.4	32
Sediment	Near Chamber 39 of PPL	4[E]				3.1	12	<0.87	11
Sediment	Oval pond near Chamber 14	4[E]				1.9	17	<1.1	16
Sediment	River Kennet	4[E]				2.4	12	<0.78	12
Sediment	Hosehill Lake	2[E]				2.2	31	1.8	27
Gullypot sediment	Falcon Gate	1[E]		<24		<2.4	19	1.2	21
Gullypot sediment	Main Gate	1[E]		<21		<1.4	14	0.56	15
Gullypot sediment	Tadley Entrance	1[E]		<25		5.5	15	<0.46	16
Gullypot sediment	Burghfield Gate	1[E]		<34		<1.4	20	0.77	19
Freshwater	Pangbourne	2[E]		<2.6		<0.29	0.011	<0.0017	0.0070
Freshwater	Mapledurham	2[E]		<2.5		<0.26	0.011	<0.0022	0.0066
Freshwater	Aldermaston	4[E]		<2.7		<0.28	0.0078	<0.0012	0.0053
Freshwater	Spring Lane	4[E]		<2.7		<0.32	<0.0024	<0.0014	<0.0018
Freshwater	Stream draining south	4[E]		<2.6		<0.25	<0.0030	<0.0011	<0.0023
Freshwater	Near Chamber 39 of PPL	4[E]		<2.6		<0.27	0.0069	<0.0017	<0.0049
Freshwater	Oval pond near Chamber 14	4[E]		<2.7		<0.24	<0.0022	<0.0014	<0.0015
Freshwater	River Kennet	4[E]		<2.7		<0.26	<0.0060	<0.0018	<0.0042
Freshwater	Hosehill Lake	4[E]		<2.7		<0.28	0.011	<0.0021	0.0063
Crude liquid effluent	Silchester treatment works	2[E]		<3.8		<0.23	<0.0032	<0.0015	<0.0022
Final Liquid effluent	Silchester treatment works	2[E]		<4.0		<0.30	<0.0040	<0.0010	<0.0028
Sewage sludge	Silchester treatment works	2[E]		<8.3		<0.24	3.2	<0.15	2.4

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			<0.22				
Signal crayfish	Ufton Bridge - Theale	1	0.000020	0.000056	0.000072	*	*		
Sediment	Pangbourne	2[E]	<0.72	<1.0	<1.2			370	530
Sediment	Mapledurham	2[E]	<0.38	0.40	<0.62			190	290
Sediment	Aldermaston	4[E]	<0.35	4.4	<1.1			310	620
Sediment	Spring Lane	4[E]	<0.42	0.46	<0.78			250	480
Sediment	Stream draining south	4[E]	<0.49	<0.31	<0.64			400	940
Sediment	Near Chamber 39 of PPL	4[E]	<0.39	<0.31	<0.72			<140	290
Sediment	Oval pond near Chamber 14	4[E]	<0.49	<0.44	<0.63			190	520
Sediment	River Kennet	4[E]	<0.36	<0.36	<0.69			<160	260
Sediment	Hosehill Lake	2[E]	<0.57	<0.45	<0.46			300	570
Gullypot sediment	Falcon Gate	1[E]	<0.36	<0.21	<2.3			250	740
Gullypot sediment	Main Gate	1[E]	<0.18	0.30	<1.5			230	520
Gullypot sediment	Tadley Entrance	1[E]	<0.36	<0.26	<1.6			250	830
Gullypot sediment	Burghfield Gate	1[E]	<0.83	<0.64	<1.5			250	600
Freshwater	Pangbourne	2[E]	<0.0028	<0.0016	<0.0048			<0.046	0.32
Freshwater	Mapledurham	2[E]	<0.0041	<0.0026	<0.0063			<0.058	0.28
Freshwater	Aldermaston	4[E]	<0.0039	<0.0030	<0.0043			<0.039	0.24
Freshwater	Spring Lane	4[E]	<0.0054	<0.0034	<0.0047			<0.028	0.16
Freshwater	Stream draining south	4[E]	<0.0027	<0.0024	<0.0045			<0.037	0.17
Freshwater	Near Chamber 39 of PPL	4[E]	<0.0021	<0.0014	<0.0042			<0.046	0.10
Freshwater	Oval pond near Chamber 14	4[E]	<0.0019	<0.0017	<0.0057			<0.029	0.086
Freshwater	River Kennet	4[E]	<0.0056	<0.0029	<0.0040			<0.040	0.11
Freshwater	Hosehill Lake	4[E]	<0.0023	<0.0017	<0.0054			<0.047	0.42
Crude liquid effluent	Silchester treatment works	2[E]	<0.0026	<0.0022	<0.35			0.081	0.64
Final Liquid effluent	Silchester treatment works	2[E]	<0.0043	<0.0032	<0.39			<0.061	0.63
Sewage sludge	Silchester treatment works	2[E]	<0.027	<0.020	<0.35			<9.3	14

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	<3.5	<0.04	0.017	<0.00073	0.015
Milk	max		<4.0	<0.05	0.030	0.0010	0.025
Potatoes		1		<0.06	0.0065	0.00044	0.0075
Wheat		1		<0.06	0.0041	0.00040	0.0034
Grass	Black Pightle, Perimeter fence	1[E]	<22	<4.5	<1.4	<0.80	<1.1
Grass	Kestrel Meads	1[E]	<13	<0.62	0.26	<0.16	0.23
Grass	Tadley, Perimeter fence	1[E]	<13	<1.7	<1.2	<0.97	<1.1
Grass	Young's Industrial Estate	1[E]	<16	<1.1	0.53	<0.056	0.42
Soil	Black Pightle, Perimeter fence	1[E]	<11	14	23	<1.5	21
Soil	Kestrel Meads	1[E]	<8.8	3.0	16	0.66	19
Soil	Tadley, Perimeter fence	1[E]	<13	2.4	18	<1.3	14
Soil	Young's Industrial Estate	1[E]	<8.2	2.2	12	<0.7	13

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	<0.000025	0.000020	<0.000044		
Milk	max		<0.000026	0.000021	<0.000047		
Potatoes		1	0.000043	0.00034	0.00063		
Wheat		1	0.000013	0.000066	0.00023		
Grass	Black Pightle, Perimeter fence	1[E]	<0.23	<0.15		5.8	140
Grass	Kestrel Meads	1[E]	<0.070	0.052		6.3	210
Grass	Tadley, Perimeter fence	1[E]	<0.088	<0.043			
Grass	Young's Industrial Estate	1[E]	<0.091	<0.067		4.7	190
Soil	Black Pightle, Perimeter fence	1[E]	<0.45	0.54		200	350
Soil	Kestrel Meads	1[E]	<0.34	<0.28		<130	410
Soil	Tadley, Perimeter fence	1[E]	<0.42	<0.21		260	370
Soil	Young's Industrial Estate	1[E]	<0.35	0.32		130	380

* *Not detected by the method used*

[a] *Except for milk, sewage effluent and water where units are Bq l^{-1}, and for sediment and soil where dry concentrations apply (except for those marked with a # which are fresh concentrations)*

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

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

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

Table 5.2(b) Monitoring of radiation dose rates near Aldermaston, 2018

Location	Ground type	No. of sampling observations	µGy h^{-1}
Mean gamma dose rates at 1m over substrate			
Pangbourne, riverbank	Grass	2	0.068
Mapledurham, riverbank	Grass and mud	1	0.062
Mapledurham, riverbank	Sand	1	0.063

Table 5.3(a) Concentrations of radionuclides in food and the environment near defence establishments, 2018

Material	Location or selection[a]	No. of sampling observations	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]		<2.2		<0.10	<0.19	<0.23	<2.3	<0.09
Silage	Barrow	1[F]		<2.9		<0.05	<2.0	<0.13	*	0.52
Sediment	Walney Channel - N of discharge point	2				<0.41	<0.39	<1.5		84
Derby										
Potatoes	Derby	1[F]				<0.09	<0.15	<0.15	<2.2	<0.07
Wheat	Derby	1[F]				<0.10	<0.62	<0.15	*	<0.10
Sediment	River Derwent, upstream	1				<0.36				2.3
Sediment	Fritchley Brook	1				<0.35				
Sediment	River Derwent, downstream	4				<1.6				4.6
Water	River Derwent, upstream	1				<0.38				
Water[c]	Fritchley Brook	1		<2.5		<0.40				<0.33
Water	River Derwent, downstream	4				<0.35				
Devonport										
Ballan wrasse	Plymouth Sound	1[F]	<25	<25	23	<0.02	<0.17	<0.05	*	0.14
Crabs	Plymouth Sound	1[F]			34	<0.09	<2.1	<0.18	*	<0.14
Shrimp	River Lynher	1[F]			22	<0.07	<0.25	<0.17	*	<0.07
Mussels	River Lynher	1[F]	<25	<25	20	<0.18	<0.98	<0.42	*	<0.14
Seaweed[d]	Kinterbury	2				<0.73				
Sediment[e]	Kinterbury	2		<18		<0.76				1.7
Sediment	Torpoint South	2		<8.0		<0.64				
Sediment	Lopwell	2		<52		<1.3				2.7
Seawater	Torpoint South	1		<3.0	<3.0	<0.25				
Seawater	Millbrook Lake	1		<2.7	<3.4	<0.25				
Sludge	Camel's Head Sewage Treatment Works	1		<14		<0.54				
Carrot		1[F]		<2.1		<0.05	<0.05	<0.10	<0.11	<0.07
Oats and Barley		1[F]		<9.6		<0.08	<1.3	<0.35	*	<0.10
Faslane										
Mussels	Rhu	1				<0.10	<0.18	<0.13		0.27
Winkles	Rhu	1				<0.10	<0.28	<0.13		0.48
Fucus vesiculosus	Garelochhead	1				<0.10	<0.25	<0.11		0.28
Fucus vesiculosus	Carnban	1				<0.10	<0.41	<0.18		0.20
Fucus vesiculosus	Rhu	1				<0.10	<0.41	<0.18		0.29
Fucus vesiculosus	Cairndhu Point	1				<0.10	<0.48	<0.11		0.34
Fucus vesiculosus	Helensburgh	1				<0.10	<0.22	<0.10		0.51
Sediment	Garelochhead	1				<0.10	<0.25	<0.17		3.5
Sediment	Carnban	1				<0.10	<0.20	<0.15		1.4
Sediment	Rhu	1				<0.10	<0.31	<0.17		4.2
Seawater	Carnban	2		<2.3		<0.10	<0.10	<0.11		<0.10
Beef muscle	Faslane	1				<0.05	<0.17			<0.05
Honey	Faslane	1				<0.05	<0.49			2.3
Wild Blackberries	Faslane	1				<0.05	<0.05			
Grass	Auchengaich Reservoir	1		<5.0		<0.05	<0.10			0.35
Grass	Lochan Ghlas Laoigh	1		<5.0		<0.05	<0.10			0.53
Soil	Auchengaich	1		<5.0		<0.13	<1.0			25
Soil	Lochan Ghlas Laoigh	1		<5.0		<0.13	<1.0			25
Freshwater	Helensburgh Reservoir	1		<1.0		<0.01	<0.01			<0.01
Freshwater	Loch Finlas	1		<1.0		<0.01	<0.01			<0.01
Freshwater	Auchengaich Reservoir	1		<1.0		<0.01	<0.01			<0.01
Freshwater	Lochan Ghlas Laoigh	1		<1.0		<0.01	<0.01			<0.01

Table 5.3(a) continued

Material	Location or selection[a]	No. of sampling observations	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
Freshwater	Loch Eck	1		<1.0		<0.01	<0.02			<0.01
Freshwater	Loch Lomond	1		<1.0		<0.01	<0.01			<0.01
Holy Loch										
Sediment	Mid-Loch	1				<0.10	<0.10	<0.19		3.8
Rosyth										
Mackerel	Rosyth	1				<0.10	<0.31	<0.22		<0.10
Winkles	St David's Bay	1				<0.10	<0.33	<0.13		0.16
Fucus vesiculosus	East of dockyard	1				<0.10	<0.18	<0.10		<0.10
Sediment	East of dockyard	1				<0.10	<0.26	<0.15		1.8
Sediment	Port Edgar	1				<0.10	<0.34	<0.13		5.4
Sediment	West of dockyard	1				<0.10	<0.52	<0.14		1.5
Sediment	East Ness Pier	1				<0.10	<0.25	<0.14		3.7
Sediment	Blackness Castle	1				<0.10	<0.13	<0.10		1.2
Sediment	Charlestown Pier	1				<0.10	<0.10	<0.10		0.63
Seawater	East of dockyard	2		<1.0		<0.10	<0.10	<0.10		<0.10
Freshwater	Castlehill Reservoir	1		<1.0		<0.01	<0.01			<0.01
Freshwater	Holl Reservoir	1		<1.0		<0.01	<0.01			<0.01
Freshwater	Gartmorn Dam	1		<1.0		<0.01	<0.01			<0.01
Freshwater	Morton No. 2 Reservoir	1		<1.0		<0.01	<0.01			<0.01

Material	Location or selection[a]	No. of sampling observations	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]	<0.21	<0.24				<0.14		
Silage	Barrow	1[F]	<0.15	<0.25				<0.82		
Sediment	Walney Channel - N of discharge point	2	<1.0	<0.87				230	510	1600
Derby										
Potatoes	Derby	1[F]	<0.26	<0.26	<0.00042	0.00032	0.0017	<0.17		
Wheat	Derby	1[F]	<0.24	<0.18	0.024	0.0014	0.021	<0.14		
Sediment	River Derwent, upstream	1			14	0.96	16		140	570
Sediment	Fritchley Brook	1			21	0.91	21		<120	590
Sediment	River Derwent, downstream	4			36	1.8	35		430	670
Water	River Derwent, upstream	1							0.040	0.14
Water[c]	Fritchley Brook	1			0.0088	<0.0015	0.0062		<0.033	0.15
Water	River Derwent, downstream	4							<0.070	0.18
Devonport										
Ballan wrasse	Plymouth Sound	1[F]	<0.08	<0.05				<0.03		
Crabs	Plymouth Sound	1[F]	<0.28	<0.17				<0.17		
Shrimp	River Lynher	1[F]	<0.24	<0.16				<0.21		
Mussels	River Lynher	1[F]	<0.51	<0.26				<0.24		
Seaweed[d]	Kinterbury	2								
Sediment[e]	Kinterbury	2						<0.56		
Sediment	Torpoint South	2								
Sediment	Lopwell	2								
Seawater	Torpoint South	1								
Seawater	Millbrook Lake	1								
Sludge	Camel's Head Sewage Treatment Works	1								
Carrot		1[F]	<0.13	<0.21				<0.42		
Oats and Barley		1[F]	<0.25	<0.38				<1.7		

Table 5.3(a) continued

Material	Location or selection[a]	No. of sampling observations	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	<0.10				0.10		
Winkles	Rhu	1	<0.10	<0.10				0.17		
Fucus vesiculosus	Garelochhead	1	<0.10	<0.11				<0.10		
Fucus vesiculosus	Carnban	1	<0.10	<0.16				<0.10		
Fucus vesiculosus	Rhu	1	<0.10	<0.16				<0.11		
Fucus vesiculosus	Cairndhu Point	1	<0.10	<0.10				<0.10		
Fucus vesiculosus	Helensburgh	1	<0.10	<0.12						
Sediment	Garelochhead	1	<0.13	0.72				0.49		
Sediment	Carnban	1	<0.13	0.48				<0.25		
Sediment	Rhu	1	<0.15	0.55				0.85		
Seawater	Carnban	2	<0.10	<0.11				<0.10		
Beef muscle	Faslane	1						<0.11		
Honey	Faslane	1						<0.08		
Wild Blackberries	Faslane	1						<0.05		
Grass	Auchengaich Reservoir	1		<0.12				<0.11		
Grass	Lochan Ghlas Laoigh	1		<0.10				<0.09		
Soil	Auchengaich	1		2.1				<0.25		
Soil	Lochan Ghlas Laoigh	1		1.7				<0.25		
Freshwater	Helensburgh Reservoir	1						<0.01	<0.010	0.065
Freshwater	Loch Finlas	1						<0.01	<0.010	0.039
Freshwater	Auchengaich Reservoir	1						<0.01	<0.010	0.015
Freshwater	Lochan Ghlas Laoigh	1						<0.01	0.011	0.035
Freshwater	Loch Eck	1						<0.01	<0.010	0.049
Freshwater	Loch Lomond	1						<0.01	<0.010	0.028
Holy Loch										
Sediment	Mid-Loch	1	<0.20	<0.26				0.47		
Rosyth										
Mackerel	Rosyth	1	<0.12	<0.20				<0.12		
Winkles	St David's Bay	1	<0.10	<0.10				<0.10		
Fucus vesiculosus	East of dockyard	1	<0.10	<0.10				<0.10		
Sediment	East of dockyard	1	<0.11	0.59				<0.18		
Sediment	Port Edgar	1	<0.14	<0.22				0.86		
Sediment	West of dockyard	1	<0.13	<0.25				<0.20		
Sediment	East Ness Pier	1	<0.13	<0.26				<0.23		
Sediment	Blackness Castle	1	<0.10	<0.10				<0.12		
Sediment	Charlestown Pier	1	<0.10	<0.10				<0.10		
Seawater	East of dockyard	2	<0.10	<0.10				<0.10		
Freshwater	Castlehill Reservoir	1						<0.01	<0.010	0.066
Freshwater	Holl Reservoir	1						<0.01	<0.010	0.028
Freshwater	Gartmorn Dam	1						<0.01	<0.010	0.088
Freshwater	Morton No. 2 Reservoir	1						<0.01	<0.010	0.054

* *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 <0.00085, <0.0022 and <0.0020 Bq l^{-1}, respectively*

[d] *The concentration of ^{99}Tc was <2.7 Bq kg^{-1}*

[e] *The concentrations of ^{238}Pu and $^{239+240}$Pu were <0.35 and 0.40 Bq kg^{-1}, respectively*

[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, 2018

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	Mud and sand	3	0.077
Barrow	Walney Channel, N of discharge point	Sand and silt	1	0.072
Devonport	Torpoint South	Mud and rock	1	0.10
Devonport	Torpoint South	Sand and stones	1	0.091
Devonport	Kinterbury Access Gate	Mud	1	0.077
Devonport	Kinterbury Access Gate	Sand and stones	1	0.079
Devonport	Lopwell	Mud	1	0.097
Devonport	Lopwell	Mud and shingle	1	0.074
Faslane	Garelochhead	Sand	2	0.053
Faslane	Gulley Bridge Pier	Sediment	2	0.058
Faslane	Rhu	Sediment	2	0.055
Faslane	Helensburgh	Sediment	2	0.063
Faslane	Carnban	Shingle	2	0.067
Faslane	Rahane	Sediment	2	0.064
Faslane	Rosneath Bay	Sediment	2	0.055
Faslane	Auchengaich	Grass	1	0.060
Faslane	Lochan Ghlas	Grass	1	0.074
Holy Loch	Kilmun Pier	Sediment	1	0.063
Holy Loch	Mid-Loch	Sediment	1	0.066
Holy Loch	North Sandbank	Sediment	1	0.063
Rosyth	Blackness Castle	Sediment	2	0.056
Rosyth	Charlestown Pier	Sand	2	<0.051
Rosyth	East Ness Pier	Sediment	2	<0.052
Rosyth	East of Dockyard	Rocks	2	0.056
Rosyth	Port Edgar	Sediment	2	0.074
Rosyth	West of Dockyard	Sediment	2	0.053

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 both sites at Amersham and Cardiff. This has resulted in a revised monitoring programme, taking effect from the second half of 2018, with reductions in sampling (including collection of fewer milk samples per year for bulk analyses) and the analysis of some foods representing a very low radiological risk.

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 continuing to carry out a project which will de-license approximately half of the site (release from regulatory control). The project is supported by ONR and aims to remove 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 less than 15 per cent of the annual dose limit in 2018

GE Healthcare Limited, Grove Centre, Amersham, Buckinghamshire

- *Total dose* for the representative person was 0.14 mSv and down in 2018
- Gaseous discharges of radon-222 decreased in 2018

Maynard Centre, Cardiff

- *Total dose* for the representative person was less than 0.005 mSv and unchanged in 2018

Doses to the public

The *total dose* from all pathways and sources of radiation was 0.14 mSv in 2018 (Table 6.1) or 14 per cent of the dose limit, and down from 0.15 mSv in 2017. The small decrease in *total dose* was mostly due to a lower modelled concentration of radon-222 in the gaseous plume in 2018 (in comparison to that in 2017). 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 2018. 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 annual *total dose* over the period 2007 – 2018 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 2018 (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 0.008 mSv, or less than 1 per cent of the dose limit to members of the public of 1 mSv, and lower than the dose in 2017 (0.011 mSv). As in previous years, atmospheric discharges of radon-222 remain the dominant contributor

in 2018 and the reason for the decrease in dose is the same as that contributing to the maximum total dose. It should be noted that the current assessment methodology uses a conservative dose factor based on this nuclide being in equilibrium with its decay products. The dose to a local angler was less than 0.005 mSv in 2018.

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 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 in 2018.

Gaseous discharges and terrestrial monitoring

The Amersham facility is permitted to discharge gaseous radioactive wastes via stacks on the site. Discharges of radon-222 decreased in 2018, in comparison to those releases in 2017. The results for the terrestrial monitoring for 2018 are given in Table 6.2(a) and (b). Sulphur-35 was positively detected at a very low concentration in one food sample (wheat) in 2018. Caesium-137 was detected in soil near the site (as in previous years), and this is likely to be due to fallout from Chernobyl and nuclear weapons testing.

Liquid waste discharges and aquatic monitoring

Radioactive liquid wastes are discharged to sewers serving the Maple Lodge STW; treated effluent subsequently enters the Grand Union Canal and the River Colne. The results of the aquatic monitoring programme for 2018 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 2018. The sludge samples contained very low concentrations of iodine-131 (reported just above the less than value, as in recent years), which were most likely to have originated from the therapeutic use of this radionuclide in a local hospital. Tritium, gross alpha and gross beta concentrations in water were below the investigation levels for drinking water in the European Directive 2013/51. Gamma dose rates over grass were generally indistinguishable from natural background in 2018 (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 radio-labelled products containing tritium and carbon-14 in 2009 and 2010, respectively.

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 rest of the site (10 per cent) was re-licensed as a stand-alone nuclear 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 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 licensed 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. The decommissioning work is due to be completed by September 2019, with an expectation that the environmental permit will be surrendered in early 2020.

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 the atmosphere and in liquid wastes. These are at much reduced quantities 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 is 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 (including milk), 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). Various earlier monitoring and research efforts have targeted Organically Bound Tritium (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 of radiation was less than 0.005 mSv (Table 6.1) in 2018, or less than 0.5 per cent of the dose limit, and unchanged from 2017. 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 2018 (as in 2017). Trends in *total doses* over time (2007 – 2018) 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 (Figure 6.1, Environment Agency, FSA, FSS, NIEA, NRW and SEPA, 2018). Since 2007, the *total doses* have generally continued to decrease over time and were low (and most recently, less than 0.005 mSv). The increase in *total dose* in 2013 was attributed to higher carbon-14 concentrations in milk.

A source specific assessment for a recreational user of the River Taff was also less than 0.005 mSv in 2018 (Table 6.1). The dose to a high-rate consumer of seafood was 0.008 mSv. The reason for the small increase in dose (from 0.006 mSv in 2017) was mostly due to higher gamma dose rates (over mud) in 2018. The dose in 2018 from terrestrial food consumption was 0.006 mSv (compared to less than 0.005 mSv in 2017). The increase in dose in 2018 was mostly due to higher carbon-14 concentrations in food (milk and potato), in comparison to those 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 2018, although discharges of tritium (and to a lesser extent cabon-14) increased in 2018, in comparison to releases 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).

The results of monitoring for 2018 are given in Tables 6.3(a) and were generally similar in comparison to those reported in previous years. Tritium concentrations in terrestrial food samples are mostly reported as less than values in 2018, although tritium was positively detected in a potato sample (close to the less than value). Carbon-14 concentrations in foodstuffs (milk and potato) increased, by small amounts, in 2018 (in comparison to those in 2017). Low concentrations of sulphur-35, which is not discharged by the site, were detected in food samples (potatoes and barley) but concentrations were generally similar to those in recent years. Phosphorus-32 and iodine-125 concentrations in food samples, and tritium concentrations in sediments (marine and terrestrial) are all reported as less than values in 2018.

In 2018, 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 2018 (as 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 (2000 – 2018) are shown in Figure 6.3. The

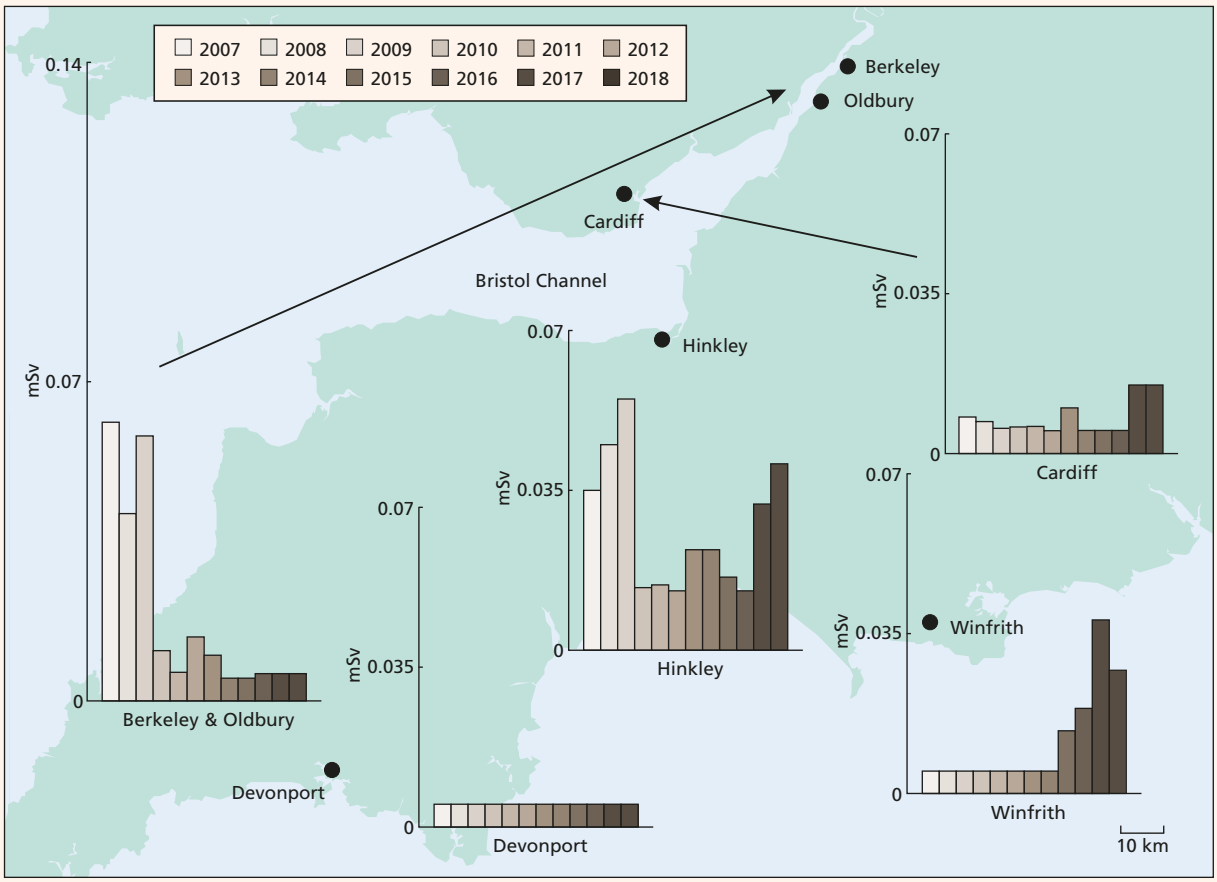


Figure 6.1. *Total dose* for major sites in the Severn Estuary and south coast, 2007-2018
(Note small doses, less than or equal to 0.005 mSv, are recorded as being 0.005 mSv)

overall decline in activity concentrations in sediments generally replicates that of the tritium discharges, during the years that discharges occurred (up to 2014). The apparent increase in tritium concentrations, in the canal and west of pipeline samples in 2015 was because concentrations are reported as less than values. All tritium concentrations in sediment are reported as less than values in 2018.

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 (2007 – 2018) 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 2018 are given in Tables 6.3(a) and (b). Overall, tritium and OBT concentrations in fish and mollusc samples were generally similar to those observed in recent years (with minor variations). In 2018, these activity concentrations were lower in dogfish (reported as less than values) in comparison to those in 2017, but positively detected (just above the less than value) in a limpet sample (unlike in recent years). It is still likely (from the positively detected values of both tritium forms in limpets) 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 seafood. 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 mean concentration of tritium in fish samples is reported as less than values in 2018. The trend

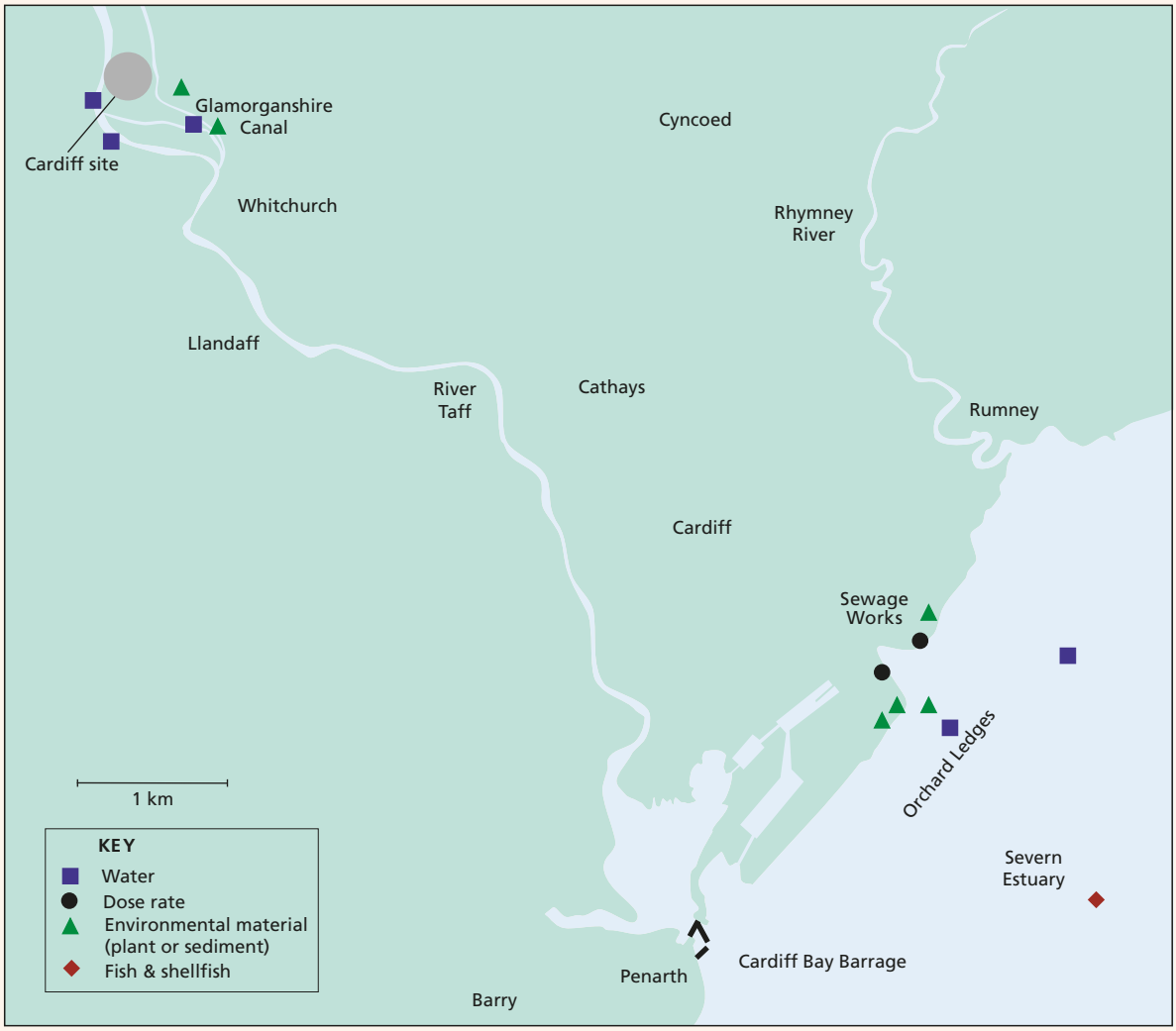


Figure 6.2. Monitoring locations at Cardiff, 2018 (not including farms)

of carbon-14 concentrations and the relationship to discharges is shown in Figure 6.5 (overall, concentrations in both species declining). Concentrations of caesium-137 in marine samples remain low and can largely be explained by other sources such as the fallout from Chernobyl and nuclear weapons testing 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 2018 were generally similar to those in 2017. It is unlikely these rates are attributable to discharges from the Maynard Centre or Pharmaron.

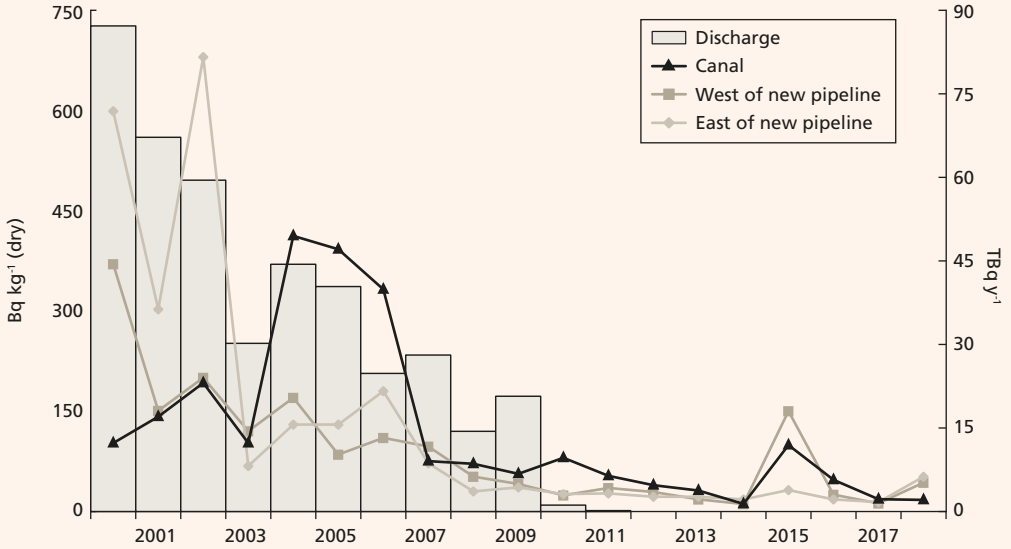


Figure 6.3. Tritium liquid discharge from Cardiff and mean concentrations in sediment near Cardiff, 2000-2018

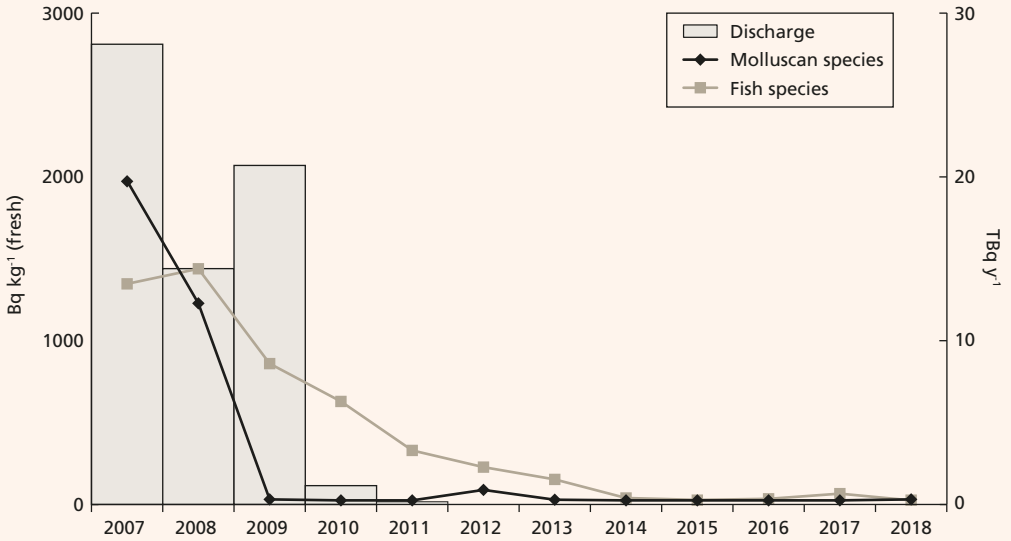


Figure 6.4. Tritium liquid discharge from Cardiff and mean concentrations in fish and molluscs near Cardiff, 2007-2018 (species include all those reported in RIFE for the given year)

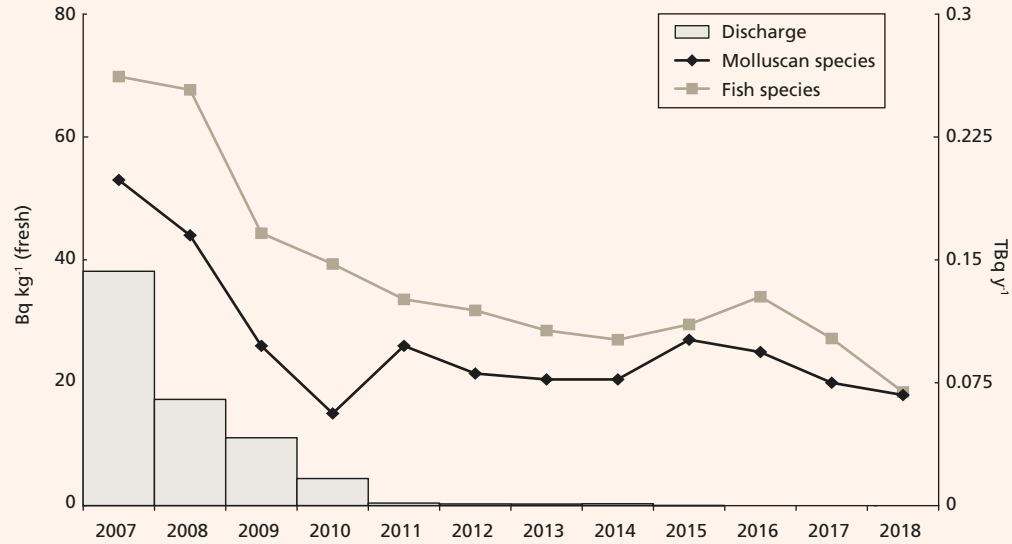


Figure 6.5. Carbon-14 liquid discharge from Cardiff and mean concentrations in fish and molluscs near Cardiff, 2007-2018 (species include all those reported in RIFE for the given year)

Table 6.1 Individual doses – radiochemical sites, 2018

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)**	**0.14[d]**	**-**	**<0.005**	**<0.005**	**-**	**<0.005**	**0.14**
Source specific doses	Anglers	<0.005	<0.005	-	<0.005	-	-	-
	Infant inhabitants and consumers of locally grown food	0.008[d]	-	<0.005	-	-	0.007	-
	Workers at Maple Lodge STW	<0.005	-	-	<0.005	<0.005	-	-
Cardiff								
***Total dose* – all sources**	**Prenatal children of occupants over sediment**	**<0.005**	**<0.005**	**-**	**<0.005**	**-**	**-**	**-**
Source specific doses	Adult seafood consumers	0.008	<0.005	-	0.008	-	-	-
	Prenatal children of recreational users of River Taff	<0.005	-	-	<0.005	<0.005	-	-
	Infant inhabitants and consumers of locally grown food	0.006	-	0.006	-	-	<0.005	-

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

[b] *External radiation from raw sewage and sludge*

[c] *Intakes of resuspended raw sewage and sludge*

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

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

Table 6.2(a) Concentrations of radionuclides in food and the environment near Amersham, 2018

Material	Location	No. of sampling observ-ations	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	<1.2	<0.10		
Sediment	Upstream of outfall (Grand Union Canal)	2[E]		<1.1	2.6	130	160
Sediment	Downstream of outfall (Grand Union Canal)	2[E]		<0.80	2.0	<120	170
Freshwater	Downstream of outfall (Grand Union Canal)	1[E]	<2.6	<0.24	<0.22	<0.057	0.37
Freshwater	River Chess	1[E]	<2.4	<0.39	<0.25	<0.061	0.045
Freshwater	River Misbourne - downstream	1[E]	<2.6	<0.37	<0.27	<0.053	<0.032
Crude effluent[d]	Maple Lodge Sewage Treatment Works	2[E]	<6.1		<0.3	<0.085	0.55
Digested sludge[e]	Maple Lodge Sewage Treatment Works	2[E]	<6.4	3.3	<0.22	<3.6	7.4
Final effluent[f]	Maple Lodge Sewage Treatment Works	2[E]	<6.8		<0.31	<0.12	0.63

Material	Location or selection[b]	No. of sampling observ-ations[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	<3.9	<0.18	<0.0060	<0.0013	<0.05		
Squash		1	<2.2	<0.20			<0.05		
Wheat		1	<3.7	3.0			<0.07		
Grass	Orchard next to site	1[E]				<1.2	<1.2	1.8	110
Grass	Water Meadows (River Chess)	1[E]				<1.7	<1.3	<1.2	230
Soil	Orchard next to site	1[E]				<0.45	6.2	290	570
Soil	Water Meadows (River Chess)	1[E]				<0.72	9.3	220	470

* *Not detected by the method used*

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

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

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

[d] *The concentration of ^{3}H as tritiated water was <4.0 Bq l^{-1}*

[e] *The concentration of ^{3}H as tritiated water was <3.8 Bq l^{-1}*

[f] *The concentration of ^{3}H as tritiated water was <4.1 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, 2018

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	0.069
Water Meadows (River Chess)	Grass	1	0.062
Orchard next to site	Grass	1	0.091

Table 6.3(a) Concentrations of radionuclides in food and the environment near Cardiff, 2018

Material	Location	No. of sampling observ-ations	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		19	<0.21
Lesser spotted dogfish	Off Orchard Ledges	1	<25	<25		18	0.33
Limpets	Lavernock Point	1	28	31		18	0.25
Seaweed	Orchard Ledges	2[E]		<17		<10	
Sediment	East of sewage outfall	2[E]		<52		<10	
Sediment	West of sewage outfall	2[E]		<43		<6.9	
Seawater	West of sewage outfall	1[E]		<15	<2.5	<2.7	

Material	Location or selection[b]	No. of sampling observ-ations[c]	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}						
			Organic ^{3}H[d]	^{3}H	^{3}H[e]	^{14}C	^{35}S	^{125}I	^{137}Cs
Terrestrial samples									
Milk[f]		2	<3.0	<3.0		19	<0.41	<0.0063	<0.05
Milk[f]	max		<3.6	<3.6		20	<0.63	<0.0070	
Potato		1	8.9	8.9		37	1.0	<0.035	<0.04
Barley		1	<14	<14		48	1.6	<0.058	<0.05
Grass	0.5km north east of site	1[E]		<15		<3.4			
Grass	0.5km north west of site	1[E]		<32		<4.9			
Sediment	Glamorgan canal	2[E]		<63		<38			
Freshwater	River Taff upstream	1[E]		<15		<2.8			
Freshwater	River Taff downstream	1[E]		<16	<2.5	<3.2			
Freshwater	Glamorgan canal	1[E]		<14	<2.6	<3.0			

[a] *Except for milk, water and effluent where units are Bq l^{-1} and for sediment where dry concentrations apply*
[b] *Data are arithmetic means unless stated as 'max' in this column. 'Max' data are selected to be maxima. If no 'max' value is given the mean value is the most appropriate for dose assessments*
[c] *The number of farms from which milk is sampled. The number of analyses is greater than this and depends on the bulking regime*
[d] *The organic fraction may be higher than the total tritium value for some analyses due to uncertainties in the analytical methods for tritium. For dose assessments in this report, the higher of the two values has been used*
[e] *As tritiated water*
[f] *The concentration of ^{32}P was <0.14 Bq l^{-1} (max <0.17 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, 2018

Location	Ground type	No. of sampling observations	µGy h^{-1}
Mean gamma dose rates at 1m over substrate			
East of Pipeline	Mud and sand	1	0.079
East of Pipeline	Mud and stones	1	0.079
West of Pipeline	Rock	1	0.097
West of Pipeline	Mud and stones	1	0.10
Peterstone Wentlooge	Mud and sand	1	0.081
Peterstone Wentlooge	Mud	1	0.081

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) increased at the LLWR, and decreased if legacy effects were excluded, in 2018
- Doses at landfill sites (excluding the LLWR) were less than 0.5 per cent of the dose limit in 2018
- Doses (dominated by the effects of naturally occurring radionuclides from legacy discharges) increased at Whitehaven in 2018

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. In March 2018, the NDA awarded the incumbent PBO, UK Nuclear Waste Management Limited (UKNWM), a third (and final) contract for the management of LLWR Limited. A five-year plan has been published setting out the long-term future of the site through to final closure, expected in 2129 (LLWR Limited, 2018). Final site clearance is expected to be achieved by 2135 (NDA, 2019).

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 2018, be distinguished from those due to Sellafield.

The current permit, issued in 2015, allows for continued waste disposal at the site, including permission to dispose of further radioactive waste beyond Vault 8. It also includes removal of annual radiological limits on disposals by burial, and instead limits disposals against a lifetime capacity for the site. In financial year 2017/18, the site commenced its long-term Repository Development Plan (LLWR Limited, 2018).

A new habits survey for Sellafield was published in 2019 and the results have been included in the dose assessments for the site (Moore *et al*., 2019).

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 2018/19) both solid radioactive wastes already disposed in Vault 8 and the solid radioactive wastes accepted by the site (with the intention to dispose and currently stored within Vaults 8 and 9, pending disposal). A total of 1,720 m^3 of waste was received by the site with the intention of disposal in financial year 2018/19, bringing the cumulative total to 251,000 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 or 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 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 annual dose would be less than 0.005 mSv. In 2018, concentrations of radionuclides in sediment from the Drigg stream were similar to those in 2017. 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, British Nuclear Fuels plc (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 2018 show that the activity concentrations have continued to be very low in the drain 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 2018 are given in Table 7.2 and these provide very limited evidence in support of the proposition that radioactivity in leachate from the LLWR might be transferring to foods. Concentrations of radionuclides were generally similar to (or lower than) those measured near Sellafield (Section 2).

The *total dose* from all pathways and sources of radiation was 0.37 mSv (values are rounded to two significant figures) in 2018, or 37 per cent of the dose limit for members of the public of 1 mSv (Table 7.1) and includes a component due to the fallout from Chernobyl and nuclear weapons testing. 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 (see Section 2.3.1). If these effects were to be excluded, and the sources of exposure from the LLWR are considered, the *total dose* was 0.053 mSv in 2018 (Table 1.2). The representative person was adults living near the site. The decrease in *total dose* (from 2017) was due to a lower estimate of direct radiation from the site in 2018. A source specific assessment of exposure for consumers of locally grown terrestrial food, using 2017 modelled activity concentrations in animal products, gives an exposure that was 0.006 mSv in 2018, and similar to that in recent years.

7.2 Metals Recycling Facility, Lillyhall, Cumbria

The Metals Recycling Facility (MRF), operated by the licence holder, Cyclife 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 quantities 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.

The current permit, issued in 2017, allows discharges of gaseous waste to the environment via a main stack and of aqueous waste to the sewer. Low discharge limits are set for both aqueous and gaseous discharges. Very small discharges were released during 2018 (Appendix 2, Tables A2.1 and A2.2). The permit includes conditions requiring Cyclife UK Limited to monitor discharges and undertake environmental monitoring. In 2018, direct radiation from the site was less than 0.001 mSv (Table 1.1), showing that the radiological impact was very low.

7.3 Other landfill sites

Some organisations are granted authorisations by SEPA (in Scotland) or permits by the Environment Agency (in England and Wales)*, respectively to dispose of solid wastes containing low quantities of radioactivity to approved landfill sites. In Northern Ireland, this type of waste is transferred to Great Britain for incineration. Waste with very low quantities 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 2018 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 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

* *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.*

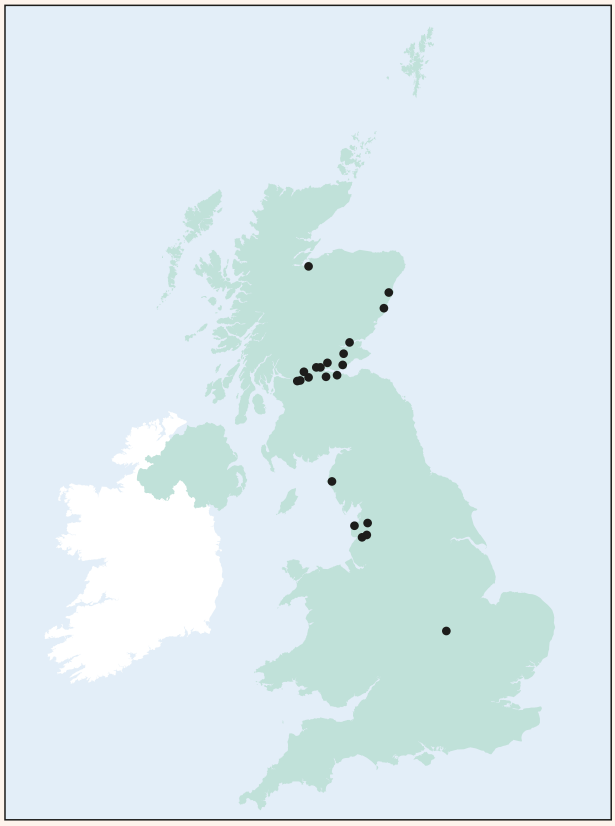


Figure 7.1. Landfill sites monitored in 2018

Dalmecoulter (North Lanarkshire) site (with the highest observed concentration of tritium) would result in a dose of less than 0.005 mSv in 2018 (Table 7.1), or less than 0.5 per cent of the dose limit for members of the public of 1 mSv. Similarly, the annual 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 the 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 (part of FCC Environmental) at the Lillyhall Landfill Site in Cumbria. Their permit, issued in 2011, allows disposal of VLLW. In March 2019, the Environment Agency launched a public consultation on the variation of the existing permit to increase the activity limits of disposal. Further information on the consultation is available on the Environment Agency's website: **https://consult.environment-agency.gov.uk/cumbria-and-lancashire/lillyhall-landfill-site-rsa-permit-variation/**
- 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 landfill site, near Kings Cliffe, 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 site in order to provide a baseline and allow detection of any future changes. In 2018, 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 values 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 in 2018 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, authorised to dispose of conditioned NORM waste, ceased in 2016. Results up to 2015 are included in earlier RIFE reports and show no significant radiological impact (e.g. Environment Agency, FSA, FSS, NIEA, NRW and SEPA, 2016).

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, the

operators of the 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 decay 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 (TENORM). Historical discharges continue to have an impact (close to the former discharge point), through the production of the decay products (from long-lived parent radionuclides, previously discharged to sea). Both polonium-210 and lead-210 are important radionuclides in that small changes in activity concentrations above background significantly influence the dose contribution from these radionuclides. This is due to their relatively high dose coefficient used to convert intake of radioactivity into a radiation 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 2018 are shown in Table 7.6. In 2018, the Environment Agency also carried out additional polonium-210 analyses in shellfish samples, further afield from the Cumbrian coastline (Lancashire, North Wales and Northern Ireland), using samples collected by the FSA and NIEA (as part of their annual monitoring programmes).

Routine analytical effort is focused on polonium-210 and lead-210, which concentrate in marine species and are the important radionuclides in terms of potential dose to the public. As in previous years, polonium-210 and other naturally occurring radionuclides were slightly enhanced near Whitehaven but quickly reduce to background values 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 2018 (where comparisons can be made) compared with those in 2017. In particular, concentrations were higher (overall) in both crabs and lobsters in 2018. However, polonium-210 concentrations in these samples continued to be within or close to the expected range due to natural sources (as in recent years). 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 values 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 values indicative of natural background. Further analysis has confirmed that this approach is unlikely to underestimate doses (Dewar *et al.*, 2014).

The additional polonium-210 analyses carried out in shellfish samples by the Environment Agency in 2018 were undertaken to obtain baseline data, providing naturally sourced polonium-210 concentrations that are unlikely to be influenced by TENORM in the Irish Sea. The results provide a comparison to annually produced results, reporting enhanced concentrations of polonium-210 near Whitehaven. The results of the additional analytical effort are also presented in Table 7.6. The ranges of polonium-210 concentrations were 3.6 – 24 Bq kg^{-1} and 19 – 85 Bq kg^{-1} in crustacean and mollusc samples, respectively. Table X4.1 (Appendix 1: CD Supplement) gives estimated values of radionuclide concentrations due to natural sources in aquatic foodstuffs, based on previous sampling and analysis, and indicates ranges of 1.1 – 35 Bq kg^{-1} and 19 – 69 Bq kg^{-1} in crustacean and mollusc samples, respectively (Young *et al.*, 2002; 2003). The polonium-210 concentrations in crustaceans (crabs and lobster) were higher near Whitehaven, in comparison to those further afield (in both annual and the additional samples) in 2018. The polonium-210 concentration (85 Bq kg^{-1}) in mussels from Carlingford Lough is outside the reported range (1.2 – 69 Bq kg^{-1}), previously estimated for natural sources (Table X4.1).

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,

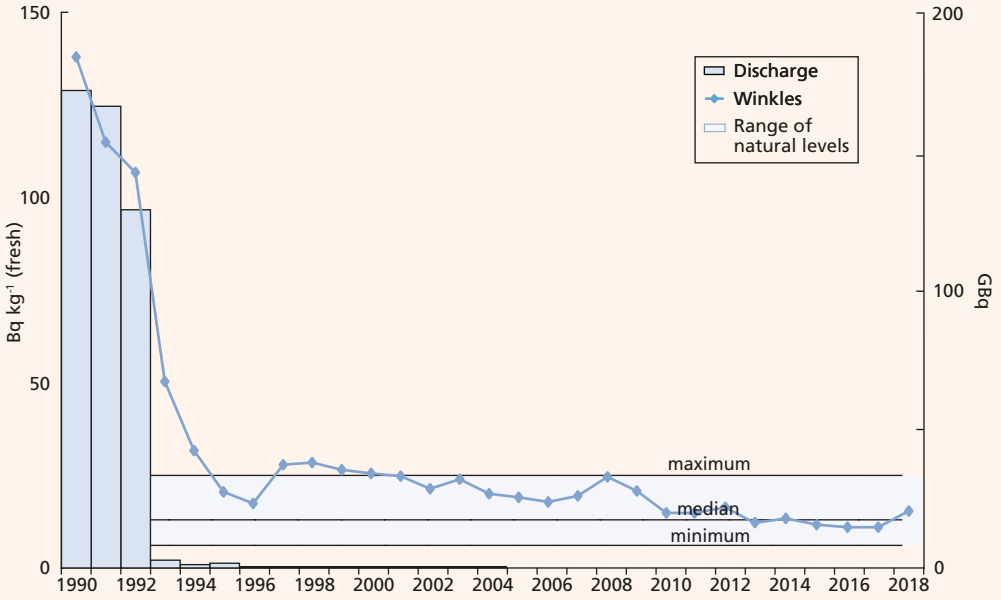


Figure 7.2. Polonium-210 discharge from Whitehaven and concentration in winkles at Parton, 1990-2018

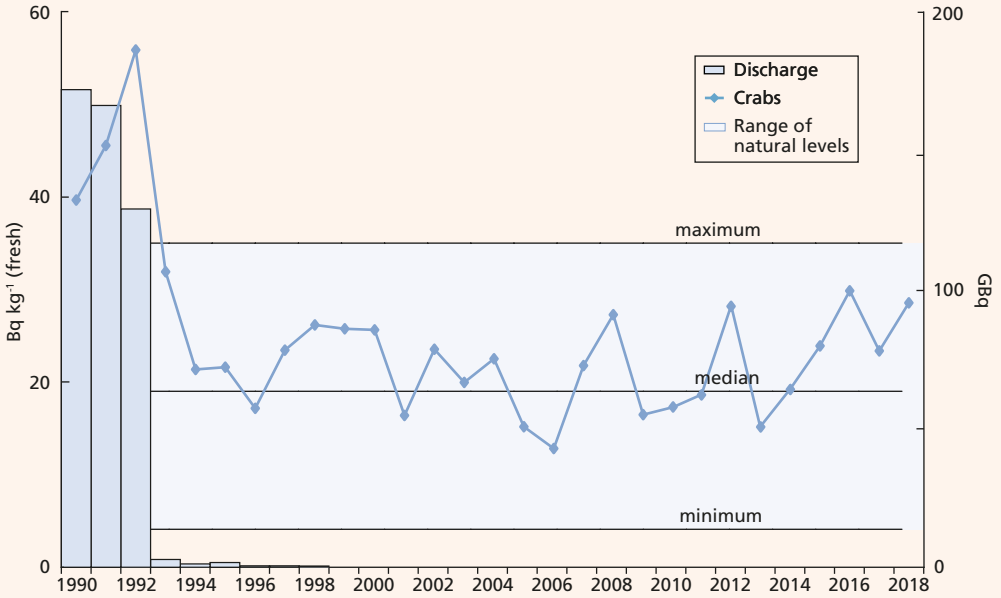


Figure 7.3. Polonium-210 discharge from Whitehaven and concentration in crabs at Parton, 1990-2018

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 seafood at high-rates were reviewed and revised in 2018 (Moore *et al.*, 2019). 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 0.37 mSv in 2018 (Table 7.1), or 37 per cent of the dose limit to members of the public, and up from 0.25 mSv in 2017. The dose includes the effects of all sources near the site: technically enhanced naturally occurring radionuclides from the non-nuclear industrial activity (i.e. TENORM) and Sellafield operations. The contribution to the *total dose* from enhanced natural radionuclides was 0.33 mSv, and was higher in 2018, in comparison to that in 2017 (0.18 mSv). The increase in *total dose* in 2018 was mostly attributed to higher concentrations of polonium-210 in locally caught crustacean shellfish (crabs and lobsters), in comparison to those in 2017. The largest contribution to dose to a seafood consumer near Whitehaven and Sellafield continues to be from

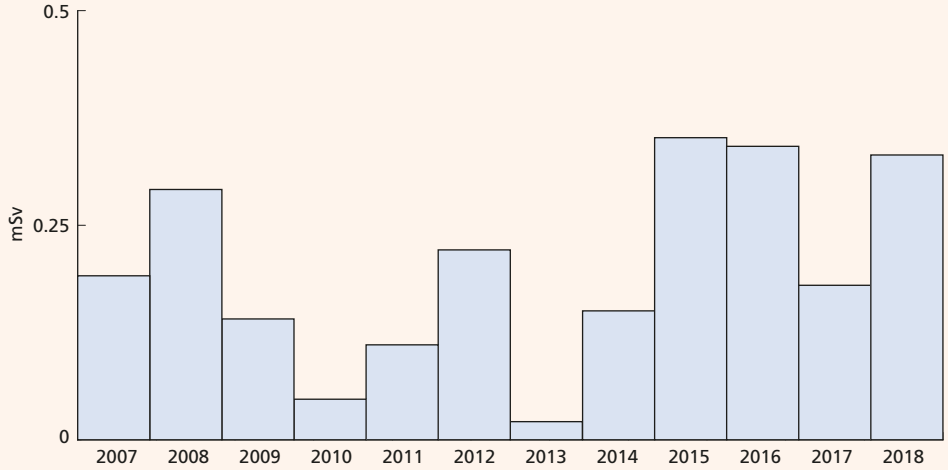


Figure 7.4. Trend in *total dose* to seafood consumers from naturally-occurring radionuclides near Whitehaven, 2007-2018

the legacy of historical discharges near Whitehaven. The source specific dose assessment, targeted directly at local consumers of seafood (at high-rates), gives a result of 0.40 mSv in 2018 (Table 7.1).

The longer-term trend in annual *total dose* over the period 2007 – 2018 is shown in Figure 7.4. The overall reduction in *total dose* (with some variability from year to year), up to 2010, reflects changes in both polonium-210 concentrations and consumption rates, primarily of lobsters and molluscs. Thereafter, variations in *total dose* over the period 2011 – 2018 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. Over a longer period, the trend is of generally declining dose (Figure 7.4, Environment Agency, FSA, FSS, NIEA, NRW and SEPA, 2018).

7.5 Former military airbase, Dalgety Bay, Fife

Radioactive items containing radium-226 and associated decay 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 activity concentrations 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 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 2018 and into 2019. 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 FSS (then Food Standards Agency in Scotland) 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 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 in 2013 (together with the appropriate persons report, which includes a comprehensive study of land ownership and history at Dalgety Bay), COMARE (Committee on Medical Aspects of Radiation in the Environment) recommended that effective remediation of the affected area be 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 2014, followed by a further publication in 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. This group ensures 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. SEPA is continuing to work with the MoD and their contractors with regard to the remediation methodology for the site.

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/**.

7.6 Former military airbase, Kinloss Barracks, Moray

Radioactive items containing radium-226 and associated decay 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 decay 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 available on SEPA's website: **https://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 in 2018 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).

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 2018, SEPA continued to undertake a small-scale survey (as part of the annual programme) of the effects of discharges from non-nuclear operators by analysing mussel samples and other materials from the River Clyde, the Firth of Forth and sludge pellets from a STW. The results are given in Table 7.11. The results in 2018 were generally similar to those in 2017. Activity concentrations were typical of the expected effects from Sellafield discharges at this distance and the presence of iodine-131 in sludge pellets (probably from a hospital source). An assessment was undertaken to determine the dose to the representative high-rate mollusc consumer. The dose was less than 0.005 mSv in 2018, 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 2018 (due to restricted access). Results up to 2016 are included in earlier RIFE reports (e.g. Environment Agency, FSA, FSS, NIEA, NRW and SEPA, 2017). In 2018, the dose rate on sediment was 0.084 μGy h^{-1} and similar to background.

Table 7.1 Individual doses – industrial and landfill sites, 2018

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[f]
***Total dose* – all sources**							
Whitehaven and LLWR near Drigg	**Adult crustacean consumers**	**0.37[d]**	**0.030**	**0.33**	**-**	**<0.005**	**-**
Source specific doses							
LLWR near Drigg	Infant consumers of locally grown food	0.006	-	-	0.006	-	-
	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 2014-18)	Seafood consumers	0.40[d]	0.042	0.33	-	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 substracting background and cosmic sources from measured gamma dose rates)*

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

Table 7.2 Concentrations of radionuclides in terrestrial food and the environment near Drigg, 2018

Material	Location or selection[b]	No. of sampling observ-ations[b]	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}								
			^{3}H	^{14}C	^{60}Co	^{90}Sr	^{95}Zr	^{95}Nb	^{99}Tc	^{106}Ru	^{125}Sb
Milk		1	<5.0	17	<0.05	0.035	<0.22	<0.55	<0.0072	<0.40	<0.10
Deer muscle		1	<4.0	33	<0.05	0.030	<0.10	<0.07	<0.035	<0.44	<0.11
Eggs		1	<9.4	37	<0.03	<0.043	<0.06	<0.08		<0.25	<0.09
Potatoes		1	7.3	15	<0.06	<0.036	<0.21	<0.21	<0.035	<0.56	<0.14
Sheep muscle		1	<10	32	<0.04	<0.043	<0.10	<0.07	<0.034	<0.35	<0.10
Sheep offal		1	<5.6	34	<0.03	0.034	<0.07	<0.07	<0.039	<0.20	<0.06
Barley		1	22	77	<0.05	0.25	<0.09	<0.08	<0.12	<0.50	<0.11
Sediment	Drigg Stream	4[E]			<0.38	<1.3	<0.51	<0.25		<2.4	<1.3
Freshwater	Drigg Stream	4[E]	<3.1		<0.27	<0.036					
Freshwater	Railway drain	1[E]	<3.1		<0.25	0.17					

Material	Location or selection[b]	No. of sampling observ-ations[b]	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}								
			^{129}I	^{134}Cs	^{137}Cs	Total Cs	^{144}Ce	^{210}Po	^{228}Th	^{230}Th	^{232}Th
Milk		1	<0.0050	<0.04	0.16		<0.30				
Deer muscle		1	<0.014	<0.05	0.95	0.95	<0.28				
Eggs		1	<0.025	<0.03	<0.03	<0.031	<0.18				
Potatoes		1	<0.021	<0.07	0.29	0.29	<0.34				
Sheep muscle		1	<0.017	<0.04	0.51	0.51	<0.35				
Sheep offal		1	<0.018	<0.02	0.19	0.19	<0.11				
Barley		1	<0.018	<0.05	0.12	0.12	<0.25				
Sediment	Drigg Stream	4[E]		<0.33	52		<1.5	5.1	9.5	9.7	9.4
Freshwater	Drigg Stream	4[E]		<0.29	<0.24			<0.0022	<0.0066	<0.0016	<0.0011
Freshwater	Railway drain	1[E]		<0.26	<0.21			<0.0020	<0.015	<0.0037	<0.0039

Material	Location or selection[b]	No. of sampling observ-ations[b]	Mean radioactivity concentration (fresh)[a], 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	<0.000059	<0.22	<0.000024		
Deer muscle		1				<0.00021	0.00014	<0.56	0.00011		
Eggs		1				<0.000030	0.000018	<0.22	0.000078		
Potatoes		1				<0.00010	0.0013	<0.25	0.0017		
Sheep muscle		1				0.000014	0.00012	<0.25	0.00041		
Sheep offal		1				0.00074	0.0055	<0.35	0.0053		
Barley		1				0.00061	0.0032	<0.24	0.0076		
Sediment	Drigg Stream	4[E]	14	<0.97	13	<2.3	14	61	33	<110	460
Freshwater	Drigg Stream	4[E]	0.011	<0.0019	0.0098	<0.0042	<0.0032	<1.1	<0.0031	<0.043	0.39
Freshwater	Railway drain	1[E]	0.013	<0.0016	0.012	<0.00063	<0.0011	<0.97	<0.0068	<0.065	0.69

[a] *Except for milk and freshwater where units are Bq l^{-1}, and for sediment where dry concentrations apply*
[b] *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, 2018

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	<5.0	<15	<0.05	<0.05
City of Glasgow	Summerston landfill	1	150	<15	<0.05	<0.05
City of Glasgow	Cathkin	1	170	<15	<0.05	<0.05
Clackmannanshire	Black Devon	1	20	<15	<0.05	<0.05
Dunbartonshire	Birdston	1	<5.0	<15	<0.05	<0.05
Dundee City	Riverside	1	17	<15	<0.05	<0.05
Edinburgh	Braehead	1	<5.0	<15	<0.05	<0.05
Fife	Balbarton	1	16	<15	<0.05	<0.05
Fife	Melville Wood	1	91	<15	<0.05	<0.05
Highland	Longman landfill	1	<5.0	<15	<0.05	<0.05
North Lanarkshire	Dalmacoulter	1	310	<15	<0.05	<0.05
North Lanarkshire	Kilgarth	1	<5.0	<15	<0.05	<0.05
Stirling	Lower Polmaise	1	18	<15	<0.05	<0.05

Table 7.4 Concentrations of radionuclides in water from landfill sites in England and Wales, 2018

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	<2.6	<5.5	<0.30	<0.25	<0.0071	<0.0020
Clifton Marsh	Borehole 19	2	<3.5	<6.7	<0.32	<0.29	<0.025	<0.0064
Clifton Marsh	Borehole 40	2	<2.7	<4.6	<0.25	<0.21	<0.0070	<0.0015
Clifton Marsh	Borehole 59	2	6.5	<4.5	<0.24	<0.21	<0.0066	<0.0022

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	<0.0014	0.053	0.0023	0.048	<0.20	1.1
Clifton Marsh	Borehole 19	2	<0.0052	<0.038	<0.0030	<0.031	<3.6	5.7
Clifton Marsh	Borehole 40	2	<0.0014	0.0060	<0.00060	<0.0038	<0.15	1.2
Clifton Marsh	Borehole 59	2	<0.0015	0.0038	<0.0010	0.0024	<0.21	0.97

Table 7.5 Concentrations of radionuclides in water near the East Northants Resource Management Facility landfill site, 2018

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	<2.5	<6.6	<0.27	0.0066	<0.0078	<0.0030	<0.0012	0.017	<0.0018	0.015	<0.14	0.17
K15A Groundwater borehole	<2.5	<7.7	<0.34	0.0054	<0.0076	<0.0015	<0.0018	0.038	<0.0041	0.038	<0.21	0.23
K17 Northern perimeter Groundwater borehole	<2.6	<4.6	<0.22	0.0097	<0.0088	<0.0019	<0.0014	0.039	0.0019	0.031	0.31	0.67
Horse Water spring		<6.6	<0.28								<0.12	0.46
Willow brook		<7.6	<0.33								<0.24	0.77

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

Table 7.6 Concentrations of naturally occurring radionuclides in the environment, 2018[a]

Material	Location	No. of sampling observ-ations	Mean radioactivity concentration (fresh)[b], 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	15	1.6						
Winkles	Nethertown	4	17	1.7	0.67	0.59	0.49	1.1	0.033	0.96
Mussels	Whitehaven	2	45	1.5						
Winkles	Ravenglass	1	16	0.85						
Prawns	Seascale	2	4.7	<0.0066						
Crabs	Parton	2	29	0.15						
Crabs	Sellafield coastal area	2	20	0.091	0.13	0.017	0.010	0.10	0.004	0.091
Lobsters	Parton	2	20	0.47						
Lobsters	Sellafield coastal area	2	9.5	0.080	0.024	0.003	0.003	0.025	0.001	0.021
Nephrops	Whitehaven	1	4.2	0.16						
Cod	Parton	2	0.20	0.051						
Cod	Whitehaven	2	0.92	0.046						
Plaice	Whitehaven	1	2.2	0.22	0.077	0.001	0.000	0.033	0.001	0.031
Plaice	Drigg	1	1.4	0.24	0.059	0.002	0.002	0.060	0.002	0.055
Annual samples (further afield)										
Winkles	South Gare (Hartlepool)	2	12	1.4						
Winkles	Middleton Sands	2	13							
Winkles	Kirkcudbright	1[S]	2.3							
Mussels	Morecambe	2	35							
Mussels	Ribble Estuary	1			0.22	0.16	0.10			
Limpets	Kirkcudbright	1[S]	5.6							
Crabs	Kirkcudbright	1[S]	9.1							
Lobsters	Kirkcudbright	1[S]	0.70							
Shrimps	Ribble Estuary	1			0.007	0.005	0.002			
Wildfowl	Ribble Estuary	1				0.005	0.003			
Sediment	Kirkcudbright	2[S]						13	<0.43	8.2
Sediment	Rascarrel Bay	1						7.6	<0.48	7.7
Additional samples - Irish Sea										
Shrimps	Morecambe	1[E]	4.7							
Shrimps	Ribble Estuary	1[E]	8.1							
Cockles	Dee Estuary	1[E]	24							
Crabs	North Anglesey	1[E]	15							
Lobsters	North Anglesey	1[E]	7.0							
Mussels	Carlingford Lough	1[E, N]	85							
Crabs	Kilkeel	1[E, N]	11							
Lobsters	Kilkeel	1[E, N]	3.6							
Winkles	Minerstown	1[E, N]	19							

[a] *Data for artificial nuclides for some of these samples may be available in the relevant sections for nuclear sites*
[b] *Except for sediment where dry concentrations apply*
[E, S] *Measurements are made on behalf of the Food Standards Agency unless labelled "E" or "S". In that case they are made on behalf of the Environment Agency or Scottish Environment Protection Agency, respectively*
[N] *Samples collected by Northern Ireland Environment Agency*

Table 7.7 Discharges of gaseous radioactive wastes from non-nuclear establishments in England, Northern Ireland and Wales, 2018[a]

	Discharges during 2018, 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	1.3E+11				6.7E+11	
^{14}C	2.6E+08				5.2E+13	5.2E+05
^{18}F	6.5E+10				3.6E+11	
^{35}S					1.5E+08	
^{99m}Tc			1.2E+08		2.4E+05	
^{106}Ru					9.9E+05	
^{125}I	5.5E+05		2.2E+07		1.4E+08	
^{129}I					7.0E+04	
^{131}I			1.5E+08		3.6E+08	
^{131m}Xe			1.5E+08			
^{137}Cs					8.8E+08	
Uranium Alpha					2.0E+00	
Plutonium Alpha					3.4E+02	
^{241}Am					6.4E+02	
Other Alpha particulate			1.4E+07		4.8E+10	
Other Beta/Gamma				1.9E+11		
Other Beta/Gamma Particulate	7.8E+12		9.7E+07		4.2E+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 2017*

Table 7.8 Discharges of liquid radioactive waste from non-nuclear establishments in England, Northern Ireland and Wales, 2018[a]

	Discharges during 2018, 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	1.0E+10		1.5E+08	1.1E+08	5.6E+12		
^{14}C	2.4E+09		1.1E+06		5.2E+11		
^{18}F	6.8E+11		3.5E+12	1.7E+11	3.1E+12		
^{32}P	3.8E+09		5.2E+09		9.6E+08		
^{33}P	1.8E+08				4.2E+08		
^{35}S	7.0E+09		7.0E+08		3.3E+09		
^{51}Cr	6.6E+08		4.3E+10	6.2E+08	1.3E+09		
^{57}Co			1.8E+08				
^{58}Co	8.8E+07						
^{60}Co	2.3E+02				1.1E+06		
^{67}Ga	6.2E+07		5.5E+09				
^{75}Se	2.5E+07		4.5E+09	9.6E+07	1.1E+08		
^{89}Sr			5.0E+08				
^{90}Sr					4.7E+02		
^{90}Y			7.4E+11	1.4E+09			
^{99}Tc	2.1E+06		5.5E+11		8.7E+02		
^{99m}Tc	1.0E+11		4.6E+13	1.5E+12	5.4E+11		
^{111}In	3.3E+09		2.6E+11	2.3E+10	2.6E+09		
^{123}I	1.9E+11		9.3E+11	6.6E+10	1.9E+10		
^{125}I	2.5E+09	5.2E+07	1.0E+09	1.2E+07	1.4E+10		
^{129}I	8.0E+03				1.0E+00		
^{131}I			8.6E+12	2.4E+11	1.3E+11		
^{134}Cs	1.0E+04				6.8E+07		
^{137}Cs	1.9E+03				4.1E+09		
^{153}Sm				2.7E+09			
^{201}Tl			1.7E+10				
^{230}Th					2.5E+08		
^{232}Th					2.3E+08		
Uranium Alpha	1.2E+06				5.2E+08		
^{237}Np					1.0E+00		
^{241}Pu					1.1E+04		
Plutonium Alpha	3.8E+04				3.1E+03		
^{241}Am	5.2E+04				5.8E+03		
^{242}Cm					7.0E+00		
Total Alpha	1.1E+07	1.8E+05	2.1E+10	6.7E+08	5.0E+10		4.1E+09
Total Beta/Gamma (Excl Tritium)	1.0E+12		5.4E+13		9.4E+12		3.4E+09
Other Alpha particulate	6.0E+06		1.3E+10		4.1E+08		
Other Beta/Gamma	4.1E+10		2.7E+12	1.4E+06	2.1E+11	1.4E+05	
Other Beta/Gamma particulate					8.3E+08		

[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 2017*

[b] *Excluding specific radionuclides*

Table 7.9 Discharges of gaseous radioactive wastes from non-nuclear establishments in Scotland by OSPAR region, 2018[a]

	Discharges during 2018, 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	1.5E+09	Nil	Nil	Nil	Nil	Nil
^{14}C	Nil	Nil	1.9E+07	Nil	4.7E+07	Nil
^{18}F	Nil	Nil	Nil	Nil	1.2E+10	Nil
^{85}Kr	Nil	Nil	Nil	Nil	Nil	Nil
^{125}I	Nil	Nil	Nil	Nil	Nil	Nil
^{131}I	Nil	Nil	Nil	Nil	Nil	Nil
^{133}Xe	Nil	Nil	Nil	Nil	Nil	Nil
^{137}Cs	Nil	Nil	Nil	Nil	Nil	Nil
Group of Two or More Specified Radionuclides	Nil	Nil	4.0E+10	Nil	Nil	9.8E+05
Other Alpha	Nil	Nil	Nil	Nil	Nil	2.7E+01
Other Beta/Gamma	2.7E+11	Nil	Nil	Nil	Nil	2.9E+03
Other Radionuclides Not Listed	1.4E+10	Nil	Nil	Nil	1.1E+10	Nil

[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, 2018[a]

	Discharges during 2018, 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	9.6E+07	Nil	2.4E+09	Nil	6.7E+08	Nil	6.0E+07
^{14}C	1.1E+06	Nil	6.9E+09	Nil	5.6E+06	4.7E+07	1.2E+06
^{18}F	Nil	1.2E+10	2.0E+07	Nil	Nil	3.1E+11	Nil
^{22}Na	3.0E+05	Nil	Nil	Nil	Nil	Nil	Nil
^{32}P	6.5E+07	5.2E+06	1.5E+07	Nil	3.7E+08	3.3E+08	3.8E+08
^{33}P	3.3E+08	Nil	1.6E+10	Nil	Nil	Nil	Nil
^{35}S	1.4E+08	Nil	1.3E+08	Nil	3.0E+09	Nil	Nil
^{51}Cr	1.5E+06	1.3E+08	Nil	Nil	Nil	6.0E+08	Nil
^{57}Co	Nil	Nil	Nil	Nil	Nil	Nil	Nil
^{60}Co	Nil	Nil	Nil	Nil	Nil	Nil	Nil
^{67}Ga	Nil	5.8E+06	Nil	Nil	Nil	Nil	Nil
^{75}Se	Nil	6.9E+06	Nil	Nil	Nil	Nil	Nil
^{89}Sr	Nil	Nil	Nil	Nil	Nil	Nil	Nil
^{90}Sr	Nil	Nil	Nil	Nil	Nil	Nil	Nil
^{90}Y	Nil	6.8E+07	Nil	Nil	Nil	7.9E+08	Nil
^{99m}Tc	Nil	2.9E+11	Nil	Nil	Nil	1.8E+12	Nil
^{111}In	Nil	5.9E+08	Nil	Nil	Nil	1.5E+10	Nil
^{123}I	Nil	4.3E+09	Nil	Nil	Nil	2.1E+10	Nil
^{125}I	2.4E+04	6.7E+05	1.3E+07	Nil	1.3E+05	1.2E+07	Nil
^{131}I	3.7E+08	2.9E+10	Nil	Nil	Nil	7.4E+10	Nil
^{134}Cs	Nil	Nil	Nil	Nil	Nil	Nil	Nil
^{137}Cs	Nil	Nil	Nil	Nil	Nil	Nil	Nil
^{153}Sm	Nil	Nil	Nil	Nil	Nil	Nil	Nil
^{169}Er	Nil	Nil	Nil	Nil	Nil	Nil	Nil
^{201}Tl	Nil	Nil	Nil	Nil	Nil	Nil	Nil
^{210}Pb	Nil	Nil	2.5E+03	2.2E+08	Nil	Nil	Nil
^{210}Po	Nil	Nil	2.0E+03	2.2E+08	Nil	Nil	Nil
^{226}Ra	Nil	Nil	5.4E+02	5.2E+08	Nil	Nil	Nil
^{228}Ra	Nil	Nil	3.0E+02	1.4E+09	Nil	Nil	Nil
^{232}Th	Nil	Nil	Nil	Nil	Nil	Nil	1.2E+06
Uranium Alpha	8.0E+00	Nil	Nil	Nil	Nil	Nil	Nil
^{237}Np	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Plutonium Alpha	1.8E-01	Nil	Nil	Nil	Nil	Nil	Nil
^{241}Am	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Group of Two or More Specified Radionuclides	Nil	Nil	Nil	Nil	Nil	Nil	1.6E+07
Other Alpha	Nil	3.2E+07	Nil	Nil	Nil	Nil	4.8E+04
Other Beta/Gamma[b]	1.5E+10	1.1E+09	4.0E+02	Nil	4.5E+07	1.1E+12	1.9E+06
Other Radionuclide Not Listed	9.5E+02	3.6E+07	4.6E+08	Nil	Nil	4.3E+10	Nil

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

Table 7.11 Monitoring in the Firth of Forth, River Clyde and near Glasgow, 2018[a]

Location	Material and selection[b]	No. of sampling observations	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		27	<1.9	<0.12		<0.13	1.3
Between Finlaystone and Woodhall	*Fucus vesiculosus*	1			4.3	<0.10		<0.10	39
Dalmuir Clydebank	Sediment	1		<15	<12	<0.10		<0.10	
Downstream of Dalmuir	Freshwater	4			<0.057	<0.10		<0.10	
River Clyde	Freshwater	4	<1.0				<0.0050		
Firth of Forth	Freshwater	4	<1.0				<0.0078		
Daldowie	Sludge pellets	4			<27	<0.10		<0.10	

Location	Material and selection[b]	No. of sampling observations	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	<0.37	0.33	0.31	<0.33	<0.21	
Between Finlaystone and Woodhall	*Fucus vesiculosus*	1	<0.28	10	0.53	<0.38	<0.38	
Dalmuir Clydebank	Sediment	1	<0.22	0.19	11	<0.33	<0.36	
Downstream of Dalmuir	Freshwater	4	<0.12	<0.10	<0.10	<0.16	<0.15	
River Clyde	Freshwater	4			<0.01			0.50
Firth of Forth	Freshwater	4			<0.01			1.7
Daldowie	Sludge pellets	4	<0.25	98	2.5	<0.44	<0.47	

[a] *Results are available for other radionuclides detected by gamma spectrometry, All such results are less than the limit of detection*
[b] *Except for water where units are Bq l^{-1}, and sludge pellets and sediment where dry concentrations apply*

8. Regional monitoring

Regional monitoring in areas remote from nuclear licensed sites has continued in 2018:

(i) to establish long distance transport of radioactivity from UK and other nuclear licensed sites
(ii) to indicate general contamination of the food supply and the environment
(iii) to provide data under UK obligations under Article 36 of the Euratom Treaty and the OSPAR Convention

The routine component parts of this programme are: sampling of seafood and environmental samples from the Channel Islands and Northern Ireland; monitoring UK ports of entry for foodstuffs from Japan and for other non-specific contamination; sampling of the UK food supply, air, rain and drinking water and seawater and sediments.

Key points

- Doses for the representative person were approximately 1 per cent (or less) of the annual public dose limit in 2018

8.1 Channel Islands

Samples of marine environmental materials provided by the Channel Island States have been analysed for quantities 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 and 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 2018 are given in Table 8.1. There was evidence of routine releases from the nuclear industry in some food and environmental samples (e.g. tritium, 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 nuclear weapons testing, due to the low values 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 2018, 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 the data indicate no significant effects from 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 of monitoring are given in Tables 8.2(a) and (b).

In 2018, the main effect of discharges from Sellafield was observed in concentrations of technetium-99 in

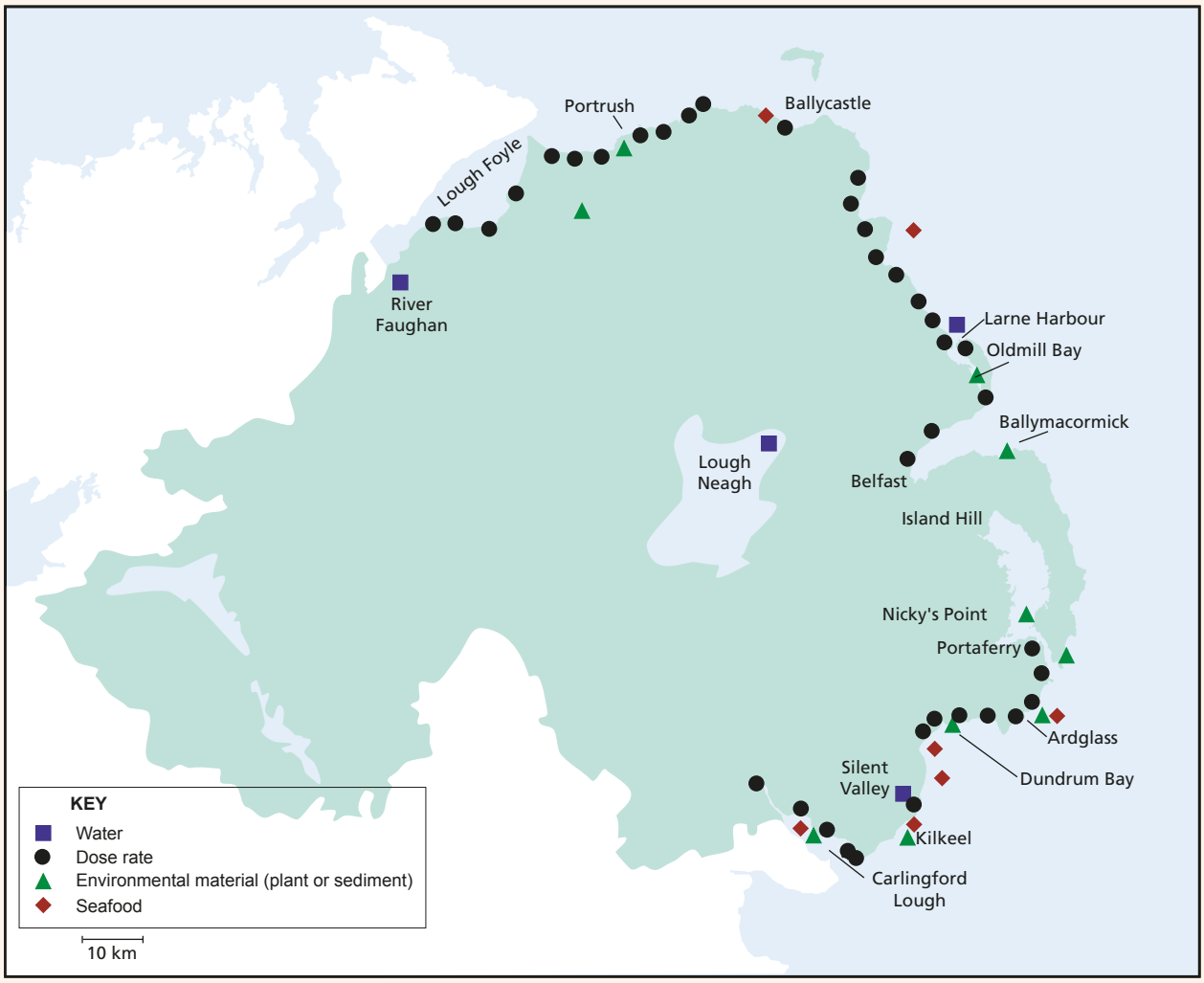


Figure 8.1. Monitoring locations in Northern Ireland, 2018

shellfish and seaweed samples. These were similar to values reported in recent years, reflecting the considerably decreased inputs to the Irish Sea (see also Section 2.3.3). Caesium-137 concentrations were low and generally similar to those in 2017. In 2018, unlike in recent years, cobalt-60 was positively detected in mud samples (Carlingford Lough) at very low concentrations. As expected, low concentrations of transuranic radionuclides were also detected in 2018. Reported concentrations are less than those found nearer to Sellafield and continued to be low, as in recent years (Figure 8.2). Further information on the trends in radioactivity in the marine environment of Northern Ireland has been published (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 established habits representative of people consuming large quantities of fish and shellfish (Smith *et al*., 2002). Based on the monitoring results from the marine environment in 2018, the annual dose from the consumption of seafood and exposure over intertidal areas was 0.011 mSv (Table 2.16), which was approximately 1 per cent of the dose limit for members of the public.

Monitoring results for the terrestrial environment of Northern Ireland are included in the following parts of Section 8.

8.4 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 8.5 and 8.6) 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 2018, 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 to those in previous years.

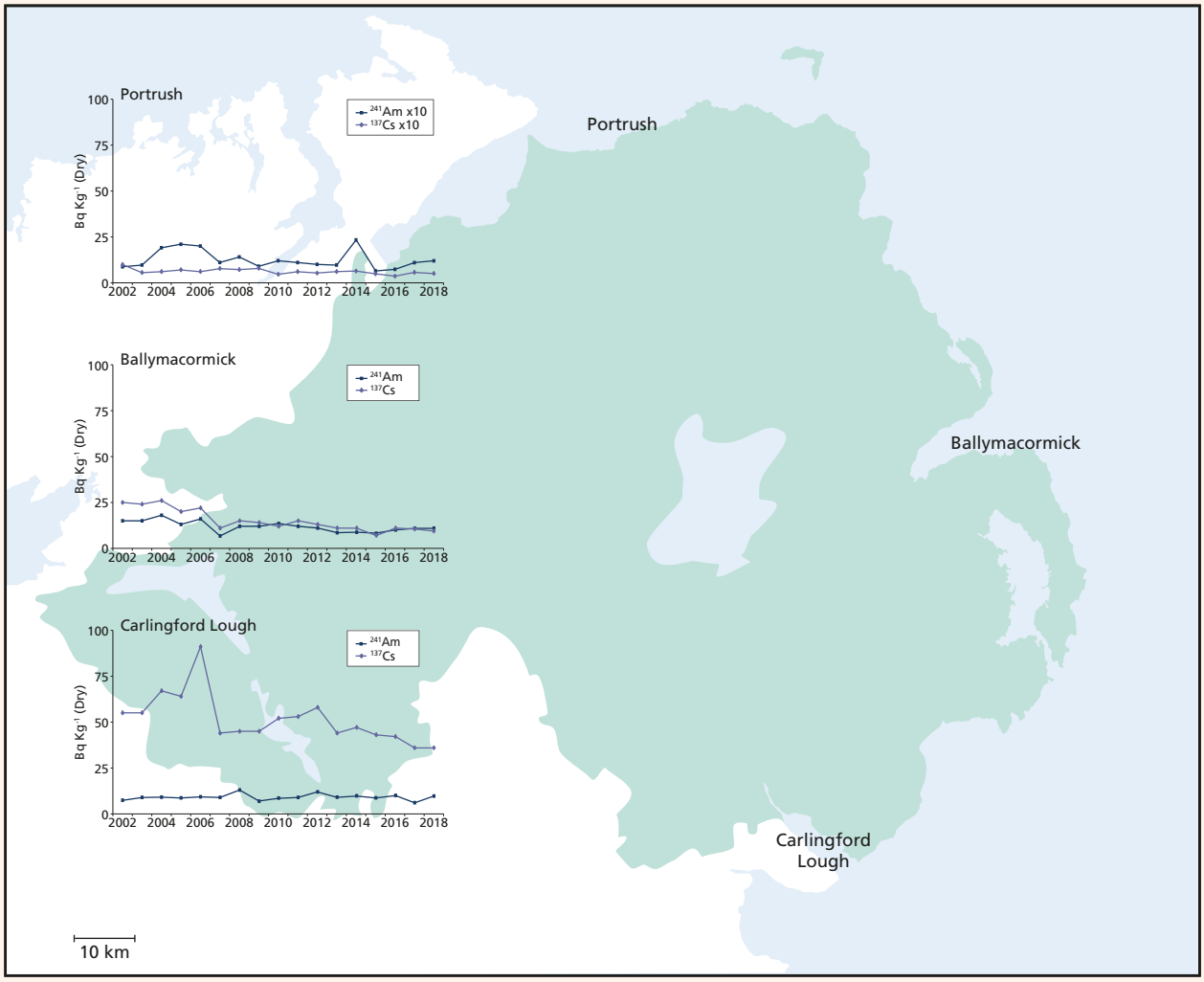


Figure 8.2. Concentrations of americium-241 and caesium-137 in coastal sediments in Northern Ireland, 2002-2018

8.5 Milk

The programme of milk sampling across dairies in the UK continued in 2018. 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 values above background activity concentrations. 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 of milk monitoring for 2018 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, Wales and Scotland were all close to the expected background concentration in milk (see Appendix 1, Annex 4). The maximum concentrations of carbon-14 in milk for England (Cornwall), Northern Ireland (Co. Antrim), Wales (Gwynedd) and Scotland (Dumfriesshire) were 22 Bq l^{-1}, 18 Bq l^{-1}, 19 Bq l^{-1} and less than 23 Bq l^{-1}, respectively. As in previous years, tritium concentrations were reported as less than values at all remote sites. In 2018, strontium-90 concentrations were reported as less than values (or just above the less than value). The mean concentration of strontium-90 detected in the UK was less than 0.036 Bq l^{-1} in 2018 (as in 2017). In the past, the concentrations of radiocaesium in milk were highest from those regions that received the greatest amounts of fallout from Chernobyl. 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 2018, the most exposed age group was infants (1 year-old). For the range of radionuclides analysed, the annual 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 were to be analysed and assessed, the dose would be is dominated by naturally occurring lead-210 and polonium-210, and man-made radionuclides would contribute to less than 10 per cent of the total dose.

8.6 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).

8.7 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 of monitoring 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 2018. 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 values 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 2018 (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 (14 Bq l^{-1} in 2018) was at Gullielands Burn (Table 8.6), which is near to the Chapelcross nuclear licensed site. A gross alpha concentration was positively detected in a surface water sample taken in December 2018 from Loch Baligill, Highland (Table 8.6), just above the investigation levels for drinking water. An additional six surface water samples were taken across the surrounding area in July and August 2019. The concentrations of gross alpha had reduced below the investigation level of 0.1 Bq l^{-1}. Further work will be undertaken during 2019 and the results will be reported in RIFE 25. All other 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 0.018 mSv in 2018 (Table 8.9), and higher than the mean annual dose in 2017 (0.015 mSv, as given in RIFE 23 errata). The highest annual dose was estimated to be 0.026 mSv for drinking water from Silent Valley, County Down. The estimated doses were dominated by naturally occurring radionuclides and are generally 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 2018, and the results are given in Table 8.10. All activity concentrations in samples were reported as below, or just above, the less than value and are generally consistent with those in recent years.

8.8 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 the 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 activity concentrations 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).

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 thirteen prefectures

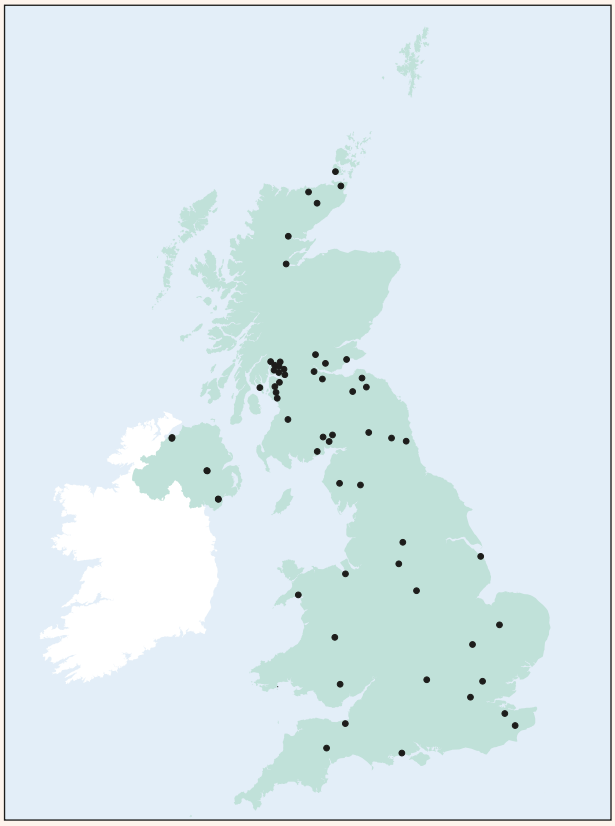


Figure 8.3. Drinking water sampling locations, 2018

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 summarised in earlier RIFE reports (e.g. Environment Agency, FSA, FSS, NIEA, NRW and SEPA, 2018). The 2016 regulation was amended in 2017 (Regulation EU/2058/2017 (EC, 2017)), lifting restrictions on some or all agricultural and fisheries products from ten Japanese prefectures. The EC will review the situation further in 2019.

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 disposed of safely 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 2018. Monitoring is carried out by local Port Health Authorities (or Local Authorities in Scotland). Following changes to the Regulations in 2016 (amended in 2017), 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 in 2018 have contained radioactivity exceeding the maximum permitted levels (100 Bq kg^{-1} and 160 Bq kg^{-1} for food and feed, respectively). 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 2018, the instruments were not triggered by a food consignment at any point of entry into the UK.

8.9 Seawater surveys

The UK Government and Devolved Administrations are committed to preventing pollution of the marine environment from ionising radiation, with the ultimate aim of reducing concentrations in the environment to near background values for naturally-occurring radioactive substances, and close to zero for artificial radioactive substances (DECC, Department of the Environment, Northern Ireland, The Scottish Government and Welsh Assembly Government, 2009). Therefore, a programme of surveillance into the distribution of key radionuclides is maintained using research vessels and other means of sampling.

The seawater surveys reported here also support international studies concerned with the quality status of coastal seas (for example, OSPAR, 2010b). A fourth periodic evaluation of progress towards internationally agreed objectives has been published by OSPAR (OSPAR, 2016). The programme of radiological surveillance work provides the source data and, therefore, the means to monitor and assess progress in line with the UK's commitments towards OSPAR's 1998 Strategy for Radioactive Substances target for 2020 (part of the North-east Atlantic Environment Strategy adopted by OSPAR for the period 2010 – 2020). The surveys also provide information that can be used to distinguish different sources of man-made radioactivity (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.

The research vessel programme on radionuclide distribution currently comprises annual surveys of the Bristol Channel/western English Channel and biennial surveys of the Irish Sea and the North Sea. The results obtained in 2018 are given in Figures 8.4 – 8.8.

A seawater survey of the North Sea was carried out in 2018. Caesium-137 concentrations are given in Figure 8.4

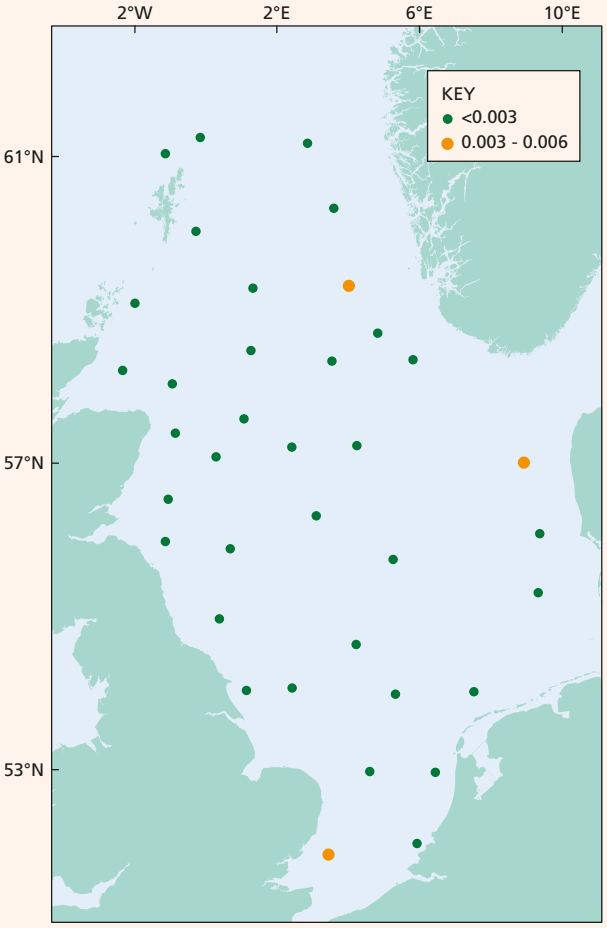


Figure 8.4. Concentrations (Bq l^{-1}) of caesium-137 in filtered surface water from the North Sea, August-September 2018

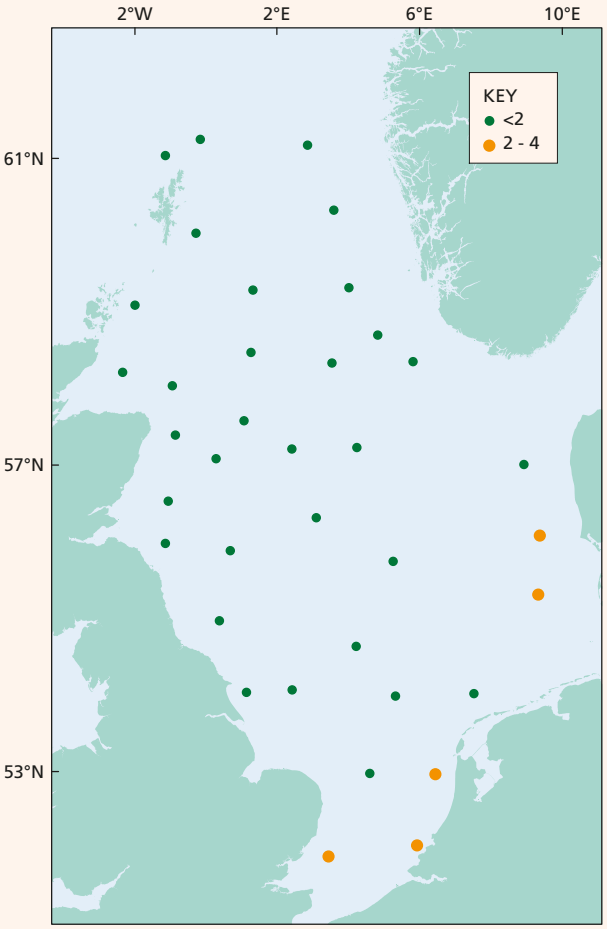


Figure 8.6. Concentrations (Bq l^{-1}) of tritium in surface water from the North Sea, August-September 2018

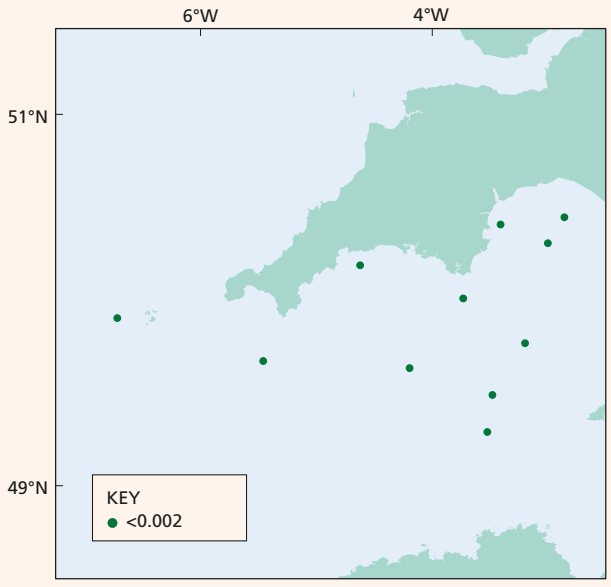


Figure 8.5. Concentrations (Bq l^{-1}) of caesium-137 in filtered surface water from the English Channel, March-April 2018

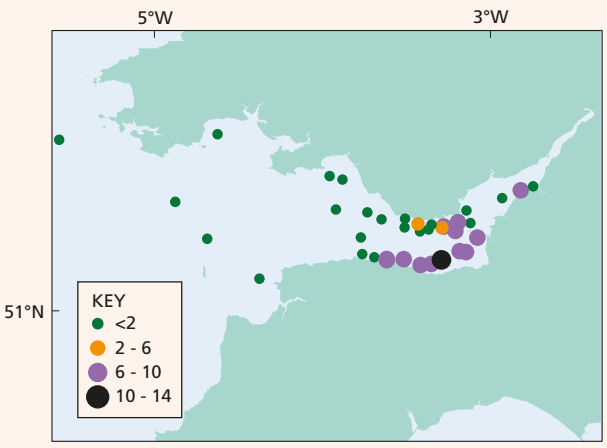


Figure 8.7. Concentrations (Bq l^{-1}) of tritium in surface water from the Bristol Channel, September-October 2018

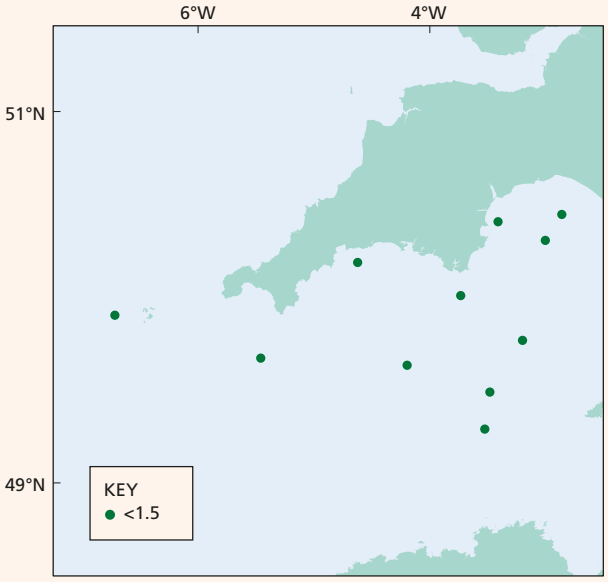


Figure 8.8. Concentrations (Bq l^{-1}) of tritium in surface water from the English Channel, March-April 2018

and show that concentrations were very low (up to 0.006 Bq l^{-1}) throughout the survey area. The few positively detected values were only slightly above those observed for global fallout levels in surface seawaters (0.0001-0.0028 Bq l^{-1}, Povinec *et al.*, 2005). The overall distribution in the North Sea is characteristic of that observed in previous surveys over the last decade, with generally positively detected values near the coast, due to the long-distance transfer, possibly from Sellafield or Chernobyl-derived activity. In 2018, there was no significant evidence of input of Chernobyl-derived caesium-137 from the Baltic (via the Skaggerak) close to the Norwegian Coast. Recently, trends and observations of caesium-137 concentrations in the waters of the North Sea (and Irish Sea), over the period 1995 – 2015, have been published (Leonard *et al.*, 2016).

Over a number of decades, the impact of discharges from the reprocessing plants at Sellafield and La Hague has been readily apparent, carried by the prevailing residual currents from the Irish Sea and the Channel, respectively (Povinec *et al.*, 2003). Caesium-137 concentrations in the North Sea have tended to follow the temporal trends of the discharges, albeit with a time lag. The maximum discharge of caesium-137 occurred at Sellafield in 1975, with up to 0.5 Bq l^{-1} caesium-137 in the North Sea surface waters in the late 1970s. Due to significantly decreasing discharges after 1978, remobilisation of caesium-137 from contaminated sediments in the Irish Sea was considered to be the dominant source of water contamination for most of the North Sea (McCubbin *et al.*, 2002).

Caesium-137 concentrations in the Irish Sea are 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 2017 seawater survey recorded concentrations of up to 0.06 Bq l^{-1} in the eastern Irish Sea. Elsewhere concentrations were generally below 0.02 Bq l^{-1}. A recent study has re-confirmed that the predominant source of caesium-137 to the Irish Sea was due to the remobilisation into the water column from activity associated with seabed sediment (Hunt *et al.*, 2013). Discharges from Sellafield have decreased substantially since the commissioning of the SIXEP waste treatment process in the mid-1980s, and this has been reflected in a near exponential decrease in shoreline seawater concentrations at St Bees (Figure 8.9). In more recent years, the rate of decline of caesium-137 concentrations with time has been decreasing at St Bees. Longer time series showing peak concentrations in the Irish Sea and, with an associated time-lag, the North Sea are also shown in Figure 8.9

In 2018, caesium-137 concentrations (reported as less than values) in the western English Channel (including those near the Channel Islands) were not distinguishable from the background of fallout from nuclear weapons testing (Figure 8.5).

A full assessment of historic long-term trends of caesium-137 in surface waters of Northern European seas is provided elsewhere (Povinec *et al.*, 2003).

Tritium concentrations in North Sea seawater in 2018 are shown in Figure 8.6 and were generally lower than those observed in the Irish Sea in 2017 (Environment Agency, FSA, FSS, NIEA, NRW and SEPA, 2018) due to the influence of discharges from Sellafield and other nuclear licensed sites. As in previous North Sea surveys, tritium concentrations were positively detected, measured just above the less than value in 2018, in a few water samples taken from the most southerly sampling locations of the North Sea. The most probable source of this is from the authorised discharges of tritium from nuclear power plants located in the vicinity (including those on the English Channel coast).

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. Tritium concentrations in the Bristol Channel were very low in 2018 and broadly similar to those in previous years, although slightly lower in the vicinity of the Welsh coast (in comparison to previous years). 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 (Leonard *et al.*, 1997a, b; 2004; McCubbin *et al.*, 2002; 2008) and an estimate of the total inventory residing

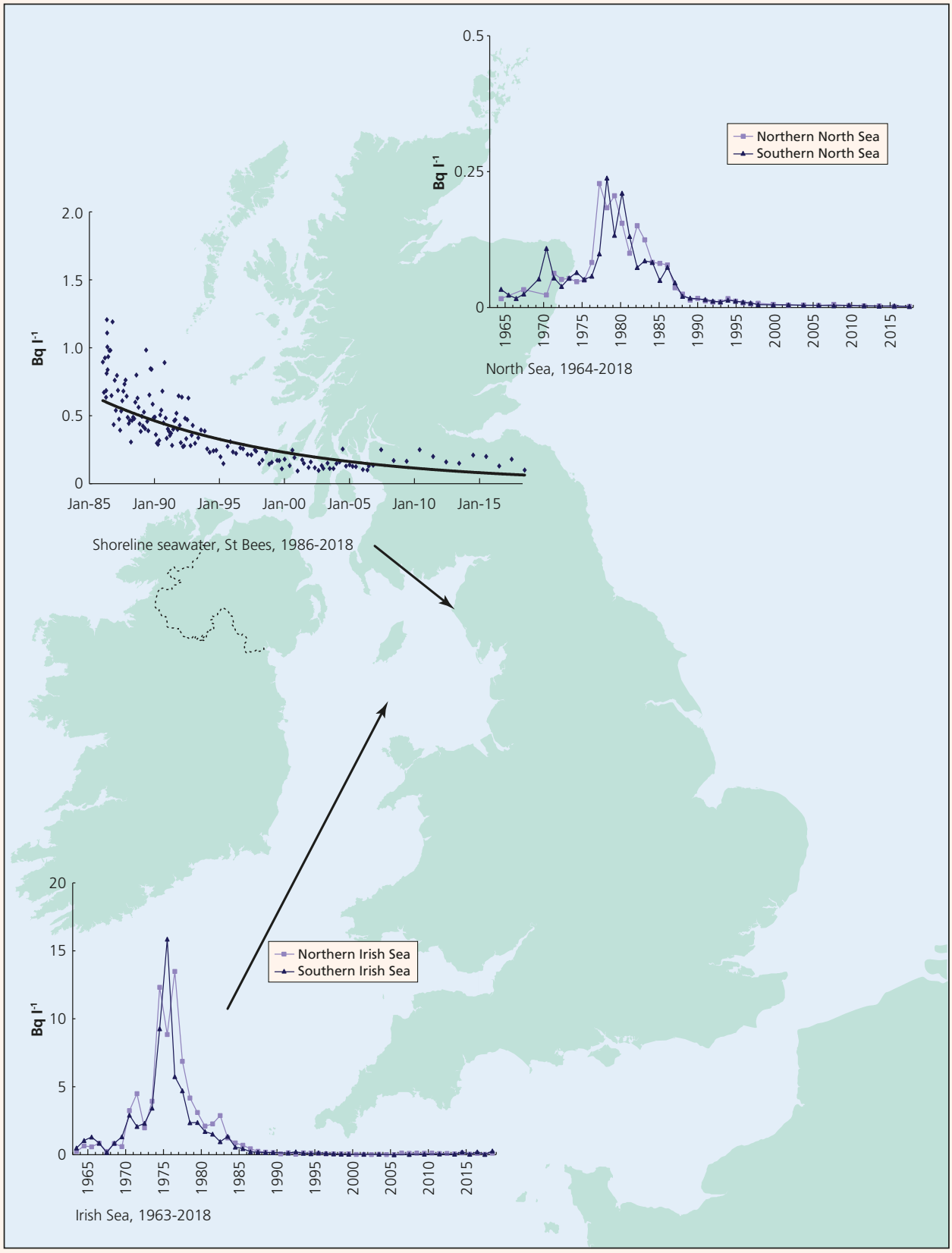


Figure 8.9. Concentration of caesium-137 in the Irish Sea, North Sea and in shoreline seawater close to Sellafield at St. Bees
(Note different scales used for activity concentrations)

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 also been published (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 (e.g. 2000b; 2009; 2010b). The Fourth Periodic Evaluation focusses on radioactive discharges from the nuclear and non-nuclear sectors, reporting clear evidence of progress towards the RSS objectives for the nuclear sector (OSPAR, 2016). Information on OSPAR's Intermediate Assessment 2017, can be found at: **https://oap.ospar.org/en/ospar-assessments/intermediate-assessment-2017/pressures-human-activities/4pe/**

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 results are collated in Table 8.11. Most radionuclides are reported as less than values. Tritium and caesium-137 concentrations 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).

Table 8.1 Concentrations of radionuclides in seafood and the environment near the Channel Islands, 2018

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										
	Crabs	1				<0.07			<0.56	<0.05
	Lobsters	1				<0.20			<1.6	<0.15
	Limpets	1				<0.06			<0.49	<0.06
	Pacific Oysters	1				<0.07			<0.61	<0.06
	Scallops	1				<0.03			<0.29	<0.03
St. Sampson's Harbour	Sand	1				<0.17			<1.9	0.27
	Seawater	2								0.0012
Jersey										
	Crabs	1				<0.06			<0.86	<0.06
	Spiny spider crabs	1				<0.07			<0.81	<0.08
	Lobsters	1				<0.10		0.15	<0.61	<0.10
La Rocque	Oysters	1				<0.04			<0.35	<0.05
Plemont Bay	*Porphyra*	2				<0.06			<0.63	<0.07
La Rozel	*Fucus vesiculosus*	4				<0.08	<0.039	1.6	<0.51	<0.07
Gorey	*Ascophyllum nodosum*	4				<0.09			<0.63	<0.06
Alderney										
	Crabs	2	<25	<25	45	<0.06		<0.23	<0.49	<0.05
	Spiny spider crabs	1				<0.11			<0.36	<0.03
	Lobsters	1				<0.05			<0.48	<0.09
	Toothed winkles	1	<25	<25	130	<0.21	<0.14		<1.2	<0.13
	Fucus vesiculosus[b]	2								
Quenard Point	*Fucus serratus*	4				<0.06	<0.036	0.78	<0.64	<0.07
Quenard Point	*Laminaria digitata*	4				<0.07			<0.70	<0.06
Little Crabbe Harbour	Sand	1				<0.11			<0.96	1.3
	Seawater	4		4.9						0.002

Table 8.1 continued

Location	Material	No. of sampling observ-ations	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}						
			^{155}Eu	^{238}Pu	^{239}Pu + ^{240}Pu	^{241}Am	^{242}Cm	^{243}Cm+ ^{244}Cm	Gross beta
Guernsey									
	Crabs	1	<0.17	0.00036	0.0010	0.0019	*	0.00017	100
	Lobsters	1	<0.32			<0.36			68
	Limpets	1	<0.14			<0.18			61
	Pacific Oysters	1	<0.18			<0.20			44
	Scallops	1	<0.10	0.00038	0.0018	0.00055	*	0.000042	64
St. Sampson's Harbour	Sand	1	<0.55	0.027	0.11	0.13	*	0.0080	520
	Seawater	2							
Jersey									
	Crabs	1	<0.18	0.00010	0.00040	0.0016	*	0.000087	98
	Spiny spider crabs	1	<0.26			<0.24			130
	Lobsters	1	<0.20	0.00029	0.0012	0.015	*	0.0014	61
La Rocque	Oysters	1	<0.08	0.00070	0.0022	0.0027	*	0.00024	39
Plemont Bay	*Porphyra*	2	<0.13			<0.17			87
La Rozel	*Fucus vesiculosus*	4	<0.16	0.0043	0.015	0.0035	*	0.00032	210
Gorey	*Ascophyllum nodosum*	4	<0.17			<0.22			230
Alderney									
	Crabs	2	<0.16	0.00017	0.00043	0.0031	*	0.00019	110
	Spiny spider crabs	1	<0.11	0.00069	0.0021	0.0028	0.000025	0.00026	89
	Lobsters	1	<0.16	0.00014	0.00050	0.0041	*	0.00035	87
	Toothed winkles	1	<0.26	0.0099	0.025	0.040	0.00034	0.0038	90
	Fucus vesiculosus[b]	2							
Quenard Point	*Fucus serratus*	4	<0.34	0.0028	0.0086	0.0072	0.00015	0.00071	160
Quenard Point	*Laminaria digitata*	4	<0.12			<0.16			190
Little Crabbe Harbour	Sand	1	<0.69			0.87			650
	Seawater	4							

* *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 1.0 Bq kg^{-1}*

Table 8.2(a) Concentrations of radionuclides in seafood and the environment in Northern Ireland, 2018[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		<0.17	<0.07	1.2
Plaice	Kilkeel	4		<0.11		<0.22	<0.10	0.25
Haddock	Kilkeel	4		<0.07		<0.16	<0.06	0.45
Herring	Ardglass	2		<0.10		<0.24	<0.09	0.31
Lesser spotted dogfish	North coast	4		<0.19		<0.44	<0.17	1.2
Skates / rays	Kilkeel	4		<0.12		<0.28	<0.11	0.77
Crabs	Kilkeel[c]	4		<0.06		<0.15	<0.06	0.15
Lobsters	Ballycastle	2		<0.07	9.8	<0.20	<0.08	0.27
Lobsters	Kilkeel[c]	4		<0.12	6.9	<0.23	<0.11	<0.19
Nephrops	Kilkeel	4		<0.07	1.6	<0.17	<0.08	0.38
Winkles	Minerstown[c]	4		<0.08		<0.23	<0.10	0.27
Mussels	Carlingford Lough[c]	2		<0.12	1.2	<0.27	<0.13	0.33
Scallops	Co. Down	2		<0.08		<0.17	<0.08	0.18
Ascophyllum nodosum	Carlingford Lough	1		<0.12		<0.23	<0.09	0.36
Fucus spp.	Carlingford Lough	3		<0.04	13	<0.10	<0.06	0.25
Fucus spp.	Portrush	4		<0.07		<0.15	<0.08	<0.08
Fucus vesiculosus	Ardglass	3		<0.04	22	<0.12	<0.04	0.38
Rhodymenia spp.	Portaferry	4		<0.07	0.35	<0.16	<0.06	1.0
Mud	Carlingford Lough	2		1.3		<0.72	<0.59	36
Mud	Ballymacormick	2		<0.24		<0.61	<0.39	9.4
Mud	Dundrum Bay	2		<0.38		<0.98	<0.60	28
Mud	Strangford Lough (Nicky's Point)	2		<0.20		<0.55	<0.24	14
Mud	Oldmill Bay	2		<0.23		<0.65	<0.43	22
Sand	Portrush	2		<0.23		<0.54	<0.26	0.50
Mud	Carrichue	2		<0.26		<0.62	<0.31	3.0
Seawater	North of Larne	5			0.0022		*	0.0073

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	<0.15			<0.13		
Plaice	Kilkeel	4	<0.19			<0.19		
Haddock	Kilkeel	4	<0.14			<0.14		
Herring	Ardglass	2	<0.24			<0.26		
Lesser spotted dogfish	North coast	4	<0.29			<0.25		
Skates / rays	Kilkeel	4	<0.26			<0.29		
Crabs	Kilkeel[c]	4	<0.18			<0.17		
Lobsters	Ballycastle	2	<0.14			<0.19		
Lobsters	Kilkeel[c]	4	<0.21			<0.22		
Nephrops	Kilkeel	4	<0.17	0.0014	0.0077	0.025	*	*
Winkles	Minerstown[c]	4	<0.19	0.033	0.19	0.14	*	*
Mussels	Carlingford Lough[c]	2	<0.23			<0.24		
Scallops	Co. Down	2	<0.14			<0.15		
Ascophyllum nodosum	Carlingford Lough	1	<0.23			<0.12		
Fucus spp.	Carlingford Lough	3	<0.17			<0.15		
Fucus spp.	Portrush	4	<0.15			<0.21		
Fucus vesiculosus	Ardglass	3	<0.13			<0.20		
Rhodymenia spp.	Portaferry	4	<0.12	0.12	0.72	1.3	*	0.0020
Mud	Carlingford Lough	2	<1.1	1.8	12	9.7	*	*
Mud	Ballymacormick	2	<0.72			11		
Mud	Dundrum Bay	2	<1.3			8.7		
Mud	Strangford Lough (Nicky's Point)	2	<0.90			4.8		
Mud	Oldmill Bay	2	<1.2			6.8		
Sand	Portrush	2	<0.59			<1.2		
Mud	Carrichue	2	<0.96	0.30	2.1	2.3	*	*
Seawater	North of Larne	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*

[c] *Data for natural radionuclides for some of these samples may be available in Table 7.6*

Table 8.2(b) Monitoring of radiation dose rates in Northern Ireland, 2018[a]

Location	Ground type	No. of sampling observations	Mean gamma dose rate in air at 1m, μGy h^{-1}
Lisahally	Mud	1	0.057
Donnybrewer	Shingle	1	0.055
Carrichue	Mud	1	0.070
Bellerena	Mud	1	0.063
Benone	Sand	1	0.059
Castlerock	Sand	1	0.062
Portstewart	Sand	1	0.056
Portrush, Blue Pool	Sand	1	0.054
Portrush, White Rocks	Sand	1	0.055
Portballintrae	Sand	1	0.055
Giant's Causeway	Sand	1	0.056
Ballycastle	Sand	1	0.054
Cushendun	Sand	1	0.058
Cushendall	Sand and stones	1	0.063
Red Bay	Sand	1	0.069
Carnlough	Sand	1	0.059
Glenarm	Sand	1	0.057
Half Way House	Sand	1	0.058
Ballygally	Sand	1	0.052
Drains Bay	Sand	1	0.053
Larne	Sand	1	0.062
Whitehead	Sand	1	0.062
Carrickfergus	Sand	1	0.057
Jordanstown	Sand	1	0.056
Strangford	Shingle and stones	1	0.094
Kilclief	Sand	1	0.069
Ardglass	Mud	1	0.084
Killough	Mud	1	0.086
Ringmore Point	Sand	1	0.073
Tyrella	Sand	1	0.078
Dundrum	Sand	1	0.084
Newcastle	Sand	1	0.11
Annalong	Sand	1	0.11
Cranfield Bay	Sand	1	0.082
Mill Bay	Sand	1	0.11
Greencastle	Sand	1	0.091
Rostrevor	Sand	1	0.11
Narrow Water	Mud	1	0.096

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

Table 8.3 Concentrations of radionuclides in diet, 2018[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		84	<0.029	<0.05
Northern Ireland	5		95	<0.034	<0.06
Scotland	12	<42	130	0.026	<0.04
Wales	5		91	<0.035	<0.06

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		67	<0.10	<0.05
East Lothian North Berwick	4		85	<0.10	<0.06
Renfrewshire Paisley	4		83	<0.10	<0.05
Ross-shire Dingwall	4		78	<0.10	<0.06

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

Table 8.4 Concentrations of radionuclides in milk remote from nuclear sites, 2018

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		18	<0.023	<0.08
Co. Armagh		1			<0.020	<0.05
Ceredigion		1			0.036	<0.05
Cheshire		1		16	<0.024	<0.04
Clwyd		1		12	<0.023	<0.04
Cornwall		1		22	<0.028	<0.03
Devon		1		17	0.027	<0.04
Dorset		1		9	<0.025	<0.04
Co. Down		1			<0.025	<0.04
Dumfriesshire		1	<5.0	<23	<0.10	<0.05
Co. Fermanagh		1			<0.022	<0.04
Gloucestershire		1		11	<0.026	<0.04
Gwynedd		1		19	0.030	<0.04
Hampshire		1		12	0.020	<0.04
Humberside		1		17	<0.025	<0.04
Kent		1		18	<0.025	<0.03
Lanarkshire		1	<5.2	<15	<0.018	<0.04
Lancashire		1		19	<0.023	<0.06
Leicestershire		1		17	<0.023	<0.03
Middlesex		1		18	<0.023	<0.04
Midlothian		1	<5.0	<17	<0.10	<0.06
Nairnshire		1	<5.0	<15	<0.10	<0.05
Norfolk		1		14	<0.021	<0.03
North Yorkshire		1		14	<0.026	<0.04
Renfrewshire		1	<5.0	<15	<0.10	<0.05
Suffolk		1		12	<0.023	<0.06
Co. Tyrone		2		9.2	<0.027	<0.05
	max					
Mean Values						
England				15	<0.024	<0.04
Northern Ireland				14	<0.023	<0.05
Wales				16	<0.030	<0.04
Scotland			<5.0	<17	<0.084	<0.05
United Kingdom			<5.0	<16	<0.036	<0.04

[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, 2018

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	<1.4	0.94			<0.0093	
	Air	4		0.0030			$<5.4\ 10^{-7}$	
Co. Down								
Conlig	Rainwater	4		1.1			<0.012	
	Air	4		0.0039			$<4.1\ 10^{-7}$	
Dumfries and Galloway								
Eskdalemuir	Rainwater	12	<1.0	1.1		<0.0053	<0.010	
	Air	12		0.0018			$<1.0\ 10^{-5}$	
City of Edinburgh								
Edinburgh Silvan	Air	7		0.0018			$<1.0\ 10^{-5}$	
North Lanarkshire								
Holytown	Rainwater	12	<1.0	0.48		<0.0085	<0.011	
	Air	12		0.0011			$<1.0\ 10^{-5}$	
North Yorkshire								
Dishforth/Leeming	Rainwater	4		1.3			<0.013	
	Air	4		0.0021			$<6.2\ 10^{-7}$	
Oxfordshire								
Chilton	Rainwater	4		1.5	53	<0.00067[b]	<0.016	<53
	Air	12			0.0028			$<4.5\ 10^{-7}$
Shetland								
Lerwick	Rainwater	12	<1.0	1.7		<0.0060	<0.010	
	Air	12		0.0016			$<1.0\ 10^{-5}$	
Suffolk								
Orfordness	Rainwater	4	<1.5	1.4			<0.011	
	Air	4		0.0038			$<4.9\ 10^{-7}$	

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	$<2.0\ 10^{-6}$	$1.0\ 10^{-5}$	$5.0\ 10^{-5}$		
	Air	4	$<1.0\ 10^{-10}$	$1.0\ 10^{-9}$	$<2.4\ 10^{-9}$		
Dumfries and Galloway							
Eskdalemuir	Air	12					<0.00020
City of Edinburgh							
Edinburgh Silvan	Air	7					<0.00020
North Lanarkshire							
Holytown	Air	12					<0.00020
Oxfordshire							
Chilton	Rainwater	4				0.042[d]	0.31[d]
Shetland							
Lerwick	Air	12					<0.00023

[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, 2018

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	<0.0098	0.035
Argyll and Bute	Auchengaich	1	<1.0		<0.01	<0.010	0.015
Argyll and Bute	Helensburgh Reservoir	1	<1.0		<0.01	<0.010	0.065
Argyll and Bute	Loch Ascog	1	<1.0		<0.01	<0.010	0.10
Argyll and Bute	Loch Eck	1	<1.0		<0.01	<0.010	0.049
Argyll and Bute	Lochan Ghlas Laoigh	1	<1.0		<0.01	0.011	0.035
Argyll and Bute	Loch Finlas	1	<1.0		<0.01	<0.010	0.039
Clackmannanshire	Gartmorn Dam	1	<1.0		<0.01	<0.010	0.088
Dumfries and Galloway	Black Esk	1	<1.0		<0.01	<0.010	0.018
Dumfries and Galloway	Gullielands Burn	1	14		<0.01	<0.011	0.22
Dumfries and Galloway	Purdomstone	1	<1.0		<0.01	<0.010	0.051
Dumfries and Galloway	Winterhope	1	<1.0		<0.01	<0.010	0.049
East Lothian	Hopes Reservoir	1	<1.0		<0.01	<0.010	0.034
East Lothian	Thorters Reservoir	1	<1.0		<0.01	<0.010	0.031
East Lothian	Whiteadder	1	<1.1		<0.01	<0.010	0.045
East Lothian	Thornton Loch Burn	1	<1.0		<0.01	0.011	0.071
Fife	Holl Reservoir	1	<1.0		<0.01	<0.010	0.028
Highland	Loch Baligill	1	<1.0		0.01	0.16	0.13
Highland	Loch Calder	1	<1.0		<0.01	0.013	0.090
Highland	Loch Glass	4	<1.0	<0.0050	<0.01	<0.0090	0.050
Highland	Loch Shurrerey	1	<1.0		<0.01	<0.010	0.048
North Ayrshire	Camphill	1	<1.0		<0.01	<0.010	0.050
North Ayrshire	Knockendon Reservoir	1	<1.0		<0.01	<0.010	0.025
North Ayrshire	Munnoch Reservoir	1	<1.0		<0.01	<0.010	0.095
North Ayrshire	Outerwards	1	<1.0		<0.01	<0.010	0.038
Orkney Islands	Heldale Water	1	<1.0		<0.01	<0.010	0.060
Perth and Kinross	Castlehill Reservoir	1	<1.0		<0.01	<0.010	0.066
Scottish Borders	Knowesdean	4	<1.0	<0.0050	<0.01	<0.027	0.032
Stirling	Loch Katrine	12	<1.0	<0.0068	<0.0071	<0.013	0.044
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	0.054

Table 8.7 Concentrations of radionuclides in sources of drinking water in England and Wales, 2018

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	<3.4	0.35	<0.0018		<0.0010	<0.038	0.47	0.35
Cornwall	River Fowey	4	<3.5	<0.033	<0.0013	<0.0085	<0.0011	0.041	0.088	0.063
County Durham	Honey Hill Water Treatment Works, Consett	4	<3.4	<0.024	<0.0028		<0.0026	0.092	0.17	0.13
County Durham	River Tees, Darlington	4	<3.5	<0.023	<0.0017	<0.0072	<0.0010	<0.015	0.086	<0.060
Cumbria	Ennerdale Lake	4	<3.7	<0.019	<0.0011		<0.0010	<0.015	<0.064	<0.056
Cumbria	Haweswater Reservoir	4	<3.7	<0.017	<0.0012		<0.0010	<0.016	<0.062	<0.054
Derbyshire	Arnfield Water Treatment Plant	4	<3.5	<0.026	<0.00089		<0.0010	<0.016	0.076	0.057
Derbyshire	Matlock, Groundwater[a]	4	<3.7	<0.018	<0.00088		<0.0010	0.13	0.11	0.084
Devon	River Exe, Exeter	2	<3.5	<0.029	<0.00078	<0.0045	<0.0015	<0.065	0.12	0.099
Devon	Roadford Reservoir, Broadwoodwidger	4	<3.4	0.061	<0.0012		<0.0010	<0.016	0.086	0.065
Greater London	River Lee, Chingford	4	<3.4	0.28	<0.0017	<0.0088	<0.0010	<0.034	0.41	0.31
Hampshire	River Avon, Christchurch	4	<3.4	0.075	<0.00099	<0.0096	<0.0010	<0.029	0.094	0.069
Humberside	Littlecoates, Groundwater	4	<3.4	0.074	<0.0010		<0.0010	<0.022	0.12	0.087
Kent	Chatham, Deep Groundwater	4	<3.4	<0.037	<0.00097		<0.0010	<0.027	0.085	0.060
Kent	Denge, Shallow Groundwater	4	<3.4	0.071	<0.0020		<0.0010	<0.032	0.11	0.073
Norfolk	River Drove, Stoke Ferry	4	<3.6	0.094	<0.0014	<0.012	<0.0010	<0.044	0.13	0.099
Northumberland	Kielder Reservoir	4	<3.7	<0.027	<0.0010		<0.0011	<0.017	<0.063	<0.054
Oxfordshire	River Thames, Oxford	4	<3.4	0.15	<0.0013	<0.0069	<0.0010	<0.034	0.22	0.16
Somerset	Ashford Reservoir, Bridgwater	4	<3.6	<0.074	<0.0010		<0.0011	<0.042	0.13	0.091
Somerset	Chew Valley Lake Reservoir, Bristol	4	<3.6	0.11	<0.0015		<0.0010	<0.030	0.18	0.13
Surrey	River Thames, Walton	4	<3.6	0.21	<0.0015	<0.0083	<0.0010	<0.028	0.26	0.19
Wales										
Gwynedd	Cwm Ystradllyn Treatment Works	4	<3.4	<0.015	<0.0011		<0.0010	<0.013	<0.038	<0.036
Mid-Glamorgan	Llwyn-on Reservoir	4	<3.7	<0.019	<0.0013		<0.0010	0.022	<0.043	<0.040
Powys	Elan Valley Reservoir	4	<3.4	<0.018	<0.0021		<0.0010	<0.016	<0.036	<0.035

[1] *Using ^{137}Cs standard*
[2] *Using ^{40}K standard*
[a] *The concentrations of ^{210}Po, ^{226}Ra, ^{234}U, ^{235}U and ^{238}U were <0.0073, 0.014, 0.034, <0.0053 and 0.017 Bq kg^{-1}, respectively*

Table 8.8 Concentrations of radionuclides in sources of drinking water in Northern Ireland, 2018

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	<4.2	0.0036	<0.015	0.0020	<0.02	0.0030	<0.0010	0.0030	<0.10	<0.17
Co. Antrim	Lough Neagh	4	<4.2	0.0043	<0.015	0.0040	<0.01	0.0040	<0.0010	0.0020	<0.10	<0.17
Co. Down	Silent Valley	4	<4.2	0.0030	<0.015	0.0090	<0.02	0.011	0.0010	0.0060	<0.10	<0.17

Table 8.9 Doses from radionuclides in drinking water, 2018[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	0.022	0.022	Matlock, Groundwater, Derbyshire	0.022
Wales[d]	<0.001			Cwm Ystradllyn Treatment Works, Gwynedd	<0.001[d]
Northern Ireland	<0.001	0.016	0.016	Silent Valley, Co. Down	0.026
Scotland[d]	<0.001			Gullielands Burn, Dumfries and Galloway	<0.001[d]
UK	<0.001	0.018	0.018	Silent Valley, Co. Down	0.026

[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, 2018

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
Scottish Borders	Cockburnspath	1	<1.0	<0.10	<0.10	<0.10
West Lothian	Livingston	1	<1.0	<0.10	<0.10	0.42
Clackmannanshire	Alva	1	<1.0	<0.10	0.10	0.12
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	0.12
Aberdeenshire	Mintlaw	1	<1.0	<0.10	<0.10	0.12
Aberdeenshire	Delgaty	1	<1.0	<0.10	<0.10	<0.10
Aberdeenshire	Huntly	1	<1.0	<0.10	<0.10	<0.10
Moray	Fochabers	1	<1.0	<0.10	<0.10	0.27
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	<0.10
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, 2018

Location	No. of sampling observations	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]	<1.0		<0.10			<0.34	<0.10	
Dounreay (Brims Ness)	2[S]	<1.0		<0.10			<0.49	<0.10	
Rosyth	1[S]	<1.0		<0.10			<0.21	<0.10	
Firth of Forth (Devon Confluence)	1[S]	<1.0		<0.10			<0.58	<0.10	
Torness[a]	2[S]	<1.0		<0.10			<0.29	<0.10	
Hartlepool (North Gare)[b]	2	<2.5		<0.34			<2.4	<0.39	
Sizewell	2	<2.6	<3.3	<0.37			<2.6	<0.41	
Bradwell (Beach pipeline)	2	<2.8		<0.39			<2.5	<0.42	
Dungeness south	2	<3.5		<0.30			<2.1	<0.33	
Winfrith (Lulworth Cove)	1			<0.34			<2.2	<0.33	
Alderney	4[C]	4.9							
Guernsey	4[C]								
Devonport (Millbrook Lake)	1	<2.7	<3.4	<0.25					
Devonport (Tor Point South)	1	<3.0	<3.0	<0.25					
Hinkley	1	15		<0.24	<0.045		<1.8	<0.28	
Berkeley and Oldbury	2	<3.0		<0.28			<2.0	<0.31	
Cardiff (West of sewage outfall)[c]	1	<2.5	<2.7						
Wylfa (Cemaes Bay)	2	<2.8		<0.32			<2.4	<0.39	
Heysham[d]	2	36		<0.44			<2.9	<0.48	
Seascale (Particulate)[e]	2			<0.03	<0.015		<0.21	<0.035	<0.026
Seascale (Filtrate)	2	13	<7.6	<0.12	<0.0040	<0.39	<0.86	<0.14	<0.17
St. Bees (Particulate)[f]	2			<0.03	<0.015		<0.21	<0.032	<0.025
St. Bees (Filtrate)	2	<17	<3.8	<0.12	<0.046	<0.63	<0.88	<0.14	<0.16
Seafield	2[S]	<1.7		<0.10			<0.30	<0.10	
Southerness	2[S]	3.6		<0.10			<0.42	<0.10	
Auchencairn	2[S]	3.1		<0.10			<0.40	<0.10	
Port Patrick	2[S]	<1.1		<0.10			<0.37	<0.10	
Hunterston[g]	2[S]	3.6		<0.10			<0.29	<0.10	
North of Larne	5[N]					0.0022			
Faslane (Carnban)	2[S]	<2.3		<0.10			<0.28	<0.10	

Table 8.11 continued

Location	No. of sampling observations	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	<0.21		<0.10		
Dounreay (Brims Ness)	2[S]	<0.10	<0.10	<0.31		<0.10		
Rosyth	1[S]	<0.10	<0.10	<0.13		<0.10		
Firth of Forth (Devon Confluence)	1[S]	<0.10	<0.10	<0.39		<0.10		
Torness[a]	2[S]	<0.10	<0.10	<0.19		<0.10		
Hartlepool (North Gare)[b]	2	<0.36	<0.29	<1.1		<0.35	<5.6	13
Sizewell	2	<0.39	<0.30	<1.2		<0.36	<4.1	15
Bradwell (Beach pipeline)	2	<0.40	<0.31	<1.2		<0.36	<3.1	12
Dungeness south	2	<0.28	<0.24	<1.0		<0.31	<3.2	13
Winfrith (Lulworth Cove)	1	<0.33	<0.27	<0.99		<0.33	<3.0	16
Alderney	4[C]	*	0.0017					
Guernsey	4[C]	*	0.0012					
Devonport (Millbrook Lake)	1							
Devonport (Tor Point South)	1							
Hinkley	1	<0.25	<0.22	<0.96		<0.31	<3.0	13
Berkeley and Oldbury	2	<0.30	<0.24	<1.0		<0.32	<2.1	6.9
Cardiff (West of sewage outfall)[c]	1							
Wylfa (Cemaes Bay)	2	<0.34	<0.28	<1.1		<0.34	<2.7	11
Heysham[d]	2	<0.42	<0.36	<1.2		<0.38	<4.5	12
Seascale (Particulate)[e]	2	<0.03	<0.03	<0.093	<0.00051	<0.10	0.27	0.10
Seascale (Filtrate)	2	<0.12	<0.11	<0.50	<0.025	<0.18	<4.1	14
St. Bees (Particulate)[f]	2	<0.028	<0.02	<0.11	<0.00041	<0.031	0.024	0.037
St. Bees (Filtrate)	2	<0.12	<0.10	<0.46	<0.030	<0.16	<2.8	15
Seafield	2[S]	<0.10	<0.10	<0.20		<0.10		
Southerness	2[S]	<0.10	<0.10	<0.27		<0.10		
Auchencairn	2[S]	<0.10	<0.10	<0.25		<0.10		
Port Patrick	2[S]	<0.10	<0.10	<0.21		<0.10		
Hunterston[g]	2[S]	<0.10	<0.10	<0.19		<0.10		
North of Larne	5[N]	*	0.0073					
Faslane (Carnban)	2[S]	<0.10	<0.10	<0.17		<0.10		

* *Not detected by the method used*

[a] *The concentration of ^{35}S was <0.50 Bq l^{-1}*

[b] *The concentration of ^{35}S was <0.45 Bq l^{-1}*

[c] *The concentration of ^{3}H as tritiated water was <15 Bq l^{-1}*

[d] *The concentration of ^{35}S was <0.64 Bq l^{-1}*

[e] *The concentrations of ^{238}Pu, $^{239+240}Pu$ and ^{241}Pu were 0.0096, 0.049 and <1.3 Bq l^{-1}, respectively*

[f] *The concentrations of ^{238}Pu, $^{239+240}Pu$ and ^{241}Pu were <0.0011, 0.0042 and <0.30 Bq l^{-1}, respectively*

[g] *The concentration of ^{35}S was 0.57 Bq l^{-1}*

Results are made on behalf of the Environment Agency unless indicated otherwise

[C] *Measurements labelled "C" are made on behalf of 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)

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APPENDIX 1. Sampling, measurement, presentation and assessment methods and data

This Appendix contains information on the methods of sampling, measurement, presentation and assessment used in the Radioactivity in Food and the Environment report. It is provided in a separate file to the main report at **https://www.gov.uk/government/publications/radioactivity-in-food-and-the-environment-rife-reports**.

APPENDIX 2. Disposals of radioactive waste

Table A2.1 Principal discharges of gaseous radioactive wastes from nuclear establishments in the United Kingdom, 2018

Establishment	Radioactivity	Discharge limit (annual equivalent)[a], Bq	Discharges during 2018	
			Bq	% of annual limit[b]
Nuclear fuel production and reprocessing				
Capenhurst (UNS Ltd)	Alpha	BAT	2.95E+05	NA
Other authorised outlets	Beta	BAT	1.08E+06	NA
Capenhurst	Uranium	7.50E+06	4.21E+05	5.6
(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, 5]	Alpha	8.80E+08	1.04E+08	12
	Beta	4.20E+10	6.26E+08	1.5
	Tritium	1.10E+15	9.02E+13	8.2
	Carbon-14	3.30E+12	4.27E+11	13
	Krypton-85	4.40E+17	6.47E+16	15
	Strontium-90	7.10E+08	1.34E+07	1.9
	Ruthenium-106	2.30E+10	4.94E+08	2.1
	Antimony-125	3.00E+10	1.33E+09	4.4
	Iodine-129	7.00E+10	1.02E+10	15
	Iodine-131	3.70E+10	3.94E+08	1.1
	Caesium-137	5.80E+09	5.11E+07	<1
	Radon-222	5.00E+11	Nil	Nil
	Plutonium alpha	1.90E+08	2.86E+07	15
	Plutonium-241	3.00E+09	2.31E+08	7.7
	Americium-241 and curium-242	1.20E+08	1.57E+07	13
Springfields	Uranium	5.30E+09	2.14E+07	<1
Springfields (National	Tritium	1.00E+08	1.06E+06	1.1
Nuclear Laboratory)	Carbon-14	1.00E+07	2.50E+04	<1
	Krypton-85[l]	7.20E+11	2.77E+10	3.8
	Other alpha radionuclides	1.00E+06	Nil	Nil
	Other beta radionuclides	1.00E+07	2.87E+02	<1
Research establishments				
Dounreay[d]	Alpha[e]	3.10E+07	9.60E+04	<1
	Non-alpha[f]	1.70E+09	1.00E+06	<1
	Tritium	1.72E+13	2.50E+10	<1
	Krypton-85[g]	5.69E+14	1.50E+10	<1
	Iodine-129	1.08E+08	1.40E+07	13

Table A2.1 continued

Establishment	Radioactivity	Discharge limit (annual equivalent) [a], Bq	Discharges during 2018	
			Bq	% of annual limit[b]
Harwell (Research Sites Restoration Ltd)	Alpha	8.00E+05	2.10E+04	2.6
	Beta	2.00E+07	6.20E+05	3.1
	Tritium	1.50E+13	2.30E+11	1.5
	Krypton-85	2.00E+12	Nil	Nil
	Radon-220	1.00E+14	4.90E+12	4.9
	Radon-222	3.00E+12	2.40E+11	8.0
	Iodines	1.00E+10	Nil	Nil
	Other radionuclides	1.00E+11	Nil	Nil
Winfrith (Inutec)	Alpha	1.00E+05	Nil	Nil
	Tritium	1.95E+13	2.42E+11	1.2
	Carbon-14	3.00E+10	9.00E+06	<1
	Other	1.00E+05	Nil	Nil
Winfrith Research Sites (Restoration Ltd)	Alpha	2.00E+06	1.08E+03	<1
	Tritium	4.95E+13	2.66E+10	<1
	Carbon-14	5.90E+09	1.10E+08	1.9
	Other	5.00E+06	4.29E+04	<1
Minor sites				
Imperial College Reactor Centre Ascot	Tritium	3.00E+08	Nil	Nil
	Argon-41	1.70E+12	Nil	Nil
Nuclear power stations				
Berkeley[h]	Beta	2.00E+07	1.76E+05	<1
	Tritium	2.00E+10	5.78E+09	29
	Carbon-14	5.00E+09	5.14E+08	10
Bradwell	Beta	6.00E+08	2.84E+05	<1
	Tritium	6.00E+12	1.37E+10	<1
	Carbon-14	9.00E+11	5.55E+08	<1
Chapelcross	Tritium	7.50E+14	2.96E+13	3.9
	All other nuclides	2.50E+09	1.18E+09	47
Dungeness A Station	Beta[i]	5.00E+08	1.48E+06	<1
	Tritium	2.60E+12	3.43E+10	1.3
	Carbon-14	5.00E+12	2.33E+09	<1
Dungeness B Station	Tritium	1.20E+13	1.26E+12	11
	Carbon-14	3.70E+12	1.06E+12	29
	Sulphur-35	3.00E+11	4.61E+10	15
	Argon-41	7.50E+13	8.14E+12	11
	Cobalt-60[i]	1.00E+08	2.82E+06	2.8
	Iodine-131	1.50E+09	2.35E+07	1.6
Hartlepool	Tritium	1.00E+13	8.84E+11	8.8
	Carbon-14	4.50E+12	2.23E+12	50
	Sulphur-35	2.30E+11	2.91E+10	13
	Argon-41	1.50E+14	8.34E+12	5.6
	Cobalt-60[i]	1.00E+08	2.01E+07	20
	Iodine-131	1.50E+09	1.81E+08	12

Table A2.1 continued

Establishment	Radioactivity	Discharge limit (annual equivalent) [a], Bq	Discharges during 2018	
			Bq	% of annual limit[b]
Heysham	Tritium	1.00E+13	9.45E+11	9.5
Station 1	Carbon-14	4.50E+12	1.68E+12	37
	Sulphur-35	2.00E+11	3.25E+10	16
	Argon-41	1.50E+14	1.08E+13	7.2
	Cobalt-60[i]	1.00E+08	7.21E+06	7.2
	Iodine-131	1.50E+09	6.33E+07	4.2
Heysham	Tritium	1.00E+13	1.38E+12	14
Station 2	Carbon-14	3.70E+12	1.81E+12	49
	Sulphur-35	2.30E+11	2.25E+10	9.8
	Argon-41	7.50E+13	1.06E+13	14
	Cobalt-60[i]	1.00E+08	8.58E+06	8.6
	Iodine-131	1.50E+09	7.05E+07	4.7
Hinkley Point	Beta	5.00E+07	2.00E+05	<1
A Station	Tritium	7.50E+11	1.20E+10	1.6
	Carbon-14	5.00E+10	5.40E+08	1.1
Hinkley Point	Tritium	1.20E+13	1.31E+12	11
B Station	Carbon-14	3.70E+12	1.53E+12	41
	Sulphur-35	3.50E+11	6.51E+10	19
	Argon-41	1.00E+14	1.13E+13	11
	Cobalt-60[i]	1.00E+08	8.58E+06	8.6
	Iodine-131	1.50E+09	4.96E+06	<1
Hunterston	Tritium	2.00E+10	6.41E+08	3.2
A Station	Carbon-14	2.00E+09	6.55E+07	3.3
	All other radionuclides	3.00E+06	5.73E+05	19
Hunterston	Particulate beta	5.00E+08	4.64E+07	9.3
B Station[d]	Tritium	1.50E+13	9.60E+11	6.4
	Carbon-14	4.50E+12	8.44E+11	19
	Sulphur-35	5.00E+11	3.00E+10	6.0
	Argon-41	1.50E+14	4.65E+12	3.1
	Iodine-131	2.00E+09	9.00E+03	<1
Oldbury	Beta	1.00E+08	5.80E+04	<1
	Tritium	9.00E+12	3.79E+10	<1
	Carbon-14	4.00E+12	3.35E+09	<1
Sizewell	Beta	8.50E+08	1.95E+04	<1
A Station	Tritium	3.50E+12	2.64E+10	<1
	Carbon-14	1.00E+11	8.82E+08	<1
Sizewell	Noble gases	3.00E+13	2.62E+12	8.7
B Station	Particulate Beta	1.00E+08	3.50E+06	3.5
	Tritium	3.00E+12	3.67E+11	12
	Carbon-14	5.00E+11	2.15E+11	43
	Iodine-131	5.00E+08	1.16E+07	2.3
Torness	Particulate beta	4.00E+08	1.04E+07	2.6
	Tritium	1.10E+13	1.32E+12	12
	Carbon-14	4.50E+12	1.33E+12	30
	Sulphur-35	3.00E+11	4.68E+10	16
	Argon-41	7.50E+13	5.09E+12	6.8
	Iodine-131	2.00E+09	5.92E+06	<1

Table A2.1 continued

Establishment	Radioactivity	Discharge limit (annual equivalent) [a], Bq	Discharges during 2018	
			Bq	% of annual limit[b]
Trawsfynydd	Particulate Beta	5.00E+07	4.60E+05	<1
	Tritium	3.75E+11	3.73E+10	9.9
	Carbon-14	1.00E+10	1.09E+09	11
Wylfa	Particulate Beta	7.00E+08	2.50E+06	<1
	Tritium	1.80E+13	1.30E+11	<1
	Carbon-14	2.30E+12	1.08E+09	<1
	Sulphur-35	4.50E+11	7.50E+08	<1
	Argon-41	1.00E+14	Nil	Nil
Defence establishments				
Aldermaston[j]	Alpha	1.65E+05	2.86E+04	17
	Particulate Beta	6.00E+05	5.15E+04	8.6
	Tritium	3.90E+13	5.74E+11	1.5
	Carbon-14	6.00E+06	Nil	Nil
	Activation products[k]	BAT	5.90E+06	NA
	Volatile beta[2]	1.00E+08	2.56E+05	<1
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	1.42E+03	28
Coulport	Tritium	5.00E+10	1.77E+09	3.5
Derby[i, m]	Alphan	3.00E+06	1.08E+06	36
	Alpha[o,p]	2.40E+04	6.60E+01	<1
	Beta[o, p]	1.80E+06	3.71E+04	2.1
Devonport[q]	Beta[i]	3.00E+05	1.82E+04	6.1
	Tritium	4.00E+09	3.67E+08	9.2
	Carbon-14	6.60E+10	3.15E+08	<1
	Argon-41	1.50E+10	8.93E+06	<1
Dounreay[d] (Vulcan)	All other radionuclides[3]	5.10E+06	1.20E+06	24
	Noble gases	5.00E+09	Nil	Nil
Rosyth[r]	Tritium	1.00E+07	Nil	Nil
	Carbon-14	5.00E+07	Nil	Nil
	Other radionuclides	1.00E+05	Nil	Nil
Radiochemical production				
Amersham (GE Healthcare)	Alpha	2.25E+06	2.33E+04	1.0
	Radionuclides T1/2<2hr	7.50E+11	4.80E+09	<1
	Tritium	2.00E+12	3.64E+10	1.8
	Radon-222	1.00E+13	1.88E+12	19
	Other including selenium-75 and iodine-131	1.60E+10	1.07E+06	<1
Cardiff (GE Healthcare)	Tritium	6.00E+12	3.26E+12	54
	Carbon-14	1.10E+12	1.92E+11	17

Table A2.1 continued

Establishment	Radioactivity	Discharge limit (annual equivalent) [a], Bq	Discharges during 2018	
			Bq	% of annual limit[b]
Industrial and landfill sites				
LLWR	Alpha	BAT	1.00E+04	NA
	Beta	BAT	6.00E+04	NA
Lillyhall	Alpha (particulate)	5.00E+05	4.43E+03	<1
(Cyclife UK Limited)	Beta (particulate)	5.00E+05	1.91E+04	3.8

* *As reported to SEPA and the Environment Agency*
[a] *In some cases permits specify limits in greater detail than can be summarised in a single table; in particular, periods shorter than one year are specified at some sites*
[b] *Data quoted to 2 significant figures except where values are <1%*
[c] *Limits for tritium, carbon-14, krypton-85 and iodine-129 vary with the mass of uranium processed by THORP*
[d] *Some discharges are upper estimates because they include 'less than' data derived from analyses of effluents at limits of detection*
[e] *All alpha emitting nuclides taken together*
[f] *All non-alpha emitting 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 Technique*
[l] *Discharges from Barrow are included with those from MoD sites because they are related to submarine activities. Discharges were made by BAE Systems Marine Ltd*
[m] *Discharges were made by Rolls Royce Marine Power Operations Ltd*
[n] *Discharge limit is for the Nuclear Fuel Production Plant Site*
[o] *Annual limits on beta and alpha derived from monthly and weekly notification levels*
[p] *Discharge limit is for the Neptune Reactor Raynesway Site*
[q] *Discharges were made by Devonport Royal Dockyard Ltd*
[r] *Discharges were made by Rosyth Royal Dockyard Ltd*
[5] *In December 2017, the THORP plant limits for strontium-90, ruthenium-106, caesium-137, plutonium-alpha, plutonium-241 and americium-241 & curium-242 were removed*
[1] *Discharge permit revised with effect from September 2017*
[2] *Discharge permit revised with effect from June 2018*
[3] *Letter of agreement revised with effect from 1 January 2017*
NA Not applicable under permit
BAT Best available technology

Table A2.2 Principal discharges of liquid radioactive waste from nuclear establishments in the United Kingdom, 2018

Establishment	Radioactivity	Discharge limit (annual equivalent)[a], Bq	Discharges during 2018	
			Bq	% of annual limit[b]
Nuclear fuel production and reprocessing				
Capenhurst	Uranium	7.50E+08	1.77E+06	<1
(Urenco UK Ltd)	Uranium daughters	1.36E+09	3.82E+06	<1
	Non-uranic alpha	2.20E+08	9.43E+06	4.3
	Technetium-99	1.00E+09	1.88E+06	<1
Sellafield[c]	Alpha	9.00E+11	1.62E+11	18
	Beta	1.80E+14	1.04E+13	5.8
	Tritium	1.80E+16	1.27E+15	7.1
	Carbon-14	2.10E+13	2.93E+12	14
	Cobalt-60	3.60E+12	2.01E+10	<1
	Strontium-90	4.50E+13	1.28E+12	2.8
	Zirconium-95 + Niobium-95	2.80E+12	5.74E+10	2.1
	Technetium-99	1.00E+13	9.31E+11	9.3
	Ruthenium-106	5.10E+13	5.40E+11	1.1
	Iodine-129	2.00E+12	3.00E+11	15
	Caesium-134	1.60E+12	3.67E+10	2.3
	Caesium-137	3.40E+13	4.36E+12	13
	Cerium-144	4.00E+12	9.23E+10	2.3
	Neptunium-237	7.30E+11	4.65E+10	6.4
	Plutonium alpha	7.00E+11	1.39E+11	20
	Plutonium-241	2.50E+13	1.88E+12	7.5
	Americium-241	3.00E+11	1.94E+10	6.5
	Curium-243+244	5.00E+10	1.47E+09	2.9
	Uranium (in kg)[d]	2.00E+03	3.11E+02	16
Springfields	Alpha	1.00E+11	7.80E+09	7.8
	Beta	2.00E+13	2.80E+11	1.4
	Technetium-99	6.00E+11	7.90E+09	1.3
	Thorium-230	2.00E+10	4.50E+08	2.3
	Thorium-232[e]	1.50E+10	1.33E+08	<1
	Neptunium-237	4.00E+10	3.36E+08	<1
	Other transuranic radionuclides	2.00E+10	2.24E+09	11
	Uranium	4.00E+10	6.50E+09	16
Research establishments				
Dounreay[e]	Alpha[f]	3.40E+09	1.50E+08	4.4
	Non-alpha[g]	4.80E+10	6.70E+09	14
	Tritium	6.90E+12	1.80E+10	<1
	Strontium-90	1.77E+11	3.90E+10	22
	Caesium-137	6.29E+11	2.90E+09	<1
Harwell (Lydebank Brook)	Alpha	3.00E+07	4.69E+06	16
	Beta	3.00E+08	1.08E+07	3.6
	Tritium	2.00E+10	1.43E+09	7.1

Table A2.2 continued

Establishment	Radioactivity	Discharge limit (annual equivalent)[a], Bq	Discharges during 2018	
			Bq	% of annual limit[b]
Harwell (sewer)	Alpha	1.00E+07	1.51E+05	1.5
	Beta	6.00E+08	1.11E+07	1.8
	Tritium	1.00E+11	7.07E+08	<1
	Cobalt-60	5.00E+06	2.27E+05	4.5
	Caesium-137	2.00E+08	3.60E+06	1.8
Winfrith (inner pipeline)[h,3]	Alpha	1.40E+10	6.70E+06	<1
	Tritium	4.00E+13	3.79E+12	9.5
	Caesium-137	1.98E+12	4.32E+08	<1
	Other radionuclides	9.80E+11	2.67E+08	<1
Winfrith (outer pipeline)	Alpha	2.00E+09	1.20E+06	<1
	Tritium	1.50E+11	2.96E+08	<1
	Other radionuclides	1.00E+09	2.86E+06	<1
Winfrith (River Frome)	Tritium	7.50E+11	Nil	Nil
Minor sites				
Imperial College Reactor Centre	Tritium	4.00E+07	Nil	Nil
Ascot	Other radioactivity	1.00E+07	Nil	Nil
Nuclear power stations				
Berkeley	Tritium	1.00E+12	3.27E+06	<1
	Caesium-137	2.00E+11	7.78E+06	<1
	Other radionuclides	2.00E+11	1.20E+06	<1
Bradwell	Tritium	7.00E+12	Nil	Nil
	Caesium-137	7.00E+11	Nil	Nil
	Other radionuclides	7.00E+11	Nil	Nil
Chapelcross	Alpha	1.00E+09	3.80E+06	<1
	Non-alpha[i]	1.00E+12	2.37E+09	<1
	Tritium	6.50E+12	5.19E+09	<1
Dungeness	Tritium	8.00E+12	2.40E+10	<1
A Station	Caesium-137	1.10E+12	1.67E+10	1.5
	Other radionuclides	8.00E+11	1.86E+10	2.3
Dungeness	Tritium	6.50E+14	2.56E+14	39
B Station	Sulphur-35	2.00E+12	2.89E+11	14
	Cobalt-60	1.00E+10	8.52E+08	8.5
	Caesium-137	1.00E+11	2.04E+09	2.0
	Other radionuclides	8.00E+10	2.73E+09	3.4
Hartlepool	Tritium	6.50E+14	4.02E+14	62
	Sulphur-35[2]	3.60E+12	1.51E+12	42
	Cobalt-60	1.00E+10	2.21E+08	2.2
	Caesium-137	1.00E+11	3.38E+09	3.4
	Other radionuclides	8.00E+10	1.32E+09	1.7

Table A2.2 continued

Establishment	Radioactivity	Discharge limit (annual equivalent)[a], Bq	Discharges during 2018	
			Bq	% of annual limit[b]
Heysham	Tritium	6.50E+14	3.19E+14	49
Station 1	Sulphur-35	2.00E+12	3.95E+11	20
	Cobalt-60	1.00E+10	2.25E+08	2.3
	Caesium-137	1.00E+11	6.29E+08	<1
	Other radionuclides	8.00E+10	5.04E+09	6.3
Heysham	Tritium	6.50E+14	3.55E+14	55
Station 2	Sulphur-35	2.00E+12	1.65E+11	8.3
	Cobalt-60	1.00E+10	1.02E+08	1.0
	Caesium-137	1.00E+11	7.84E+08	<1
	Other radionuclides	8.00E+10	1.34E+10	17
Hinkley Point	Tritium	1.00E+12	7.90E+07	<1
A Station	Caesium-137	1.00E+12	1.17E+08	<1
	Other radionuclides	7.00E+11	3.62E+08	<1
Hinkley Point	Tritium	6.50E+14	2.36E+14	36
B Station	Sulphur-35	2.00E+12	2.87E+11	14
	Cobalt-60	1.00E+10	9.95E+07	<1
	Caesium-137	1.00E+11	5.56E+08	<1
	Other radionuclides	8.00E+10	3.24E+09	4.1
Hunterston	Alpha	2.00E+09	3.53E+08	18
A Station	All other non-alpha[t]	6.00E+10	5.09E+08	<1
	Tritium	3.00E+10	7.70E+07	<1
	Caesium-137	1.60E+11	1.88E+08	<1
	Plutonium-241	2.00E+09	5.00E+07	2.5
Hunterston	Alpha	1.00E+09	2.08E+07	2.1
B Station	All other non-alpha	1.50E+11	5.14E+09	3.4
	Tritium	7.00E+14	1.48E+14	21
	Sulphur-35	6.00E+12	3.30E+11	5.5
	Cobalt-60	1.00E+10	4.70E+08	4.7
Oldbury	Tritium	1.00E+12	1.51E+11	15
	Caesium-137	7.00E+11	3.82E+10	5.5
	Other radionuclides	7.00E+11	4.47E+10	6.4
Sizewell	Tritium	5.00E+12	3.50E+10	<1
A Station	Caesium-137	1.00E+12	1.09E+11	11
	Other radionuclides	7.00E+11	6.69E+10	10
Sizewell	Tritium	8.00E+13	1.12E+13	14
B Station	Caesium-137	2.00E+10	3.12E+08	1.6
	Other radionuclides	1.30E+11	4.30E+09	3.3
Torness	Alpha	5.00E+08	3.81E+06	<1
	All other non-alpha	1.50E+11	4.34E+09	2.9
	Tritium	7.00E+14	2.95E+14	42
	Sulphur-35	3.00E+12	5.28E+11	18
	Cobalt-60	1.00E+10	3.63E+08	3.6

Table A2.2 continued

Establishment	Radioactivity	Discharge limit (annual equivalent)[a], Bq	Discharges during 2018	
			Bq	% of annual limit[b]
Trawsfynydd	Tritium	3.00E+11	6.10E+08	<1
	Caesium-137	1.50E+10	2.30E+08	1.5
	Other radionuclides[j]	3.00E+10	4.60E+08	1.5
Wylfa	Tritium	1.50E+13	9.57E+11	6.4
	Other radionuclides	1.10E+11	6.01E+09	5.5
Defence establishments				
Aldermaston (Silchester)[k]	Alpha	1.00E+07	1.40E+06	14
	Other beta emitting radionuclides	2.00E+07	1.83E+06	9.2
	Tritium	2.50E+10	1.20E+08	<1
Aldermaston (to Stream)[k, l]	Tritium	NA	2.60E+08	NA
Barrow[m]	Tritium	1.20E+10	1.00E+06	<1
	Carbon-14	2.95E+08	9.00E+06	3.1
	Cobalt-60	1.34E+07	2.00E+04	<1
	Other gamma emitting radionuclides	3.50E+06	5.00E+04	1.4
Derby[n]	Alpha[o]	2.00E+09	5.19E+07	2.6
	Alpha[p]	3.00E+05	8.94E+03	3.0
	Beta[p]	3.00E+08	2.76E+05	<1
Devonport (sewer)[q]	Tritium	2.00E+09	4.72E+07	2.4
	Cobalt-60	3.50E+08	3.05E+06	<1
	Other radionuclides	6.50E+08	7.55E+07	12
Devonport (estuary)[q]	Tritium	7.00E+11	1.23E+10	1.8
	Carbon-14	1.70E+09	2.79E+07	1.6
	Cobalt-60	8.00E+08	1.30E+07	1.6
	Other radionuclides	3.00E+08	2.66E+07	8.9
Faslane	Alpha	2.00E+08	1.00E+05	<1
	Beta[i,r]	5.00E+08	9.90E+05	<1
	Tritium	1.00E+12	5.82E+09	<1
	Cobalt-60	5.00E+08	4.90E+05	<1
Rosyth[s]	Tritium	3.00E+08	1.88E+07	6.3
	Cobalt-60	1.00E+08	3.94E+06	3.9
	Other radionuclides	1.00E+08	6.52E+06	6.5
Radiochemical production				
Amersham (GE Healthcare)[r]	Alpha	3.00E+08	3.86E+06	1.3
	Tritium	1.41E+11	1.70E+06	<1
	Other radionuclides	6.50E+10	4.31E+08	<1

Table A2.2 continued

Establishment	Radioactivity	Discharge limit (annual equivalent)[a], Bq	Discharges during 2018	
			Bq	% of annual limit[b]
Industrial and landfill sites				
LLWR	Alpha	BAT	5.02E+07	NA
	Beta	BAT	9.24E+08	NA
	Tritium	BAT	5.65E+10	NA
Lillyhall (Cyclife UK Limited)	Alpha	5.00E+05	7.33E+02	<1
	Beta	5.00E+05	8.43E+03	1.7

[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 Limited*
[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*
[t] *Excluding tritium, caesium-137 and plutonium-241*
[2] *The discharge permit was revised with effect from 9 October 2017: the limit for sulphur-35 was revised*
[3] *The discharge permit was revised with effect from 1 January 2018 (Magnox Limited)*

NA Not applicable under permit
BAT Best available technology

Table A2.3 Disposals and receipt with the intention of disposal of solid radioactive waste at nuclear establishments in the United Kingdom, Financial Year 2018/19

Radionuclide or group of radionuclides	Total vault disposed[a] waste FY18/19 (Bq)	Cumulative total vault disposed[a] waste (Bq)
Tritium	6.24E+11	2.75E+13
Carbon-14	1.65E+10	4.89E+11
Chlorine-36	7.59E+09	7.15E+11
Calcium-41	5.35E+05	1.20E+10
Selenium-79	4.90E+02	4.90E+02
Molybdenum-93	1.10E+03	1.40E+06
Zironium-93	2.68E+03	3.83E+10
Niobium-94	2.30E+08	6.92E+09
Technetium-99	7.27E+08	3.04E+12
Silver-108m	5.50E+09	1.12E+10
Iodine-129	3.15E+06	3.32E+09
Caesium-135	1.14E+05	5.25E+08
Radium-226	8.80E+04	7.32E+10
Thorium-229	9.19E+03	5.38E+05
Thorium-230	4.63E+05	7.05E+09
Thorium-232	4.44E+05	3.57E+10
Protactinium-231	3.96E+03	2.44E+09
Uranium-233	2.51E+06	5.69E+10
Uranium-234	1.60E+09	4.65E+11
Uranium-235	4.57E+07	3.18E+10
Uranium-236	2.36E+08	2.74E+10
Uranium-238	1.24E+09	5.26E+11
Neptunium-237	7.96E+07	4.30E+10
Plutonium-238	2.74E+10	2.22E+11
Plutonium-239	6.46E+09	5.02E+11
Plutonium-240	6.73E+09	3.23E+11
Plutonium-241	7.95E+10	9.78E+12
Plutonium-242	3.18E+06	9.88E+08
Americium-241	1.90E+10	1.37E+12
Americium-242m	8.07E+03	5.87E+10
Americium-243	4.98E+06	5.60E+08
Curium-243	2.88E+07	3.34E+09
Curium-244	1.92E+08	2.04E+10
Curium-245	2.03E+05	5.47E+06
Curium-246	1.70E+05	2.04E+06
Curium-248	Nil	4.98E+07
OTHRT**	Nil	4.81E+06
PUALD**	Nil	1.01E+11
UALD**	Nil	1.13E+10
URRM**	Nil	2.38E+10
Others*	7.35E+11	6.48E+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
2018/19	1.72E+03	2.51E+05	2.39E+04	4.35E+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, 2018*

Establishment Transfer from	Volume m^3	Total Activity Bq	Alpha Bq	Beta/Gamma Bq
Research establishments				
Dounreay[a]	Nil		Nil	Nil
Nuclear Power Stations				
Chapelcross[b]	4.13E+02	2.37E+10	NA	NA
Hunterston A	1.21E+02		9.81E+08	1.31E+09
Hunterston B	3.22E+01		2.61E+06	1.09E+09
Torness	5.52E+01		3.29E+06	5.33E+11
Defence establishments				
Coulport	Nil		Nil	Nil
Dounreay (Vulcan)	Nil		Nil	Nil
Faslane	Nil		Nil	Nil
Rosyth[c]	5.10E+00		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*
[c] *Transfers of cobalt-60 and 'all other radionuclides' were Nil and 1.26E+06 Bq, respectively*
NA Not Applicable

Table A2.5 Summary of unintended leakages, spillages, emissions or unusual findings of radioactive substances from nuclear licensed sites in the UK in 2018

Site	Month/Year	Summary of incident	Consequences and action taken
Aldermaston and Burghfield (AWE)	April 2018	During an inspection it was found that the High Efficiency Particulate in Air (HEPA) filters, serving the ventilation system of a legacy facility, were being operated beyond their design life as set out in relevant good practice.	Following the facility inspection, the Environment Agency recorded two non-compliances with the site permit. In addition, the Environment Agency and the Office for Nuclear Regulation required AWE to undertake a detailed technical review of the HEPA filters and ventilation systems and to prepare an appropriate remediation programme in facilities across both of its nuclear sites. Although this issue was extensive there was no environmental impact as a result of the shortfalls.
Dounreay	May 2018	It was identified that High Efficiency Particulate Air filters present within a ventilation system, on the Dounreay site, had exceeded the maximum age specified within the relevant DSRL standard.	SEPA investigated DSRL's filter age management arrangements. As a result, SEPA sent a Final Warning Letter to DSRL.
Heysham 1	From July 2018	Analysis of borehole groundwater samples by EDF in July 2018 found an increasing trend in tritium activity in two boreholes. The source is believed to be from the Turbine Hall Basement drains. A survey identified cracks within this drain line to an extent that effluent was able to leak out into the ground.	The Environment Agency concluded that this issue represented a non-compliance with two permit conditions in the Radioactive Substances Activity permit. These non-compliances were assessed as Category 3 in the Compliance Categorisation System (representing a minor impact). The concentration of tritium measured in the borehole groundwater in relation to this issue was 116 Bq l^{-1}, which is just above the investigation level for drinking water (100 Bq l^{-1}). The surface water drain has since been relined. Additional samples are being taken by EDF to confirm that the surface drain line was the source of the tritium.
Sellafield	January – February 2018	Discharges of beta radionuclides were elevated from the Site Ion Exchange Plant (SIXEP), arising from failures in the management of the ion exchange bed change procedure.	The Environment Agency issued a warning letter to Sellafield Limited. Sellafield Limited have since put measures in place to prevent a recurrence of this incident. The environmental impact was considered to be minor.
Sellafield	March 2018	Associated with a spell of cold weather, a water supply pipe on a pipe bridge (in the separation area) developed a leak. The backed up water flowed into an historical containment sump beneath a series of storage tanks.	Some contaminated water leaked into the ground and some was discharged to sea, thus bypassing the monitoring arrangements. The Environment Agency provided advice and guidance to Sellafield Limited to ensure that asset management is improved for this system and that all outstanding actions from Sellafield Limited management investigation are completed. The environmental impact was negligible.
Sellafield	July – October 2018	A number of defects were identified within the external ducting of a ventilation system which serves analytical and plutonium facilities.	The Environment Agency investigation highlighted shortfalls within the systems of maintenance. The Environment Agency issued an enforcement notice and a warning letter requiring Sellafield Limited to take action to repair those defects identified, and to put maintenance and repair programmes in place that ensure asset condition is appropriate in future. The environmental impact of this event was minor.
Sellafield	October 2018	A liquor leak occurred from the pressure wash equipment associated with the Redundant Sludge Tanks, within the first-generation Magnox Storage Pond.	The investigation by Sellafield Limited estimated that a total of 39 litres of liquor was released, containing an estimated total alpha activity of 0.291 MBq. A proportion of the liquor had been discharged to sea via the lagoon drainage system. The Environment Agency issued advice and guidance to Sellafield Limited to prevent a re-occurrence of this incident. The environmental impact was negligible.

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
BPM	Best Practicable Means
BSS	Basic Safety Standards
BSSD 13	Basic Safety Standards 2013
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
CGN	China General Nuclear
CNLS	Cardiff Nuclear Licensed Site
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 Point 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
Euratom	European Atomic Energy Community
EASR 18	Environmental Authorisations (Scotland) Regulations 2018
EARP	Enhanced Actinide Removal Plant
EC	European Commission
EDF	Electricité de France
EIA	Environmental Impact Assessment
ENRMF	East Northants Resource Management Facility
EPR	Environmental Permitting Regulations
EPR 16	Environmental Permitting (England and Wales) Regulations 2016
EPR 18	Environmental Permitting (England and Wales) Regulations 2018
EPR™	European Pressurised Reactor™
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
IRR 17	Ionising Radiations Regulations 2017
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
LoA	Letter Of Agreement
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 Screening
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
PARCOM	Paris Commission
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
RSR 18	Radioactive Substances (Modification of Enactments) Regulations (Northern Ireland) 2018
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 Licensed Company
SRP	Society for Radiological Protection
STW	Sewage Treatment Works
THORP	Thermal Oxide Reprocessing Plant
TENORM	Technologically Enhanced Naturally Occurring Radioactive Material
TRAMP	Terrestrial Radioactive Monitoring Programme
UCP	Urenco ChemPlants Limited
UKAEA	United Kingdom Atomic Energy Authority
UKAS	UK Accreditation Service
UKNWM	UK Nuclear Waste Management Limited
UOC	Uranium Ore Concentrate
UNS	Urenco Nuclear Stewardship Limited
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	These are 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.
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.
TENORM	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, FSS 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.

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 **https://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 Edinburgh Centre for Carbon Innovation, High School Yards, Infirmary Street, Edinburgh, EH1 1LZ. Environment Agency reports are available from **https://www.gov.uk/government/organisations/environment-agency**. A charge may be made to cover costs.

Table A4.1 Extramural Projects

Topic	Reference	Further details	Target completion date
Dredging assessment (Hinkley Point C)	C7458HINK2	N	Published Q1, 2018
Project to investigate Polonium 210 legacy discharges to the Irish Sea	N/A	E, F	Published 2019, RIFE 24, 2019
Soil and herbage survey	UKRSR01 and SCO00027	E, S	Q4, 2020
Offshore Dose Assessment Model	N/A	S	Q1, 2020
Thorium Transfer Work	N/A	S	In press
NORM Biota Project	N/A	S	In press
PhD research project – Assessing the hazard from radioactive particles in the environment	N/A	S	2021
Background monitoring in urban environments	N/A	S	Q2, 2020
FSS/SEPA Bottled Water Study	N/A	S	Q1, 2020
Clyde Estuary Assessment	N/A	S	Q2, 2020
Dungeness and Winfrith Habits Surveys	N/A	E, F, O	Q1, 2020
Dounreay Habits Survey	N/A	S	2019

E Environment Agency
F Food Standards Agency
N Natural Resources Wales
O Office for Nuclear Regulation
S Scotland and Northern Ireland Forum for Environmental Research or SEPA

Environment Agency
Reactor Assessment and Radiological Monitoring, Nuclear Regulation Group (North)
Cumbria and Lancashire Area, Lutra House, Preston, Lancashire PR5 8BX

Food Standards Agency
Food Policy Division
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 CE24 0TP

Northern Ireland Environment Agency
Industrial Pollution and Radiochemical Inspectorate
Klondyke Building, Cromac Avenue, Lower Ormeau Road, Belfast BT7 2JA

Scottish Environment Protection Agency
Radioactive Substances Unit
Strathallan House, Castle Business Park, Stirling FK9 4TZ

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