Radioactivity in Food and the Environment, 2019

25th edition

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food.gov.uk

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Cyfoeth Naturiol Cymru
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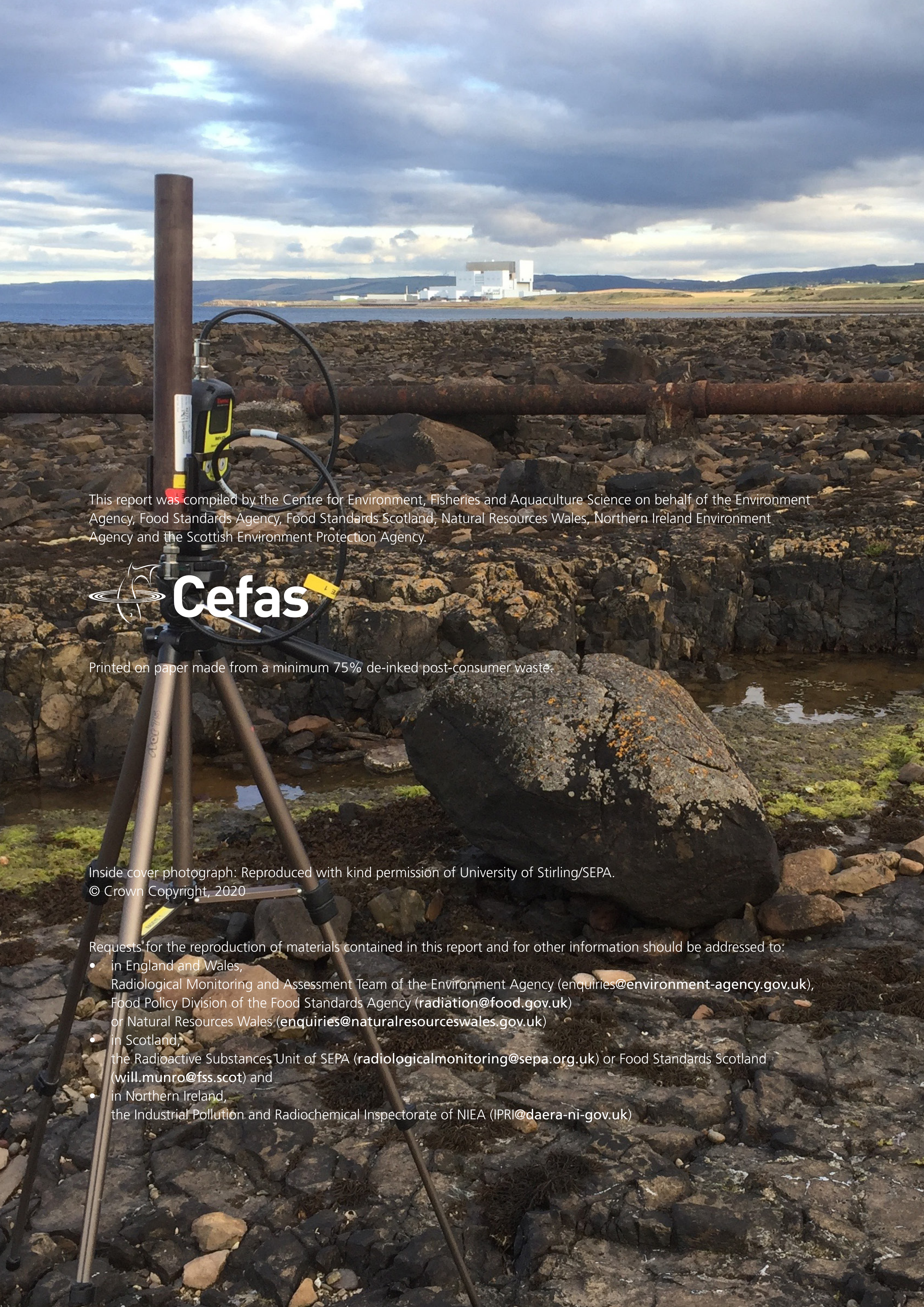
Radioactivity in Food and the Environment, 2019

RIFE – 25

November 2020



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

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Foreword

The UK's environmental regulators and food safety agencies are delighted to present the 25th anniversary edition of the Radioactivity in Food and the Environment (RIFE) report. This year marks a quarter of a century since the landmark RIFE report was first published by the Ministry of Agriculture, Fisheries and Food in 1996; the first joint monitoring and assessment report for the whole of the UK.

Radioactive substances and radiation have had many beneficial uses including in medicine, hospitals and in power generation. They are unlikely to be harmful if controlled in the right way. Suitable regulation aims to ensure these benefits, whilst keeping people and the environment safe. Our combined independent monitoring of radioactivity in food and the environment is an important part of our regulatory process and fulfils a vital reassurance role. The RIFE monitoring programme supports the requirements of the permitting legislation across the UK, together with a number of other national and international agreements, policies, regulations and standards.

In common with previous issues of this report, RIFE 25 sets out the findings of the monitoring programmes of radioactivity in food and the environment carried out in 2019 throughout the UK by the Environment Agency, Food Standards Agency, Food Standards Scotland, Northern Ireland Environment Agency, Natural Resources Wales and the Scottish Environment Protection Agency.

Monitoring results and subsequent assessments demonstrate that radioactivity in food and the environment is safe. The exposure of members of the public to radiation resulting from authorised discharges of radioactive waste and direct radiation near nuclear and non-nuclear sites was well below legal limits in 2019.

Over the past 25 years, the RIFE publication has evolved into its current format and will continue to develop in future reports. In addition to the annual RIFE reports, RIFE trends reports have provided more detailed examination from the compilation of results over a number of years.

RIFE 25 acknowledges the significant effort and commitment of a large number of people, who have contributed in so many different ways over many years, and of the organisations that have participated and supported the sample collection and analysis, the habits surveys and RIFE reporting programmes.

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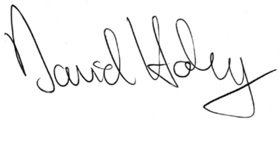

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General Summary

Radioactivity is all around us. It occurs naturally in the earth's crust and it can be found in the food we eat, the water we drink and the air we breathe. We are also exposed to man-made radioactivity, such as in medical applications used in hospitals and nuclear power. It is a legal requirement to make sure the amount of man-made radioactivity that people are exposed to from discharges is kept within a safe limit. Around the world strict regulations are in place to protect the general public and the environment.

In the UK, the exposure to man-made radioactivity in the environment mainly comes from releases from UK nuclear sites. Each year, the environmental regulators and food safety agencies publish their Radioactivity in Food and the Environment (RIFE) report. The RIFE programme monitors the environment and the diet of people who live or work near nuclear sites throughout the UK. The report brings together all the results of monitoring of radioactivity in food and the environment by the RIFE partners.

This year marks 25 years since the landmark RIFE report was published; the first joint monitoring and assessment report for the whole of the UK.

The main aim of the RIFE programme is to monitor the environment and the diet of people who live or work near nuclear and other sites. From this monitoring, we can estimate the amount of radioactivity the general public is exposed to, and particularly to those small groups of people who are most exposed because of their age, diet, location or way of life.

An additional comparison can be made with the exposure from natural radioactivity using a different approach to those exposures estimated for people who live or work near nuclear and other sites. Public Health England has published estimates of exposures to the UK population from naturally occurring and man-made sources of radioactivity. Most recent values show that naturally occurring sources, particularly radon gas, accounted for around 84 per cent of the exposure from all sources of radioactivity. Man-made radioactivity in the environment, from the nuclear industry and from the testing of nuclear weapons in the past, accounted for less than 0.2 per cent of the radiation exposure to the UK population.

At the request of the UK Government, an international team of senior safety experts conducted an Integrated Regulatory Review Service (IRRS) peer review mission in October 2019. The purpose of this mission was to evaluate the UK's regulatory framework for nuclear and radiation safety against the International Atomic Energy Agency (IAEA) safety standards. The peer review noted areas of good practice and some areas for improvement. The UK's environmental regulators will continue to work with partners to continuously improve protection of the public and the environment. The review report and government response is available on **https://www.gov.uk/government/publications/nuclear-and-radiological-safety-review-of-the-uk-framework-2019**.

The headlines from the 2019 RIFE programme are:

For all sites

- Exposure of the public from all sources of man-made radioactivity in food and the environment was low and well within the legal limit of 1 millisievert per year*, demonstrating that radioactivity in food and the environment is safe.
- Overall, between 2018 and 2019 there were no major changes of radioactivity measured in food and the environment.

For nuclear sites

- In 2019, people living around the Cumbrian coast (near Sellafield), Capenhurst, Amersham and Springfields were the most exposed from releases of radioactivity. The highest exposure was 24 per cent of the legal limit in 2019 due to people eating locally produced seafood around the Cumbrian coast, and down from 37 per cent in 2018.
- In Scotland, people eating food collected from areas along the Dumfries and Galloway coastline were the most exposed from releases of radioactivity. The exposure in 2019 was approximately 3 per cent of the legal limit, and as in previous years, this was mostly due to the effects of past discharges from the Sellafield site.
- The highest exposure from releases of radioactivity in Wales was for those people living near the former Trawsfynydd nuclear power station which is being decommissioned. This was due to them eating locally produced food, containing radioactivity released from past discharges from the station. The exposure was approximately 4 per cent of the legal limit.

For other areas

- In Northern Ireland, exposure of the public from man-made radioactivity in 2019 was estimated to be less than 1 per cent of the legal limit.

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* *On average our radiation exposure, mostly due to natural sources, amounts to about 2.3 millisieverts (mSv) per year.*

- A survey on the Channel Islands confirmed that the radiation exposure due to discharges from the French fuel reprocessing plant at La Hague and other local sources was less than 0.5 per cent of the legal 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 the radiation exposure from man-made radionuclides in people's general diet was very small (less than 0.5 per cent of the legal limit) in 2019.

Overall, between 2018 and 2019 there have been no major changes in radioactivity in samples measured around UK nuclear sites and other locations remote from these sites. Exposure from all sources of man-made radioactivity to members of the public was well below legal limits, demonstrating that radioactivity in food and the environment is safe.

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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 near UK nuclear licensed sites

Radiation doses to people living near nuclear licensed sites are assessed using data 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, 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 to compare with the *total dose* assessment method.

Figure S1 and Table S show the assessed *total doses* in 2019 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.

Doses to individuals are determined for those people most exposed to radiation ("representative person"*). 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 2019, radiation doses from authorised/permitted releases of radioactivity, to people 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 2019 were similar to those in 2018. These were the Cumbrian coastal community*** near Sellafield (0.24 mSv), Capenhurst (0.17 mSv), Amersham (0.14 mSv) and Springfields (0.14 mSv). The doses received near Capenhurst, Amersham and Springfields 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". 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 "critical group".*

** *As part of its withdrawal from the European Union, the UK formally left the European Atomic Energy Community (Euratom) on 31 January 2020. The UK is now in the Transition Period which will end on 31 December 2020. Euratom rules and arrangements will continue to apply for the UK until the end of the transition period and will be transposed into domestic legislation thereafter. Euratom provides the framework for cooperation between EU Member States in the civil nuclear sector. During the transition period, the UK is legally obliged to implement Directives and respect the laws and obligations required by Euratom membership. As such, the UK has continued to 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.*

*** *The Cumbrian coastal community are exposed to radioactivity resulting from both current and historical discharges from the Sellafield site and naturally occurring radioactivity discharged from the former phosphate processing works at Whitehaven, near Sellafield.*

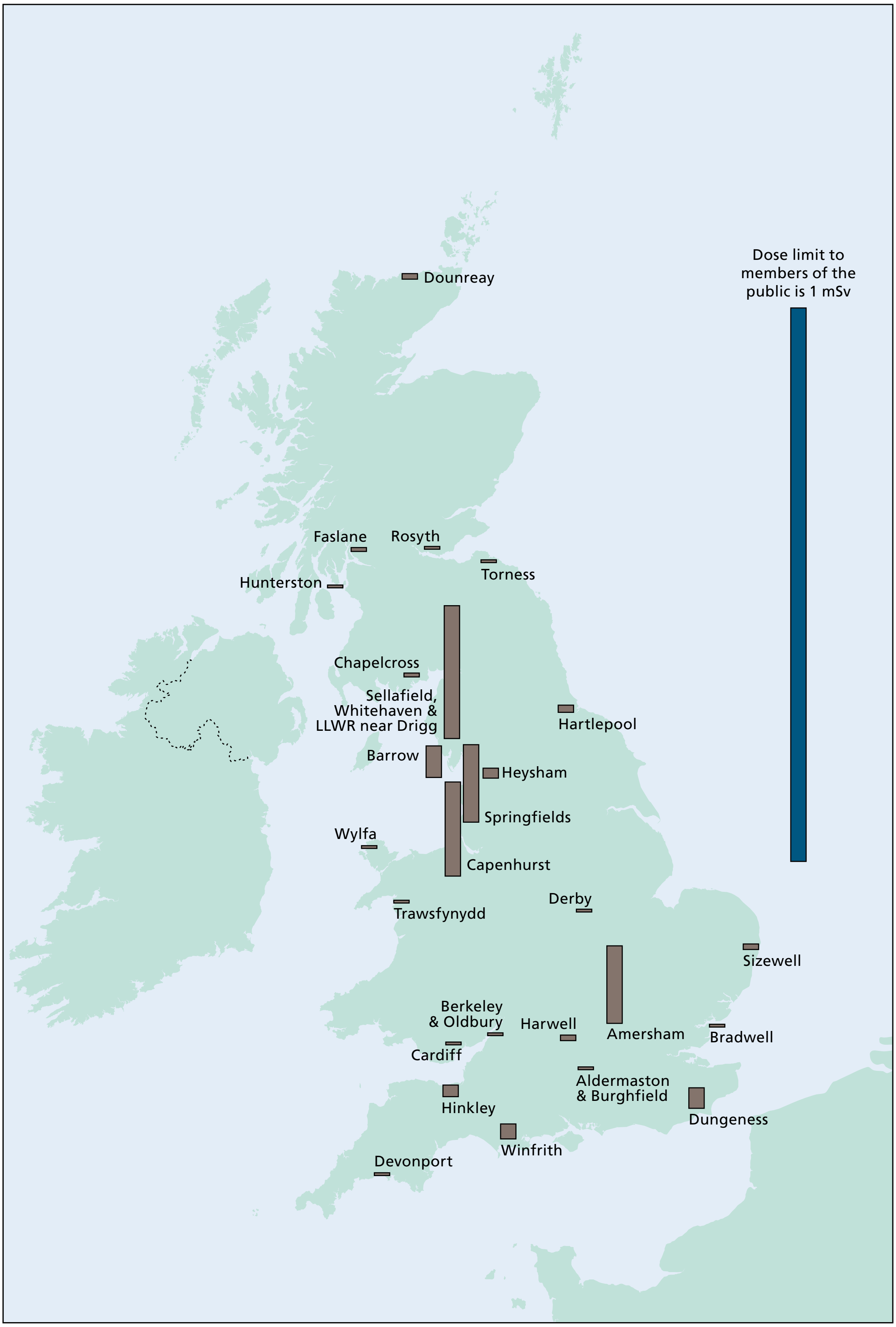


Figure S1. *Total doses* in the UK due to radioactive waste discharges and direct radiation, 2019
(Exposures at Sellafield, Whitehaven and Drigg receive a significant contribution to the dose from technologically enhanced naturally occurring radionuclides from previous non-nuclear industrial operations)

Summary Table S *Total doses* due to all sources at major UK sites, 2019[a]

Establishment	Exposure, mSv[b] per year	Contributors[c]
Nuclear fuel production and processing		
Capenhurst	0.17	Direct radiation
Springfields	0.14	Direct radiation
Sellafield[d]	0.24	Crustaceans, Molluscs, ^{210}Po
Research establishments		
Dounreay	0.010	Green vegetables, potatoes, root vegetables, $^{129}I^{e}$, ^{238}Pu, $^{239+240}Pu$, ^{241}Am
Harwell	0.010	Direct radiation
Winfrith	0.027	Direct radiation
Nuclear power stations		
Berkeley and Oldbury	<0.005	Direct radiation
Bradwell	<0.005	Gamma dose rate over sediment
Chapelcross	0.007	Milk, $^{35}S^{e}$, ^{90}Sr
Dungeness	0.037	Direct radiation
Hartlepool	0.013	Direct radiation, gamma dose rate over sediment
Heysham	0.018	Gamma dose rate over sediment
Hinkley Point	0.021	Gamma dose rate over sediment
Hunterston	<0.005	Direct radiation
Sizewell	0.010	Direct radiation
Torness	<0.005	Direct radiation
Trawsfynydd	0.005	Exposure over sediment
Wylfa	<0.005	Gamma dose rate over sediment
Defence establishment		
Aldermaston and Burghfield	<0.005	Milk, $^{3}H^{e}$, $^{137}Cs^{e}$, ^{234}U, ^{238}U
Barrow	0.057	Gamma dose rate over sediment
Derby	<0.005	Water, $^{60}Co^{e}$
Devonport	<0.005	Fish, gamma dose rate over sediment, $^{241}Am^{e}$
Faslane	0.007	Fish, gamma dose rate over sediment, ^{137}Cs, $^{241}Am^{e}$
Rosyth	<0.005	Direct radiation, 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[d]	0.24	Crustaceans, Molluscs, ^{210}Po
Whitehaven[d]	0.24	Crustaceans, Molluscs, ^{210}Po

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

[b] *Committed effective dose calculated using methodology of ICRP 60 to be compared with the annual dose limit of 1 mSv. Data are presented to 2 significant figures or 3 decimal places. Data below 0.005 mSv are reported as <0.005 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 doses from man-made and naturally occurring radionuclides were 0.052 and 0.19 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*

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

The highest dose to the Cumbrian coastal community near Sellafield was mostly due to historical liquid discharges. In 2019, the representative person, from the Cumbrian coastal community, was a high-rate mollusc consumer (who also consumed significant quantities of other seafood) and a change in the representative person from that in 2018 (adults consuming crustacean shellfish). The estimated dose was 0.24 mSv in 2019. Most of this dose (0.19 mSv) was due to the historical discharges of Technologically Enhanced Naturally Occurring Radioactive Material (TENORM) from the former phosphate processing plant near Whitehaven. The remainder of the dose (0.052 mSv) was due to the permitted discharges of artificial radionuclides by the nuclear industry. In the previous year (for 2018), the representative person received a dose of 0.37 mSv (including a contribution of 0.33 mSv and 0.034 mSv related to the former phosphate processing plant and the nuclear industry, respectively). The decrease in dose in 2019 to the Cumbrian coastal community, was attributed to lower polonium-210 concentrations in crustaceans (crabs). The largest contribution to dose to seafood consumers in the Cumbrian coastal community 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 present in the environment from radioactive decay of Naturally Occurring Radioactive Materials (NORM). 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 2019. From a radiological assessment perspective, the effects from the Sellafield site and the phosphate processing plant (near Whitehaven) both impact the same area and therefore the contributions to doses are both considered in Section 2.3.1.

In Scotland, the representative person consuming food (fish, shellfish and wildfowl) collected from areas along the Dumfries and Galloway coastline received the highest source specific dose from authorised releases of radioactivity. The dose to adults was 0.031 mSv in 2019, and a small increase from 2018 (0.029 mSv). As in previous years, most of the dose in 2019 was due to the effects of past discharges from the Sellafield site.

The highest dose in Wales was in the vicinity of the Trawsfynydd nuclear power station. This site is being decommissioned. The representative person was a consumer of locally produced food and the dose was a consequence of past permitted discharges. The source specific dose to 1-year-old infants was 0.041 mSv in 2019, and an increase from 2018 (0.025 mSv).

Radioactivity concentrations in samples collected near UK nuclear licensed sites

There were no major variations in environmental concentrations of radioactivity in 2019 compared to those in 2018. Near Sellafield, the environmental concentrations of most radionuclides have declined over the past three decades, albeit much slower in recent years. However, in 2019, mean concentrations of caesium-137, plutonium-239+240 and americium-241 in lobsters (Sellafield Coastal), and of caesium-137 in winkles (Nethertown), are the lowest reported values in recent years.

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 (Oslo and Paris Convention) Radioactive Substances Strategy (RSS). Specifically, significant 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.

External dose rates measured near UK nuclear licensed sites

Radioactivity in sediments in intertidal areas can potentially make a significant contribution in the total radiation exposure to 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 2019 compared with 2018. 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.

Non-routine surveys

During 2019, 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 (199 in 2019 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. A summary report of assessing the risk to people's health from radioactive objects on beaches around the Sellafield site was published by PHE in February 2020 (Oatway *et al.*, 2020).

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 2018). Fishing restrictions in a specific area around Dounreay are still in force under the Food and Environment Protection Act (FEPA) 1985 (United Kingdom - Parliament, 1985).

"Special" (or *ad hoc*) sampling related to nuclear licensed site operation is undertaken at sites when the need arises or in the need to provide one-off data sets.

In 2019, sampling related to regional monitoring was needed at Caithness (Scotland) (see Section 7.7). This followed the detection of increased beta activity in air at the Dounreay site in April 2019. The activity could not be linked to any Dounreay facility and instead had an off-site component. Elevated beta activity was also noted in air filter measurements across Scotland.

In 2019, additional freshwater sampling was undertaken in response to increased concentrations in Loch Baligill in 2018 (see Section 7.7).

In order to check compliance with the Council Directive 2013/51/EURATOM (which includes compliance for radioactive substances in water intended for human consumption), a bottled water survey was carried out in 2019 from producers across Scotland (see Section 7.10).

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.

In 2019, 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 Dungeness, Sellafield and Winfrith in England. The findings were used to confirm the adequacy of current monitoring programmes, to 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.

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

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

Additional monitoring in the UK and surrounding seas was undertaken to assess the impact of non-nuclear sites, the concentrations of radioactivity across the UK (measured as part of the regional monitoring programme) and overseas incidents that may have introduced radioactivity into the environment.

(i) Non-nuclear sites

In the past, liquid waste slurry (regarded as TENORM) containing thorium and uranium was discharged from a phosphate processing plant near Whitehaven (Cumbria) into the Irish Sea. Discharges 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, two decay products, polonium-210 and lead-210, in fish and shellfish (near Whitehaven) have been found to be higher than the maximum expected concentration ranges due to naturally sourced radioactivity (i.e. natural background). Concentrations have declined significantly since the plant ceased operations in 1992. Thereafter, polonium-210 and lead-210 were within or close to the expected concentration ranges of natural background. Estimates in seafood are made by subtracting the median of the expected natural concentration range of these radionuclides from the measured values. These radionuclides are important in that small changes in values above background significantly influence their dose contribution to the combined dose. The representative person in the area who consumed large amounts of seafood received a dose of 0.24 mSv in 2019 and polonium-210 was the most contributing radionuclide. This estimation of 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, for example, from hospitals and industrial sites 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 2019 and into 2020. 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, working collaboratively with stakeholders. 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 6.5 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 2019 (i) to establish long distance transport of radioactivity from UK and other nuclear licensed sites, (ii) to identify any general contamination of the food supply and the environment and (iii) to provide data in compliance with 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 less than 1 per cent of the annual limit of 1 mSv for members of the public in 2019. 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. Artificial radionuclides only contributed a small proportion of the total public radiation dose in people's general diet and this was much less than 0.5 per cent of the limit in 2019.

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 2019, no requests were received by the Marine Management Organisation (MMO) to apply for additional licences for the disposal of dredged material at sea.

(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 2019. 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 2019. 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 2019, 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 are carried out on behalf of the Environment Agency, Food Standards Agency, Food Standards Scotland, Natural Resources Wales, Northern Ireland Environment Agency and the Scottish Environment Protection Agency and are independent of the industries discharging radioactive wastes. The programmes include monitoring in support 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 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 2019. The analytical results of the environmental radioactivity monitoring programmes are reported in tables in the relevant sections (Sections 2 – 7, inclusive). The values provided in the tables are given in three different forms, (i) measurable values (referred to as "positively detected"), (ii) less than values (i.e. the lowest activity concentration, or dose rate measurement, that can be reliably detected for a given analytical method), and (iii) not detected values (ND) (i.e. insufficient evidence is available to determine the existence of a radionuclide). Where the results are an average of more than one measurement, and each value is positively detected, then the result in the table is reported as being positively detected. Alternatively, where there is a mixture of values (i.e. positively detected and less than values), or all are and less than values, then the result in the table is reported as a less than value, preceded by a "less than" symbol ("<").

Only results that are the most relevant for assessing the impact of radionuclide concentrations in food and the environment are provided in each site table. This ensures that reporting of the more meaningful results is more manageable. For example, gamma-ray spectrometry can provide a large number of less than values and may not be reported. To identify and include the most relevant values, to be included in each individual table, one of more of the following conditions is required:

(i) All radionuclide results (both positively detected and less than values) are reported in the site table if the radionuclide is specified in the relevant permit/authorisation (as indicated for each site in Appendix 2, Tables A2.1 and A2.2),

(ii) All radionuclide results (both positively detected and less than values) are reported that have been analysed using a radiochemistry method (e.g. plutonium radionuclides),

(iii) For any radionuclide that is reported as positively detected in the previous 5 years of annual reporting, all activity concentration data of that radionuclide are reported (i.e. only excluded from the table after 5 continuous years of reporting "less than values")

(iv) For any radionuclide that is reported as positively detected in one of the samples, all activity concentration data of that radionuclide are reported for other samples presented in the table (terrestrial and marine) in that year

(v) Naturally occurring radionuclides measured by gamma-ray spectrometry (e.g. potassium-40) are not usually reported unless the intention is to establish whether there is any enhancement above the expected background concentrations (e.g. from landfill sites)

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**).

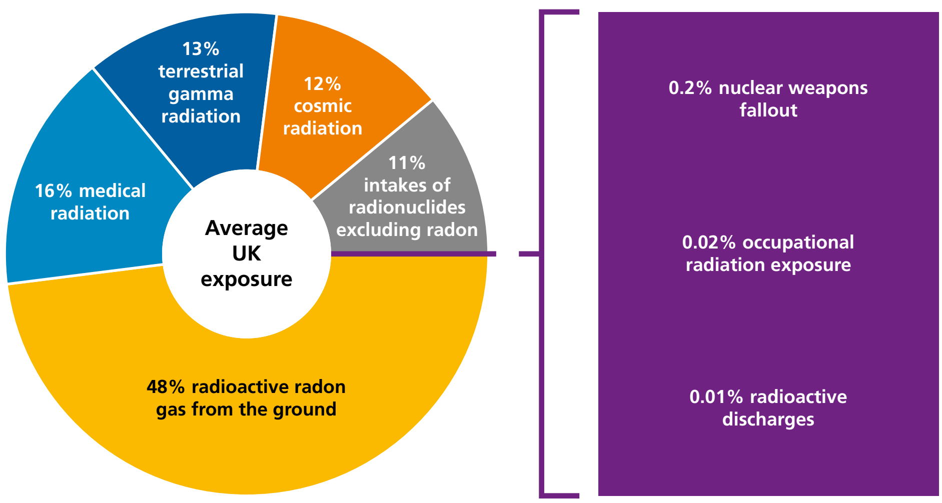


Figure S2. Average UK population exposure from natural and man-made sources of radioactivity (Oatway *et al.*, 2016)

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 2019 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 radiation doses are summarised for major industrial sites; all doses were below the legal limit in 2019

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 2019. 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, Northern Ireland, Wales 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 members 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 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 in 2018 by the Environmental Permitting (England and Wales) (Amendment) (No. 2) Regulations 2018 (EPR 18) (United Kingdom - Parliament, 2018) in order to transpose changes brought about by BSSD 13, and then by the Environmental Permitting (England and Wales) (Amendment) (EU Exit) Regulations 2019 (EPR 19) in 2019 (United Kingdom - Parliament, 2019) to ensure (at the end of the Transition Period following the UK's Exit from the EU) the regulations remain fully operable.

* *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.*

In 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 (RSA 93) (United Kingdom - Parliament, 1993). A guidance document was also published in 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)

In 2018, the Environmental Authorisations (Scotland) Regulations 2018 (EASR 18) came into force for radioactive substances activities in Scotland (Scottish Government, 2018) and replaced RSA 93 transposing BSSD 13. EASR currently applies to onshore activities and RSA 93 remains in force offshore. A guidance document has been also published to support the implementation of the regulations. 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. This framework is being developed in a phased manner and currently the regulations only apply to radioactive substances activities.

In order to transpose the requirements of BSSD 13, the Ionising Radiations Regulations 2017 (IRR 17) (United Kingdom - Parliament, 2017) came into force in 2018 (replacing the Ionising Radiations Regulations 1999). The Health and Safety Executive (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 estimate and 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. In previous 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, 2019). Reviews are carried out to ensure the monitoring programmes are appropriate and are consistent with advice in the joint Agency technical guidance (Environment Agency, FSA and SEPA, 2010), resulting in an adjustment and consolidation of the monitoring around some sites. The Environment Agency, FSA, FSS, NRW, NIEA, SEPA and BEIS have also published a RIFE summary report (OSPAR, 2018). 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.

The analysis and measurements for the monitoring programmes was carried out by various 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)
- Public Health England (PHE)
- SOCOTEC UK Limited

Appendix 1 is in a separate 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 estimate and 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 2019, 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 considers the doses from radioactive discharges (gaseous and liquid) to the environment from nuclear licensed sites combined with the dose from site radiation sources (direct radiation). This assessment gives an estimate of the annual *total dose* to people living in the vicinity of the nuclear licensed sites. The *total dose* assessment is the principle method for measuring radiation exposure to the general public.

Exposure from direct radiation may be a significant contributor to dose, close to a nuclear site, from radiation emitting from sources on the site*. The regulation of direct radiation is the responsibility of the Office for Nuclear Regulation (ONR). In 2018 , EDF (Electricité de France) Energy revised their method of direct dose assessment (for the calendar year) for operating power stations based on measurements of external radiation dose rates at the site boundary, distances to the point of exposure 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, values since 2018 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 provide a check on the adequacy of the annual *total dose* method and provide information for a range of additional exposure 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 (i.e. the "representative person"). The results from both of these assessments are for comparison with legal limits. The effective doses (defined in Appendix 3) 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, 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 2019

The results of the assessment for each site are summarised in Table 1.2 (see also Figure S1 and Table S in the Technical Summary). These data are presented in three parts. The 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 2019 were much 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

* *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 concentrations 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 Select the highest dose for the person representing the most exposed	Calculate dose from gaseous discharges to people representing those most exposed	Calculate dose from liquid discharges to people representing those most exposed	
Dose quantity	*Total dose*	Dose from gaseous discharges	Dose from liquid discharges	Dose from direct radiation

Figure 1.1. The dose assessment process for major nuclear sites

discharges were generally adult consumers of seafood or people who spend long periods of time over contaminated sediments.

The representative person in the Cumbrian coastal community (near Sellafield), who received the highest annual *total dose*, consumed mollusc at high-rates, together with other seafood. 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 people living near the Capenhurst, Amersham and Springfields sites; these doses were almost entirely due to direct radiation from the sites and a small fraction of the dose limit.

1.2.3 *Total dose* trends

A time-series of annual *total dose* from 2008 - 2019 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 in the Cumbrian coastal community (near Sellafield, Whitehaven and the Low Level Waste Repository (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.

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 previous years. The changes in *total dose* at Heysham (2011 and 2016), Hinkley Point (2010 and 2017), Springfields (2012) and Trawsfynydd (2018) were largely due to findings from new habits surveys. At Springfields, the increase in *total dose* in recent years 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.

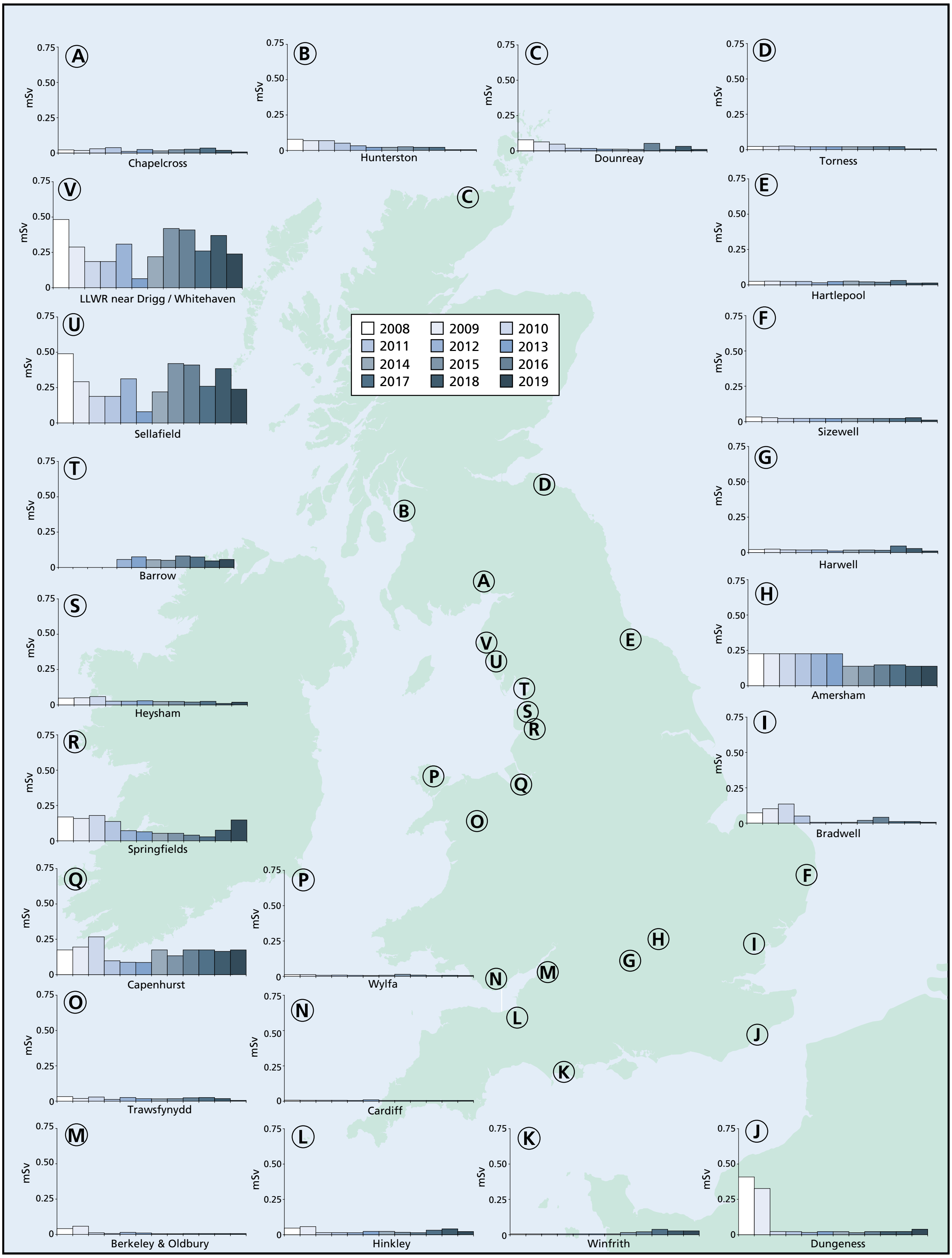


Figure 1.2. *Total doses* around the UK's nuclear sites due to radioactive waste discharges and direct radiation (2008-2019).
(Exposures at Sellafield/Whitehaven/LLWR receive a significant contribution to the dose from technologically enhanced naturally occurring radionuclides from previous non-nuclear industrial operations)

1.2.4 Source specific dose results for 2019

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 to the Cumbrian coastal community (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 $\mu Gy\ h^{-1}$) 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.

Between December 2018 and February 2019, SEPA held a public consultation on a draft plan to improve the Scottish environment, including setting out actions to maintain the current high levels of compliance obligations and continue to go beyond compliance standards. 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/**.

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

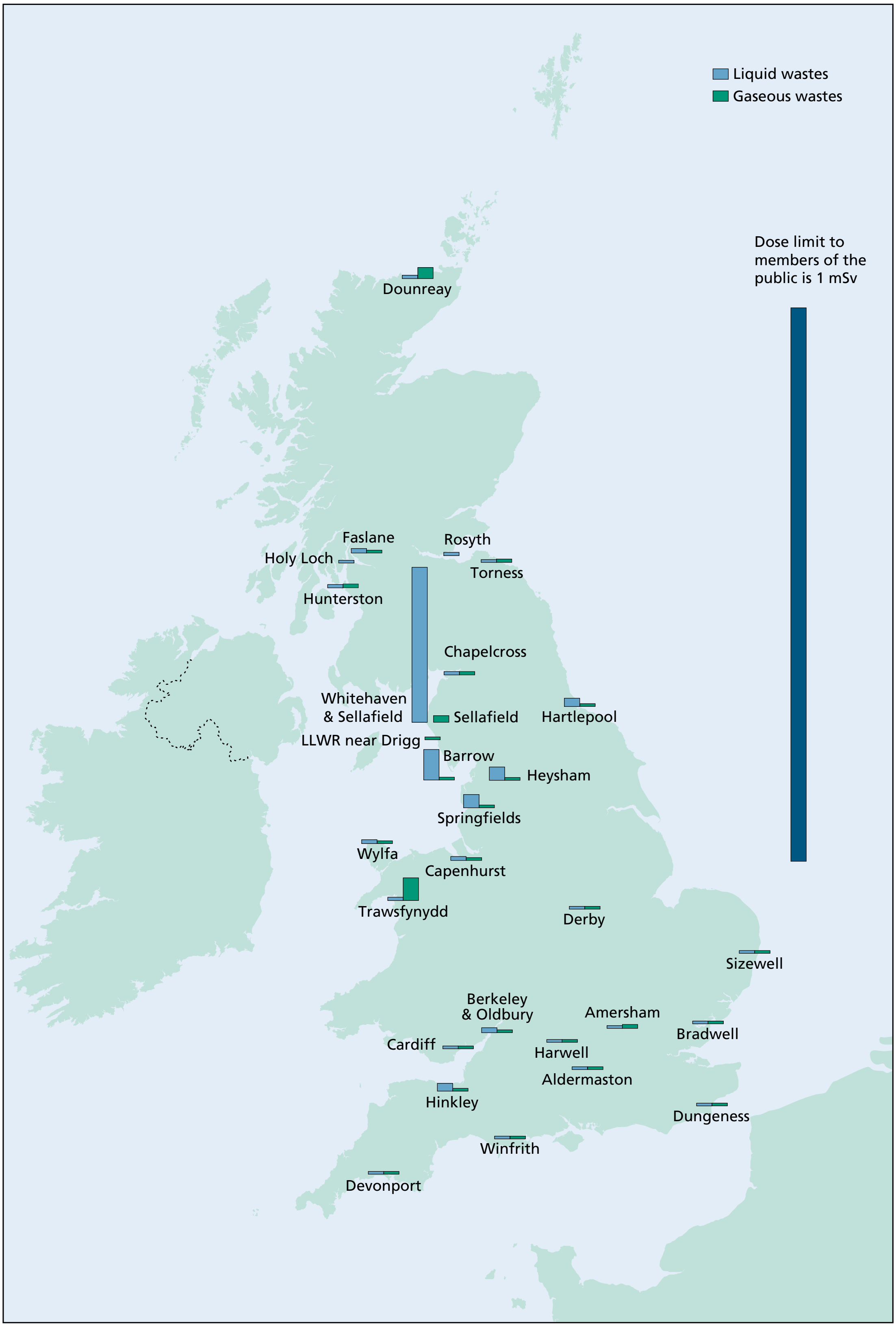


Figure 1.3. Source specific doses in the UK, 2019 (Exposures at Whitehaven and Sellafield receive a significant contribution to the dose from technologically enhanced naturally occurring radionuclides from previous non-nuclear industrial operations)

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 LLWR near Drigg for disposal and solid wastes containing low quantities of radioactivity can also be disposed of to permitted landfill sites (see Section 6). 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 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 19, RSR 18 or EASR 18) in 2019, 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 6). 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 2019, 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 2019, 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 6 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, 2019a).

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 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 2019.

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.

* *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, 2019 (Showing main initial operation. Some operations are undergoing decommissioning)

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 (Defra, 2002), to describe how the UK would implement the agreements reached at the 1998 and subsequent meetings of OSPAR. The Strategy was revised to include the expansion of its scope to include gaseous discharges, from decommissioning as well as operational activities, and from the non-nuclear as well as the nuclear industry sectors (DECC, Department of the Environment Northern Ireland, the Scottish Government and Welsh Assembly Government, 2009). 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 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 the approach and work in progress within the OSPAR Convention can be found on OSPAR's website **https://www.ospar.org**. 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, 2020). 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, 2019a; b). The UK submission concerning the implementation of the principle of using BAT has also been published (OSPAR, 2018). 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, 2010). 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). 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 next OSPAR Quality Status Report is expected to be published in 2023.

The importance of an integrated approach to stewardship of the marine environment has long been established in the UK. The reports *"Safeguarding Our Seas"* (Defra, Scottish Executive and Welsh Assembly Government, 2002) and "*Charting Progress 2*" (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 and maintain 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). In October 2019, following a public consultation, the UK published an update of the Marine Strategy Part One. It includes an assessment of progress towards the achievement of GES for UK seas and sets out revised targets and indicators for the next 6 years (Defra, Department of the Environment Northern Ireland, Scottish Government, Welsh Government, 2019). Further details on the Marine Strategy Framework Directive are provided on the GOV.UK website: **https://jncc.gov.uk/news/uk-updates-its-assessment-of-the-marine-environment/**

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, of which three were being actively pursued in 2019 (Hinkley Point C, Sizewell C, and Bradwell B).

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

Figure 1.5. Potential sites for new nuclear power stations

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 completed the first assessment step of GDA (Step 2) in 2018. ONR completed Step 3 of the GDA in February 2020 (ONR, 2020) and regulators have taken the decision to progress to Step 4 of the GDA.

The construction of NNB GenCo's new twin UK European Pressurised Reactor™ (EPR™) nuclear power station continues at Hinkley Point C in Somerset. ONR 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 been managing radioactive waste for many decades with formal consent under 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. Further information relevant to the UK demonstrating compliance under the Joint Convention is available in earlier RIFE reports (e.g. Environment Agency, FSA, FSS, NIEA, NRW and SEPA, 2019).

The Nuclear Decommissioning Authority (NDA), a non-departmental public body, manages the decommissioning and clean-up of the civil public sector nuclear sites. The NDA reports to BEIS and is responsible to Scottish ministers. The role of the NDA is strategic, developing and implementing an overall strategy for cleaning up the civil public sector nuclear legacy. The NDA's Strategic Objective for radioactive waste is to manage radioactive waste and dispose of it where possible, or place it in safe, secure and suitable storage, ensuring the delivery of the UK and Devolved Administrations' policies. The Energy Act 2004 (United Kingdom - Parliament, 2004) requires the NDA to review and publish its strategy every 5 years. The most recent strategy was published in 2019 (NDA, 2019a) and the business plan for 2020/23 is available (NDA, 2020). In 2019, the NDA published an inventory and forecast of radioactive wastes in the UK (as of 1 April 2019) jointly with BEIS (NDA and BEIS, 2019) and a Mission Progress Report in 2019 (NDA, 2019b).

In 2007, the UK Government and Devolved Administrations issued a UK-wide policy document, setting out principles for the long-term management of solid LLW (Defra, DTI and the Devolved Administrations, 2007). Following the introduction of the LLW policy, the UK LLW Strategy was published in 2010 (NDA, 2010). A new UK LLW Strategy was published in 2016 (DECC, Scottish Government, Welsh Government and Northern Ireland Department of Environment, 2016). Some LLW, mostly from non-nuclear sites, and some very low level radioactive waste is currently disposed of in landfill by controlled burial (Section 6). There is still a large amount of solid LLW that will require disposal. Some will be sent to the LLWR near Drigg. The LLW from Dounreay can be disposed of at the new Dounreay LLW Facility close to the site.

The NDA, along with its wholly owned subsidiary Radioactive Waste Management Limited (RWM), are responsible for the implementation of UK and Welsh Government policies on the long-term management of Higher Activity radioactive Waste (HAW) through geological disposal. Scottish Government policy is that the long-term management of higher activity radioactive waste should be in near-surface facilities. Facilities should be located as near to the site where the waste is produced as possible.

The UK Government's initial 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, 2014).

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. Further information on Devolved Administrations' policies is available on the GOV.UK website: **https://www.gov.uk/government/collections/geological-disposal-facility-gdf-for-high-activity-radioactive-waste**

No specific GDF sites have been selected or are currently under consideration (BEIS, 2018b). Further information on the aspects of GDF is also available on this website.

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 2018 – 19 (CoRWM, 2019), proposed work programme for 2018 – 2021 (CoRWM, 2018a) and a position paper on selecting a site based on the "best geology" for a GDF (CoRWM, 2018b).

Guidance on requirements for authorisation for geological and near-surface disposal facilities has been published (Environment Agency and NIEA, 2009; Environment Agency, NIEA and SEPA, 2009; Environment Agency, 2013). SEPA has issued a policy statement on how it will regulate the disposal of LLW from nuclear licensed sites (SEPA, 2012) and published interim guidance on the regulation of *in-situ* disposals of radioactive material on nuclear authorised premises (SEPA, 2014). In May 2019, SEPA issued guidance on the decommissioning of non-nuclear facilities (e.g. for a single laboratory) from radioactive use (SEPA, 2019b)

Decommissioning of many nuclear sites in Great Britain is underway. Following the environment agencies' consultation on the draft guidance, "Guidance on Requirements for Release of Nuclear Sites from Radioactive

Substances Regulation", referred to as "GRR", the operational feedback from the trial use of the guidance (at three sites) were used to refine the structure and clarity of the guidance. This was published in 2018 (SEPA, Environment Agency and NRW, 2018). This guidance describes what operators must do in order to release sites 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 7 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 Agriculture Environment and Rural Affairs, 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 (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 2019, no new requests were received to apply for additional licences for the disposal of dredged material at sea.

1.3.5 Other sources of radioactivity

There are several other man-made sources of radioactivity that may affect the food chain and the environment. These could include disposals of material from offshore installations, transport incidents, satellite re-entry, releases from overseas nuclear installations and the operation of nuclear powered submarines. PHE has assessed incidents involving the transport of radioactive materials in the UK (Jones and Harvey, 2014). PHE have also considered the effects of discharges into the marine environment from the oil and gas industry, with the estimated highest individual dose (per head of population) being less than 0.001 mSv per year (Harvey *et al.,* 2010). 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 2019. Low concentrations of radionuclides were detected in the marine environment around the Channel Islands (Section 7) 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 has been 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. 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.

In November 2019, the UK Government announced "an indefinite suspension" to fracking, after a report by the Oil and Gas Authority (OGA), an independent subsidiary of BEIS, found it was not possible to predict the probability or size of tremors caused by the practice.

Further information on the previous involvement by each of the environment agencies to support engagement with industry, and other related issues to shale gas extraction, is available in earlier RIFE reports (e.g. Environment Agency, FSA, FSS, NIEA, NRW and SEPA, 2019).

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 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. 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). In 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 2018 (BEIS, 2018c). 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.

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 by PHE, 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). Figure S2 provides a breakdown of the exposure to the UK population by source. 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 during historical testing of nuclear weapons in the atmosphere (global fallout) 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, is available on the website: **https://www.phe-protectionservices.org.uk/radiationandyou/**

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, 2019*

Site	Exposure [a] mSv
Nuclear fuel production and reprocessing	
Capenhurst	0.17
Sellafield	0.003
Springfields	0.14
Research establishments	
Dounreay	0.005
Harwell	0.010
Winfrith	0.027
Nuclear power stations	
Berkeley	Bgd[b]
Bradwell	Bgd[b]
Chapelcross	Bgd[b]
Dungeness	0.037[c]
Hartlepool	0.003
Heysham	0.003[d]
Hinkley Point	<0.001[e]
Hunterston	0.003[f]
Oldbury	0.002
Sizewell	0.009[g]
Torness	0.004
Trawsfynydd	Bgd[b]
Wylfa	Bgd[b]
Defence establishments	
Aldermaston	Bgd
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, h]
Industrial and landfill sites	
LLWR near Drigg	0.027
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*

[a] *Values presented in main table to 2 significant figures or 3 decimal places. Values 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] *Value for Dungeness A. Dungeness B (0.0027) not used. The dose to workers at Dungeness A from Dungeness B was 0.0027. The dose to workers at Dungeness B from Dungeness A was 0.032*

[d] *Value for Heysham 1. Heysham 2 (0.0025) not used*

[e] *Value for Hinkley B. Hinkley A (Bgd[b]) not used. The dose to workers at Hinkley A from Hinkley B was 0.0004. The dose to workers at Hinkley B from Hinkley A was Bgd[b]. The dose to workers at Hinkley C from Hinkley A was Bgd[b]*

[f] *Value for Hunterston B. Hunterston A (0.0025) not used. The dose to workers at Hunterson A from Hunterson B was 0.0008. The dose to workers at Hunterston B from Hunterston A was 0.0024*

[g] *Value for Sizewell B. Sizewell A (Bgd[b]) not used. The dose to workers at Sizewell A from Sizewell B was 0.0090. The dose to workers at Sizewell B from Sizewell A was Bgd[b]*

[h] *Site de-licensed by ONR on 10 December 2019*

Table 1.2 *Total doses* integrated across pathways, 2019

Site	Representative person[a]	Exposure[b], mSv Total	Dominant contributions[c]
A Gaseous releases and direct radiation from the site			
Aldermaston & Burghfield	Infant milk consumers	<0.005[d]	Milk, ^{3}H[e], ^{137}Cs[e], ^{234}U, ^{238}U
Amersham	Local adult inhabitants (0–0.25km)	0.14[d]	Direct radiation
Barrow	Adult potato consumers	<0.005	Gamma dose rate over sediment, potatoes, ^{137}Cs[e]
Berkeley & Oldbury	Prenatal children of local inhabitants (0–0.25km)	<0.005	Direct radiation
Bradwell	Prenatal children of other domestic vegetable consumers	<0.005	Green vegetables, ^{14}C
Capenhurst	Local child inhabitant (0–0.25km)	0.17[d]	Direct radiation
Cardiff	Infant milk consumers	<0.005	Milk, ^{14}C, ^{35}S
Chapelcross	Infant milk consumers	0.007	Milk, ^{35}S[e] ^{90}Sr
Derby	Children potato consumers	<0.005[d]	Potatoes, ^{234}U[c], ^{238}U
Devonport	Adult root vegetable consumers	<0.005	Root vegetables, ^{131}I[c], ^{241}Am[e]
Dounreay	Adult mushroom consumers	0.010	Green vegetables, potatoes, root vegetables, ^{129}I[e], ^{238}Pu, $^{239+240}Pu$, ^{241}Am
Dungeness	Local adult inhabitants (0.25–0.5km)	0.037	Direct radiation
Faslane	Adult occupants for direct radiation	<0.005	Direct radiation
Hartlepool	Local adult inhabitants (0–0.25km)	0.011	Direct radiation, gamma dose rate over sediment
Harwell	Local adult inhabitants (0–0.25km)	0.010[d]	Direct radiation
Heysham	Local adult inhabitants (0–0.25km)	0.006	Direct radiation, gamma dose rate over sediment, external and inhalation, ^{14}C
Hinkley Point	Prenatal children of local inhabitants (0.5–1km)	<0.005	Direct radiation, gamma dose rate over sediment, external and inhalation, ^{14}C
Hunterston	Prenatal children of local inhabitants (0.5–1km)	<0.005	Direct radiation
LLWR near Drigg	Local adult local inhabitants (0–0.25km)	0.029	Direct radiation
Rosyth	Local adult inhabitants (0.5–1km)	<0.005	Direct radiation, gamma dose rate over sediment
Sellafield	Infant milk consumers	0.006[d]	Milk, ^{14}C, ^{90}Sr, ^{129}I[e]
Sizewell	Local adult inhabitants (0–0.25km)	0.010	Direct radiation
Springfields	Local adult inhabitants (0.5–1km)	0.14[d]	Direct radiation
Torness	Prenatal children of local inhabitants (0.5–1km)	<0.005	Direct radiation
Trawsfynydd	Adult green vegetable consumers	<0.005	Exposure over sediment, potatoes, ^{137}Cs
Winfrith	Local adult inhabitants (0.5–1km)	0.027	Direct radiation
Wylfa	Adult potato consumers	<0.005	Fish, gamma dose rate over sediment, potatoes, ^{14}C, ^{241}Am
B Liquid releases from the site			
Aldermaston & Burghfield	Adult consumers of fish affected by liquid discharges	<0.005	Fish, ^{131}I[e]
Amersham	Adult consumers of fish affected by liquid discharges	<0.005	Crustacean, fish, gamma externa over riverbank, ^{3}H[e], ^{137}Cs
Barrow	Adult occupants on houseboats	0.057	Gamma dose rate over sediment
Berkeley & Oldbury	Adult occupants over sediment	<0.005	Fish, gamma dose rate over sediment, ^{241}Am
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	Prenatal children of occupants over sediment	<0.005	Gamma dose rate over sediment
Chapelcross	Adult wildfowl consumers	0.006	Molluscs, wildfowl, ^{137}Cs, $^{239+240}Pu$, ^{241}Am
Derby	Adult consumers of locally sourced water	<0.005	Water, ^{60}Co[e]
Devonport	Adult consumers of marine plants and algae	<0.005	Fish, gamma dose rate over sediment, ^{241}Am[e]
Dounreay	Adult occupants over sediment	0.005	Gamma dose rate over sediment
Dungeness	Adult fish consumers	0.009	Direct radiation, fish, ^{241}Am
Faslane	Adult fish consumers	0.007	Fish, gamma dose rate over sediment, ^{137}Cs, ^{241}Am[e]
Hartlepool	Adult occupants over sediment	0.013	Direct radiation, gamma dose rate over sediment
Harwell	Adult occupants over sediment	<0.005	Gamma dose rate over riverbank

Table 1.2 continued

Site	Representative person[a]	Exposure[b], mSv Total	Dominant contributions[c]
Heysham	Adult occupants over sediment	0.018	Gamma dose rate over sediment
Hinkley Point	Adult occupants over sediment	0.021	Gamma dose rate over sediment
Hunterston	Adult mollusc consumers	<0.005	Moluscs, $^{239+240}Pu$, ^{241}Am
LLWR near Drigg[f]	Adult mollusc consumers	0.24[g]	Crustaceans, ^{210}Po
Rosyth	Adult occupants over sediment	<0.005	Gamma dose rate over sediment
Sellafield[f]	Adult mollusc consumers	0.24[g]	Crustaceans, molluscs, ^{210}Po
Sizewell	Adult occupants over sediment	<0.005	Direct radiation, gamma dose rate over sediment
Springfields	Adult occupants on houseboats	0.024	Gamma dose rate over sediment
Torness	Adult mollusc consumers	<0.005	Fish, molluscs, ^{241}Am
Trawsfynydd	Adult occupants over sediment	0.005	Exposure over sediment
Whitehaven[f]	Adult mollusc consumers	0.24[g]	Crustaceans, molluscs, ^{210}Po
Winfrith	Adult fish consumers	0.005	Direct radiation, fish, ^{241}Am
Wylfa	Adult occupants over sediment	<0.005	Gamma dose rate over sediment
C All sources			
Aldermaston & Burghfield	Infant milk consumers	<0.005[d]	Milk, ^{3}H[e], ^{137}Cs[e], ^{234}U, ^{238}U
Amersham	Local adult inhabitants (0–0.25km)	0.14[d]	Direct radiation
Barrow	Adult occupants on houseboats	0.057	Gamma dose rate over sediment
Berkeley & Oldbury	Prenatal children of local inhabitants (0–0.25km)	<0.005	Direct radiation
Bradwell	Adult occupants on houseboats	<0.005	Gamma dose rate over sediment
Capenhurst	Local child inhabitant (0–0.25km)	0.17[d]	Direct radiation
Cardiff	Prenatal children of occupants over sediment	<0.005	Gamma dose rate over sediment
Chapelcross	Infant milk consumers	0.007	Milk, ^{35}S[e], ^{90}Sr
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[e]
Dounreay	Adult mushroom consumers	0.010	Green vegetables, potatoes, root vegetables, ^{129}I[e], ^{238}Pu, $^{239+240}Pu$, ^{241}Am
Dungeness	Local adult inhabitants (0.25–0.5km)	0.037	Direct radiation
Faslane	Adult fish consumers	0.007	Fish, gamma dose rate over sediment, ^{137}Cs, ^{241}Am[e]
Hartlepool	Adult occupants over sediment	0.013	Direct radiation, gamma dose rate over sediment
Harwell	Local adult inhabitants (0–0.25km)	0.010[d]	Direct radiation
Heysham	Adult occupants over sediment	0.018	Gamma dose rate over sediment
Hinkley Point	Adult occupants over sediment	0.021	Gamma dose rate over sediment
Hunterston	Prenatal children of local inhabitants (0.5–1km)	<0.005	Direct radiation
LLWR near Drigg[f]	Adult mollusc consumers	0.24[g]	Crustaceans, molluscs, ^{210}Po
Rosyth	Local adult inhabitants (0.5–1km)	<0.005	Direct radiation, gamma dose rate over sediment
Sellafield[f]	Adult mollusc consumers	0.24[g]	Crustaceans, molluscs, ^{210}Po
Sizewell	Local adult inhabitants (0–0.25km)	0.010	Direct radiation
Springfields	Adult mushroom consumers	0.14	Direct radiation
Torness	Prenatal children of local inhabitants (0.5–1km)	<0.005	Direct radiation
Trawsfynydd	Adult occupants over sediment	0.005	Exposure over sediment
Whitehaven[f]	Adult molluscs consumers	0.24[g]	Crustaceans, molluscs, ^{210}Po
Winfrith	Local adult inhabitants (0.5–1km)	0.027	Direct radiation
Wylfa	Adult occupants over sediment	<0.005	Gamma dose rate over sediment

[a] *Selected on the basis of providing the highest dose from the pathways associated with the sources as defined in A, B or C*
[b] *Data are presented to 2 significant figures or 3 decimal places. Data below 0.005 mSv are reported as <0.005 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 and based on these measurements, an upper estimate of dose is calculated*
[d] *Includes a component due to natural sources of radionuclides*
[e] *The assessed contribution is based on data at limits of detection*
[f] *The effects of liquid discharges from Sellafield, Whitehaven and LLWR near Drigg are considered together when assessing exposures at these sites because their effects are manifested in a common area of the Cumbrian coast*
[g] *The doses from man-made and naturally occurring radionuclides were 0.052 and 0.19 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*

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

Site	2003	2004	2005	2006	2007	2008	2009	2010	2011
Aldermaston and Burghfield	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Amersham		0.24	0.24	0.22	0.23	0.22	0.22	0.22	0.22
Barrow									
Berkeley and Oldbury		0.12	0.090	0.042	0.061	0.041	0.058	0.011	0.006
Bradwell		0.09	0.067	0.075	0.070	0.070	0.098	0.13	0.048
Capenhurst		0.080	0.080	0.085	0.12	0.17	0.19	0.26	0.095
Cardiff	0.038	0.023	0.023	0.011	0.008	0.007	0.006	0.006	0.006
Chapelcross		0.022	0.023	0.024	0.019	0.021	0.017	0.029	0.037
Derby							<0.005	<0.005	<0.005
Devonport		<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Dounreay	0.012	0.011	0.043	0.029	0.059	0.078	0.063	0.047	0.018
Dungeness		0.48	0.55	0.63	0.28	0.40	0.32	0.022	0.021
Faslane		<0.005	<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	0.025
Harwell		0.017	0.022	0.026	0.022	0.020	0.023	0.018	0.017
Heysham		0.036	0.028	0.037	0.038	0.046	0.049	0.057	0.025
Hinkley Point		0.026	0.027	0.048	0.035	0.045	0.055	0.014	0.014
Hunterston		0.10	0.090	0.074	0.090	0.077	0.067	0.067	0.050
LLWR near Drigg[b]	0.66	0.58	0.40	0.43	0.37	0.47	0.28	0.18	0.18
Rosyth		<0.005	<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	0.18
Sizewell		0.045	0.086	0.090	<0.005	0.031	0.026	0.020	0.021
Springfields		0.17	0.15	0.13	0.11	0.16	0.15	0.17	0.13
Torness		0.024	0.025	0.024	0.022	0.022	0.022	0.025	0.020
Trawsfynydd		0.032	0.021	0.028	0.018	0.031	0.018	0.028	0.012
Whitehaven[b]	0.66	0.58	0.40	0.43	0.37	0.47	0.28	0.18	0.18
Winfrith	<0.005	<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	0.008

Site	2012	2013	2014	2015	2016	2017	2018	2019
Aldermaston and Burghfield	<0.005	<0.005	<0.005	<0.005	<0.005	0.010	0.010	<0.005
Amersham	0.22	0.22	0.14	0.14	0.15	0.15	0.14	0.14
Barrow	0.057	0.076	0.055	0.051	0.082	0.074	0.046	0.057
Berkeley and Oldbury	0.014	0.010	<0.005	<0.005	0.006	<0.005	<0.005	<0.005
Bradwell	<0.005	<0.005	<0.005	0.017	0.036	0.011	0.011	<0.005
Capenhurst	0.085	0.080	0.17	0.13	0.17	0.17	0.16	0.17
Cardiff	0.005	0.010	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Chapelcross	0.011	0.024	0.014	0.022	0.026	0.035	0.019	0.007
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	0.017	0.012	0.012	0.010	0.058	0.010	0.035	0.010
Dungeness	0.015	0.021	0.021	0.014	0.021	0.021	0.022	0.037
Faslane	<0.005	<0.005	<0.005	<0.005	0.009	<0.005	0.010	0.007
Hartlepool	0.015	0.024	0.027	0.022	0.020	0.031	0.012	0.013
Harwell	0.018	0.010	0.016	0.017	0.015	0.046	0.028	0.010
Heysham	0.025	0.028	0.023	0.023	0.019	0.025	0.010	0.018
Hinkley Point	0.013	0.022	0.022	0.016	0.013	0.032	0.041	0.021
Hunterston	0.032	0.021	0.021	0.025	0.021	0.023	<0.005	<0.005
LLWR near Drigg[b]	0.30	0.061	0.22	0.42	0.41	0.25	0.37	0.24
Rosyth	<0.005	<0.005	<0.005	0.006	0.017	0.026	0.010	<0.005
Sellafield[b]	0.30	0.076[c]	0.22	0.42	0.41	0.25	0.37	0.24
Sizewell	0.021	0.021	0.020	0.021	0.021	0.021	0.026	0.010
Springfields	0.068	0.060	0.050	0.050	0.038	0.028	0.075	0.14
Torness	0.020	0.020	0.020	0.020	0.021	0.021	<0.005	<0.005
Trawsfynydd	0.025	0.017	0.013	0.014	0.019	0.024	0.017	0.005
Whitehaven[b]	0.30	0.061	0.22	0.42	0.41	0.25	0.37	0.24
Winfrith	<0.005	<0.005	<0.005	0.014	0.019	0.038	0.038	0.027
Wylfa	0.006	<0.005	0.007	0.013	0.008	<0.005	0.006	<0.005

[a] *Where no data is given, no assessment was undertaken due to a lack of suitable habits data at the time. Data in italics signify assessments performed to show trends in* total dose *over the five-year period from 2004–2008, using subsequently obtained habits data. Data are presented to 2 significant figures or 3 decimal places. Data below 0.005 mSv are reported as <0.005 mSv*

[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, 2019*

Establishment	Radiation exposure pathways	Gaseous or liquid source[a]	Exposure, mSv[b] per year	Contributors[c]
Nuclear fuel production and processing				
Capenhurst	Inadvertent ingestion of water and sediment and external[d]	L	0.007	Ext
	Terrestrial foods, external and inhalation near site[j]	G	<0.005[g]	^{3}H[h], ^{99}Tc[h], ^{234}U, ^{238}U
Springfields	Fish and shellfish consumption and external in intertidal areas	L	0.013	Ext
	Terrestrial foods, external and inhalation near site	G	<0.005[g]	^{14}C, ^{90}Sr[h], ^{129}I[h], ^{241}Pu[h]
	External in intertidal areas (children playing)[a,h]	L	<0.005	Ext
	Occupancy of houseboats	L	0.024	Ext
	External in intertidal areas (farmers)	L	0.023	Ext
	Wildfowl consumers	L	<0.005	Ext
Sellafield[l]	Fish and shellfish consumption and external in intertidal areas (2015–2019 surveys) (excluding naturally occurring radionuclides)[m]	L	0.063	Ext, ^{241}Am
	Fish and shellfish consumption and external in intertidal areas (2015–2019 surveys) (including naturally occurring radionuclides)[n]	L	0.27	Ext, ^{210}Po
	Fish and shellfish consumption and external in intertidal areas (2019 surveys) (excluding naturally occurring radionuclides)[e]	L	0.061	Ext, ^{241}Am
	Terrestrial foods, external and inhalation near Sellafield[j]	G	0.012	^{14}C, ^{90}Sr, ^{106}Ru[h], ^{129}I[h], ^{241}Am
	Terrestrial foods at Ravenglass[e]	G/L	0.017	^{14}C, ^{90}Sr, ^{106}Ru[h], ^{144}Ce[h]
	External in intertidal areas (Ravenglass)[i]	L	0.007	Ext, ^{241}Am
	Occupancy of houseboats (Ribble estuary)	L	0.024	Ext
	Occupancy of houseboats (Barrow)	L	0.055	Ext
	External (skin) to bait diggers	L	0.077[g]	Beta
	Handling of fishing gear	L	0.14	Beta
Research establishments				
Culham	Water consumption[k]	L	<0.005	^{137}Cs[h]
Dounreay	Fish and shellfish consumption and external in intertidal areas	L	0.006	Ext
	Terrestrial foods, external and inhalation near site	G	0.020	^{129}I, ^{238}Pu[h], $^{239+240}$Pu, ^{241}Am
Harwell	Fish consumption and external to anglers	L	<0.005	Ext
	Terrestrial foods, external and inhalation near site[e]	G	<0.005	^{3}H[h], ^{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[e]	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	0.009	Ext
	Terrestrial foods, external and inhalation near site[j]	G	<0.005	^{14}C, ^{35}S
Bradwell	Fish and shellfish consumption and external in intertidal areas	L	<0.005	Ext, ^{241}Am
	Terrestrial foods, external and inhalation near site[e]	G	<0.005	^{3}H[h], ^{14}C
Chapelcross	Wildfowl, fish and mollusc consumption and external in intertidal areas	L	0.006	^{137}Cs, $^{239+240}$Pu ^{241}Am
	Crustacean consumption	L	<0.005	^{90}Sr[h], ^{137}Cs[h], ^{238}Pu[h], $^{239+240}$Pu, ^{241}Am
	Terrestrial foods, external and inhalation near site[e]	G	0.006	^{35}S[h], ^{90}Sr
Dungeness	Fish and shellfish consumption and external in intertidal areas	L	<0.005	^{241}Am
	Terrestrial foods, external and inhalation near site[e]	G	<0.005	^{14}C, ^{35}S[h], ^{60}Co[h]
Hartlepool	Fish and shellfish consumption and external in intertidal areas	L	0.015	Ext, ^{241}Am
	Terrestrial foods, external and inhalation near site[e]	G	<0.005	^{14}C, ^{35}S[h], ^{60}Co[h]
Heysham	Fish and shellfish consumption and external in intertidal areas	L	0.024	Ext, ^{241}Am
	External in intertidal areas (turf cutters)	L	0.006	Ext
	Terrestrial foods, external and inhalation near site[e]	G	<0.005	^{14}C, ^{35}S[h], ^{60}Co[h]

Table 1.4 continued

Establishment	Radiation exposure pathways	Gaseous or liquid source[a]	Exposure, mSv[b] per year	Contributors[c]
Hinkley Point	Fish and shellfish consumption and external in intertidal areas	L	0.014	Ext, ^{241}Am
	Terrestrial foods, external and inhalation near site[e]	G	<0.005	^{14}C, ^{35}S, ^{60}Co[h]
Hunterston	Fish and shellfish consumption and external in intertidal areas	L	0.006	Ext, $^{239+240}$Pu, ^{241}Am
	Terrestrial foods, external and inhalation near site[e]	G	0.007	^{14}C, ^{35}S[h], ^{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[e]	G	<0.005	^{14}C, ^{35}S[h]
Torness	Fish and shellfish consumption and external in intertidal areas	L	<0.005	^{241}Am
	Terrestrial foods, external and inhalation near site[e]	G	0.006	^{14}C, ^{35}S, ^{90}Sr
Trawsfynydd	Fish consumption and external to anglers	L	0.006	Ext, ^{14}C
	Terrestrial foods, external and inhalation near site[e]	G	0.041	^{241}Am
Wylfa	Fish and shellfish consumption and external in intertidal areas	L	0.007	Ext, ^{241}Am
	Terrestrial foods, external and inhalation near site[e]	G	<0.005	^{14}C, ^{35}S[h]
Defence establishments				
Aldermaston & Burghfield	Fish consumption and external to anglers	L	<0.005[i]	Ext, ^{131}I[h]
	Terrestrial foods, external and inhalation near site[e]	G	<0.005[g]	^{3}H[h], ^{137}Cs[h], ^{234}U, ^{238}U
Barrow	Occupancy of houseboats	L	0.055	Ext
	Terrestrial food consumption	G	<0.005	^{3}H[h], ^{137}Cs[h]
Derby	Water consumption, fish consumption and external to anglers[k]	L	<0.005	Ext, ^{60}Co[h]
	Terrestrial foods, external and inhalation near site[d]	G	<0.005	^{234}U, ^{238}U
Devonport	Fish and shellfish consumption and external in intertidal areas	L	<0.005	^{241}Am[h]
	Occupancy of houseboats	L	<0.005	Ext
	Terrestrial foods, external and inhalation near site	G	<0.005	^{131}I[h], ^{241}Am[h]
Faslane	Fish and shellfish consumption and external in intertidal areas	L	0.008	Ext, ^{137}Cs, ^{241}Am[h]
	Terrestrial food consumption	G	<0.005	^{137}Cs
Holy Loch	External in intertidal areas	L	0.005	Ext
Rosyth	Fish and shellfish consumption and external in intertidal areas	L	0.006	Ext, ^{241}Am[h]
Radiochemical production				
Amersham	Fish consumption and external to anglers	L	<0.005	Ext, ^{3}H[h], ^{137}Cs
	Terrestrial foods, external and inhalation near site[e]	G	0.007	^{222}Rn
Cardiff	Fish and shellfish consumption and external in intertidal areas[f]	L	<0.005	Ext
	Terrestrial foods, external and inhalation near site[e]	G	<0.005	^{14}C, ^{35}S, ^{129}I[h]
	Inadvertent ingestion and riverbank occupancy (River Taff)[f]	L	<0.005	^{3}H[h], ^{14}C[h]
Industrial and landfill				
LLWR near Drigg	Terrestrial foods[e]	G	0.005	^{14}C, ^{90}Sr, ^{106}Ru[h], ^{137}Cs
	Fish and shellfish consumption and external in intertidal areas (2015–2019 surveys) (including naturally occurring radionuclides)[l,n]	L	0.27	Ext, ^{210}Po
	Water consumption[k]	L	<0.005	^{134}Cs[h], ^{137}Cs[h], ^{210}Po[h]
Whitehaven	Fish and shellfish consumption and external in intertidal areas (2015–2019 surveys) (excluding artificial radionuclides)[l,o]	L	0.21	^{210}Po
	Fish and shellfish consumption and external in intertidal areas (2015–2019 surveys) (including artificial radionuclides)[l,p]	L	0.27	Ext, ^{210}Po

Table 1.4 continued

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

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

[b] *Unless otherwise stated represents committed effective dose calculated using methodology of ICRP-60 to be compared with the annual 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. Data are presented to 2 significant figures or 3 decimal places. Data below 0.005 mSv are reported as <0.005 mSv*

[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] *10-year-old*

[e] *1-year-old*

[f] *Prenatal children*

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

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

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

[j] *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)*

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

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

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

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

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

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), are the operators of the Tails Management Facility. This new plant, on a separate part of the site, opened in 2019 and is currently undergoing commissioning.

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 was historically a separate licensed site and located on the Sellafield site, with three nuclear reactors. The site licence for Windscale site was transferred to Sellafield Limited in 2008. The site operators were granted a revised permit in 2017, that covers Sellafield only (amalgamating the Sellafield and Windscale nuclear sites). The decommissioning of the Windscale AGR was completed in 2011.

Decommissioning activities are continuing at Windscale. Most of the radioactive wastes derive from decontamination and decommissioning operations.

Key points

- *Total doses* for the representative person were 24 per cent (or less) of the annual dose limit for all assessed sites. *Total doses* decreased to the Cumbrian coastal community near Sellafield, compared to the values in 2018 and remained well below the limit

Capenhurst, Cheshire

- *Total dose* for the representative person was 0.17 mSv and increased in 2019

Springfields, Lancashire

- *Total dose* for the representative person was 0.14 mSv and increased in 2019
- Gaseous discharges of krypton-85 (National Nuclear Laboratory) increased, and liquid discharges of "other transuranic radionuclides" decreased, in 2019

Sellafield, Cumbria

- *Total doses* for the representative person were 0.24 mSv (or less) of the public dose limit and decreased in 2019
- The highest *total doses* were from seafood, dominated by the effects of naturally occurring radionuclides. Historical discharges from the Sellafield site made a lesser contribution
- Radiation dose from historical discharges of naturally occurring radionuclides (non-nuclear industry) was lower in 2019. The contribution to *total dose* from Sellafield discharges increased in 2019
- Gaseous discharges of krypton-85, iodine-129 and carbon-14, and liquid discharges of iodine-129 and caesium-137 decreased, in 2019
- The mean concentrations of caesium-137, plutonium-239+240 and americium-241 in lobsters (Sellafield Coastal), and of caesium-137 in winkles (Nethertown), are the lowest reported values in recent years.

Gaseous wastes are regulated from specific stacks from Windscale and liquid radioactive wastes are discharged to the Irish Sea via the Sellafield site pipelines. Both gaseous and liquid discharges are included as part of the regulated Sellafield discharges. Discharges of both gaseous and liquid radioactive wastes are minor compared to those from other Sellafield discharges. 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.

Gaseous and liquid discharges from each of these sites (Capenhurst, Springfields and Sellafield) are regulated by the Environment Agency. In 2019, 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 "Hex") 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 2020. 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 UUK permit was varied and updated in 2019 to incorporate the requirements of "GRR" guidance. The consolidated permit also included changes arising from EPR 18 (for implementation of BSSD 13). No environmental discharge limits were changed as part of the variation process, but the incinerator limits were removed (along with removal of the incinerator).

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 0.17 mSv in 2019 (Table 2.1), or 17 per cent of the dose limit, and up from 0.16 mSv in 2018. This dose was almost entirely due to direct radiation from the Capenhurst site. The representative person was children living near the site and unchanged from 2018. The increase in *total dose* was due to a higher estimate of direct radiation (resulting in changes in different contributions from food consumption, for each of the different age groups) from the site in 2019. The trend in annual *total dose* over the period 2008 – 2019 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 2019 (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 0.007 mSv in 2019 (up from 0.006 mSv in 2018). The small increase in dose was due to higher gamma dose rates measured over the riverbank at Rivacre Brook in 2019. 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 2019 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. In 2019, isotopes of uranium in silage were enhanced by small amounts (most likely due to natural variation), in comparison to those in 2018. Figure 2.2 shows the trends over time (2008 – 2019) of technetium-99 concentrations in grass. The overall trend reflects the reductions in discharges of technetium-99 from the enrichment of reprocessed uranium in the past. 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,

Figure 2.1. *Total dose* at nuclear fuel production and reprocessing sites, 2008-2019
(Exposures at Sellafield/Whitehaven/LLWR receive a significant contribution to the dose from technologically enhanced naturally occurring radionuclides from previous non-nuclear industrial operations)

and gross alpha and beta. Dose rate measurements were taken on the banks of the Rivacre Brook and surrounding area. Results for 2019 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 2019.

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 higher in 2019, in comparison to those in 2018, but similar to those in other 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 2019. Measured gamma dose rates near to the discharge point were higher in 2019, in comparison to those in 2018. Downstream of the Rivacre Brook, at the location where children play, dose rates over grass were also higher in 2019.

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. During the period 2008 – 2018, the overall trend was a reduction of liquid discharges over time, with most of the reductions attributed to progress in decommissioning some of the older plant and equipment. A small increase in liquid discharges of technetium-99 was reported in 2019.

Concentrations of technetium-99 in sediment (Rivacre Brook) from liquid discharges were detectable close to the discharge point in 2019 (and slightly higher, in comparison to those in 2018). 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 the effects of normal dispersion in the environment. The lowest activity concentrations at Rock Ferry were reported in 2016.

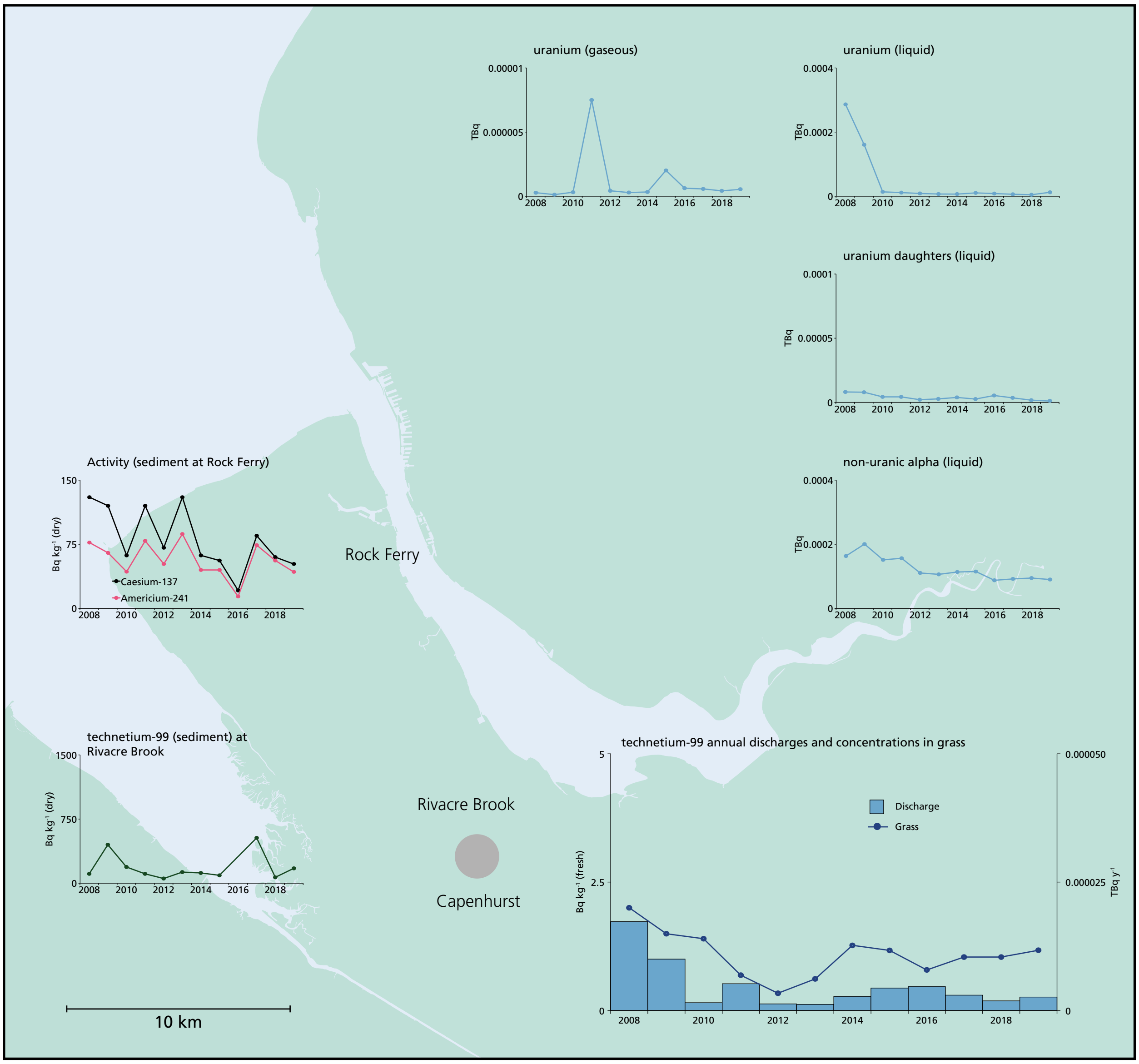
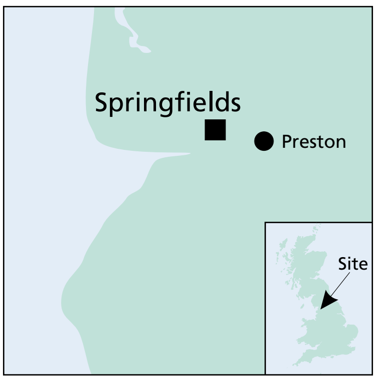


Figure 2.2. Discharges of gaseous and liquid radioactive wastes and monitoring of the environment, Capenhurst (2008-2019) (Note different scales used for discharges and activity concentrations)

2.2 Springfields, Lancashire



The Springfields site at Salwick, near Preston, is operated by Springfields Fuels Limited (SFL) under the management of Westinghouse Electric UK Limited, on behalf of the NDA. The main commercial activity is the manufacture of fuel elements for nuclear reactors and the production of uranium hexafluoride. Other important activities include recovery of uranium from residues and decommissioning redundant plants and buildings, under contract to the NDA, who retain responsibility for the historical nuclear liabilities on the site.

Research and development, carried out by the National Nuclear Laboratory, produces small amounts of other gaseous radionuclides that are also discharged under permit (see Appendix 2, Table A2.1).

Monitoring around the site is carried out to check not only for uranium concentrations, but also for other radionuclides discharged in the past (such as actinide 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 2019, based on a five-year rolling

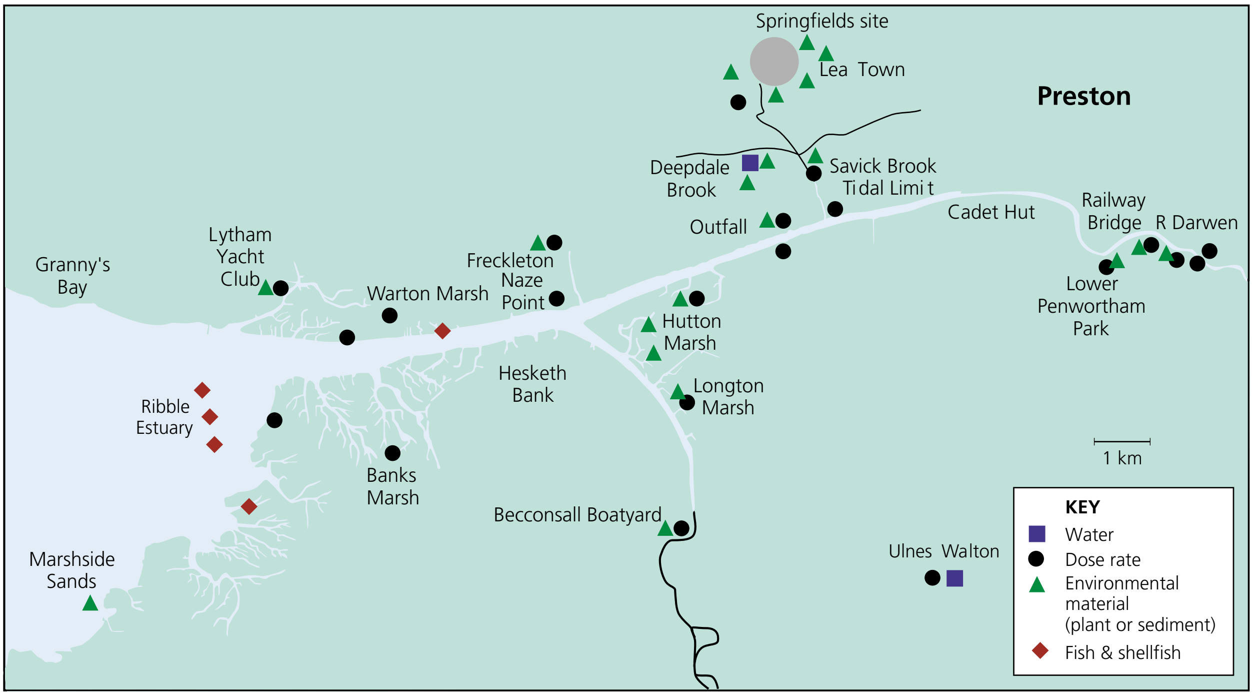


Figure 2.3. Monitoring locations at Springfields, 2019 (not including farms)

average (2015 – 2019), the habits information was revised, resulting in a higher occupancy rate 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 0.14 mSv in 2019 (Table 2.1), or 14 per cent of the dose limit, up from 0.075 mSv in 2018. In 2019, the representative person was adults consuming mushrooms at high-rates. Most of the dose to the representative person was from direct radiation. The annual direct radiation exposure (given in Table 1.1) was higher in 2019 (0.14 mSv) in comparison to that in 2018 (0.075 mSv). However, the increase in exposure was not due to a significant increase in measured dose rates around the site, but resulted from a higher occupancy of some workers undertaking a specific responsibility (associated with the rail line) close to the site. This work was completed in 2019. The increase in the *total dose* from 2018 was mostly due to the higher contribution of direct radiation included in the assessment in 2019.

Source specific assessments give exposures that were all less than the *total dose* in 2019 (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 0.024 mSv in 2019, or approximately 2 per cent of the dose limit for members of the public of 1 mSv, and down from 0.034 mSv in 2018. The reason for the change in dose in 2019 (from 2018) was mostly attributed to lower gamma dose rates over salt marsh (at Freckleton). This dose is estimated using a revised (more cautious) method, by using generally higher gamma dose rates measured in the vicinity of two houseboat locations (at Becconsall and Freckleton) in 2019 than those previously measured beneath the houseboats at Becconsall. Gamma dose rate measurements at Becconsall were not taken directly underneath a houseboat in 2019 (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.

Source specific doses for a high-occupancy houseboat dweller (together with dose rates) over the period 2008 – 2019 are given in Figure 2.4. The estimated dose decreased in 2012, following on from direct measurements (measured beneath the houseboats at Becconsall). Thereafter (up to and including 2017), the change in dose was due to the variation in gamma dose rates. In 2018, the apparent increase in dose (from 2017) was due to using a more cautious method of assessment.

The dose for high-rate consumers of seafood (including a contribution from external exposure) was 0.013 mSv in 2019. Of this dose, approximately 0.012 mSv was from

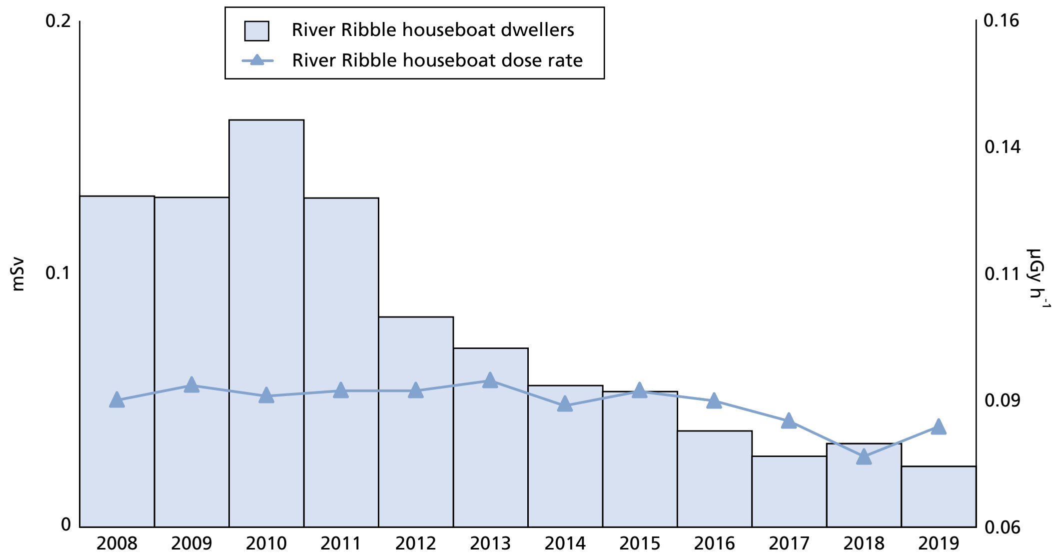


Figure 2.4. Source specific dose to houseboat occupants and dose rates at Springfields, 2008-2019

external exposure (the remainder being from consumption of fish and shellfish). The most important radionuclides were caesium-137 and americium-241 from past discharges from the Sellafield site.

A source specific assessment for external exposure to farmers was 0.023 mSv in 2019 (Table 2.1) and unchanged from 2018. The estimated doses to wildfowlers from external exposure over salt marsh and the consumption of game, to high-rate consumers of locally grown food, and to children playing on the banks of the estuary were all less than 0.005 mSv in 2019.

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 (NNL) research and development facilities. Discharges of krypton-85 from NNL increased in 2019, in comparison to those in 2018. The increase was due to the processing of uranium fuel pins that commenced in late 2018 and was completed in early 2020.

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, soil and freshwater samples were collected and analysed for isotopes of uranium. Data for 2019 are given in Table 2.3(a). Uranium isotope concentrations in beetroot were similar to those in 2018. 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 (2008 – 2019) of gaseous uranium discharges and total uranium radionuclide concentrations in food (cabbage; 2008 – 2013: beetroot; 2014 – 2019). Over the period, uranium discharges have declined, with the lowest value reported from this site in 2019. 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 "other transuranic radionuclides" decreased (due to the completion in 2018 of a specific project by National Nuclear Laboratory) in 2019, in comparison to releases in 2018. Compared to previous years, discharges are now generally lower for beta-emitting radionuclides. 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

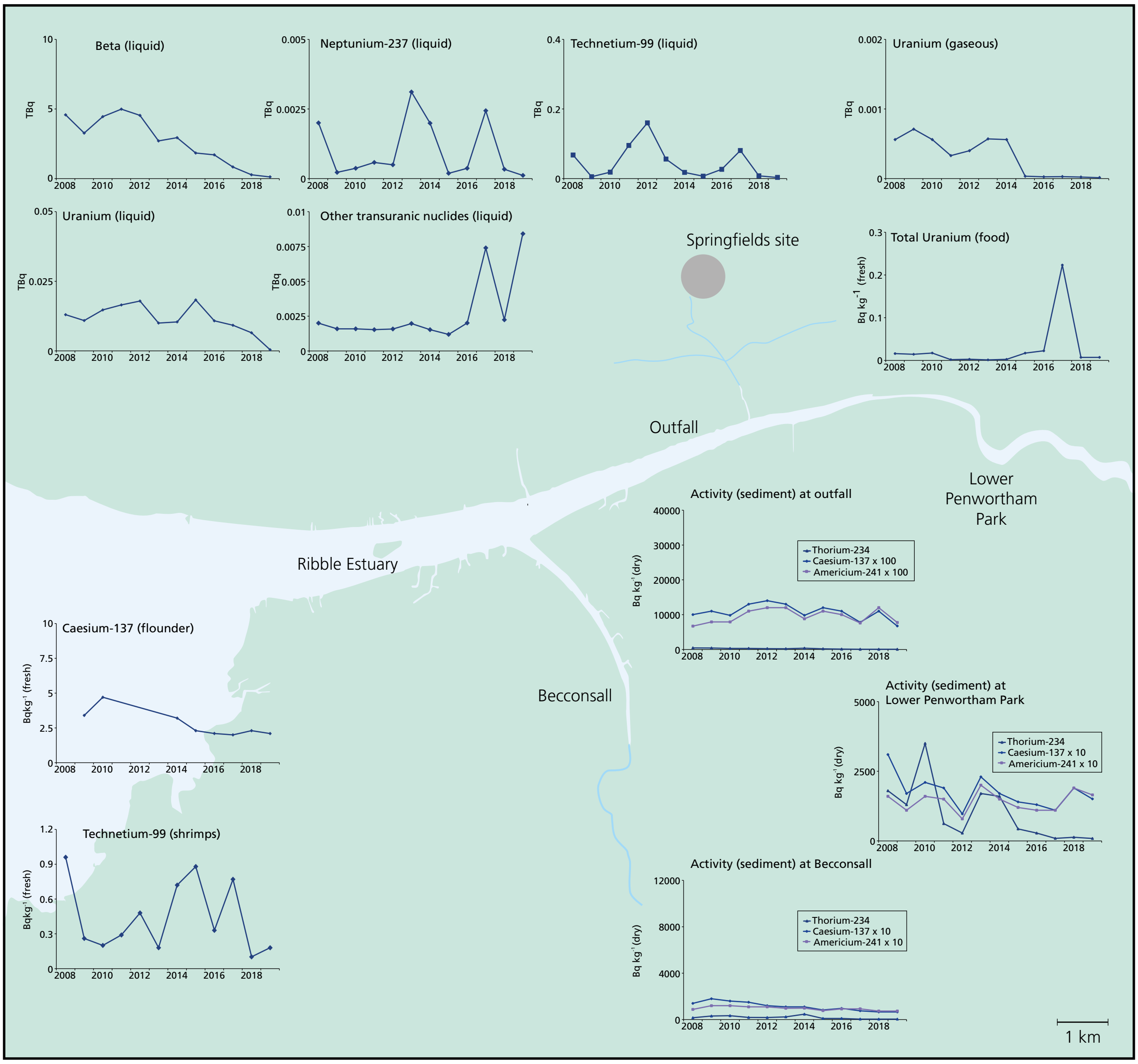


Figure 2.5. Discharges of gaseous and liquid radioactive wastes and monitoring of the environment, Springfields 2008–2019 (Note different scales used for discharges and activity concentrations)

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 (in 2012), technetium-99 discharges have generally declined, with the lowest value (reported as < 1 per cent of the annual limit) from this site in 2019. 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 2019 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 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 2019, thorium-234 concentrations in sediments (over the range of sampling sites) were generally similar compared to those in 2018. 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), with the lowest values reported at both locations in 2019.

Caesium-137, americium-241 and plutonium radionuclides were found in biota and sediments from the Ribble Estuary in 2019. 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 (2008 – 2019) 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 2019, gamma dose rates in the estuary, including rates measured for houseboat assessments (at Becconsall), were generally higher (by small amounts) to those in 2018, 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 2019, the main operations on the Sellafield site were: fuel reprocessing at the Magnox Reprocessing Plant, the decommissioning and clean-up of redundant nuclear facilities and waste treatment and storage.

Nuclear fuel reprocessing at THORP ceased in 2018, resulting in reduced gaseous and liquid discharges in 2019. THORP will continue to serve the UK until the 2070s as a storage facility for spent fuel. Magnox reprocessing continued in 2019/20, but was paused towards the end of the financial year. It is expected to restart during 2020 in reducing the final 1 per cent (538 tonnes) of fuel left to reprocess. The Sellafield site also contains the Calder Hall Magnox nuclear power station, which ceased generating in 2003 and is undergoing decommissioning. De-fuelling operations of Calder Hall were completed in 2019 (NDA, 2020).

Sellafield Limited applied to vary its environmental permit in October 2018, given the projected reduction in radioactive discharges to the environment following the completion of reprocessing operations. The Environment Agency consulted on the variation application in late 2018 and responses were taken into account in the determination of the application. The Environment Agency then consulted on a draft decision and draft permit from 7 October to 1 December 2019. The proposed changes were:

- 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)
- Updating the permit to the latest template so that it reflects recent guidance changes

The Environment Agency considered the received responses to the consultations and decided to grant the application subject to the conditions in the varied permit. The varied permit will come into effect on 1 October 2020. The existing environmental permit will remain in existence until this new date. Relevant published documents are available on the Citizen Space and GOV.UK websites: **https://consult.environment-agency.gov.uk/cumbria-and-lancashire/sellafield-radioactive-substances-activities-rsa-p**

https://www.gov.uk/government/consultations/sellafield-radioactive-substances-activities-rsa-permit-variation

Sellafield Limited continued retrievals of sludge from legacy pond facilities in 2019 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.

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 2019, some changes were found in the amounts (and mixes) of seafood species consumed and intertidal occupancy rates (Moore *et al*., 2020a). Revised figures for consumption rates, together with occupancy rates, are provided in Appendix 1 (Table X2.2). 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, related to liquid discharges from Sellafield in Cumbria.

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 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 products of the long-lived parent radionuclides discharges to sea. Naturally occurring radionuclides from this (non-nuclear) industrial activity are also monitored and assessed (see Section 6.4). From a radiological assessment perspective, the effects from the Sellafield site and the former phosphate works 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 2019 (Moore *et al*., 2020a). 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 6.4) 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 (due to TENORM) from historical discharges is difficult to determine above a variable background (see Appendix 1, Annex 4).

In 2019, the highest *total dose* to the Cumbrian coastal community*, near Sellafield, was assessed to have been 0.24 mSv (Table 2.17), or 24 per cent of the dose limit to members of the public, and down from 0.37 mSv in 2018. As in previous years, most of this dose was due to radioactivity from sources other than those resulting from Sellafield discharges i.e. from historical discharges of naturally occurring radionuclides from past non-nuclear industrial activity. The representative person was adults consuming molluscan shellfish at high-rates who also consumed significant quantities of other seafood. In 2019, this represents a change in the representative person from that in 2018 (adults consuming crustacean shellfish), which is due the revision of habits information (an increase in the breadth of seafood species being consumed by individuals). The decrease in *total dose* in 2019 was mostly attributed to lower concentrations of polonium-210 in locally caught crustaceans (crabs), in comparison to those in 2018. 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 (0.003 mSv, Table 1.1) in 2019 was considered in the *total dose* assessments, but this made no contribution to the highest *total dose.*

The most significant contributors to the *total dose* in 2019 were from crustacean, mollusc, external exposure over sediments and fish consumption (75, 13, 7 and 5 per cent, respectively). The most important radionuclide was polonium-210 (76 per cent) with transuranic radionuclides (including plutonium-239+240, americium-241) contributing approximately 10 per cent of the dose.

The dose in 2019 from artificial radionuclides discharged by Sellafield (including external radiation) and from historical discharges of naturally occurring radionuclides (from past non-nuclear industrial activity) contributed

* *The Cumbrian coastal community are exposed to radioactivity resulting from both current and historical discharges from the Sellafield site and naturally occurring radioactivity discharged from the former phosphate processing works at Whitehaven, near Sellafield.*

0.052mSv and 0.19 mSv, respectively (*values are rounded to two significant figures). In 2018, the contributions were 0.034 mSv and 0.33 mSv, respectively. In 2019, the contribution from the external radiation was 0.018 mSv (0.004 mSv in 2018). Data for naturally occurring radionuclides in fish and shellfish, and their variation in recent years, are discussed in Section 6.4.

The contribution to the *total dose* of 0.052 mSv in 2019 from artificial radionuclides (including external radiation) was higher, in comparison to that in 2018 (0.034 mSv). The increase in the contribution to the *total dose* from 2018 was mostly attributed to the revision of habits information. The contributing radionuclides in 2019 were mostly americium-241, plutonium-239+240 and iodine-129 (29, 14, and 10 per cent, respectively). External exposure was 34 per cent (13 per cent in 2018) of the *total dose* from artificial radionuclides.

The contribution to the *total dose* of 0.19 mSv in 2019 from naturally occurring radionuclides (from past non-nuclear industrial activity) was lower, in comparison to that in 2018 (0.33 mSv). In 2019, the most contributing radionuclide was polonium-210 (~ 97 per cent). The decrease in the *total dose* was mostly attributed to lower concentrations of polonium-210 in locally caught crustaceans (crabs) in 2019, in comparison to those in 2018. In 2019, polonium-210 concentrations (above expected background) in locally caught lobsters contributed 0.18 mSv to the *total dose*. Polonium-210 concentrations (above expected natural background) in fish and mollusc samples contributed 0.004 mSv and 0.008 mSv, respectively to the *total dose* in 2019.

Contributions to the highest annual *total dose* each year (2008 – 2019), 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 2008, 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 collected marine plants). The largest proportion of the *total dose,* 2008 and again from 2011 – 2012 and 2014 – 2018, 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 changes in dose were largely due to variations 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 Figure 2.7 (2008 – 2019) and Figure 2.8 (2015 – 2019), respectively. The overall trend from the nuclear industry 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 2008 – 2019. 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 0.24 mSv in 2019 (10-year-old children: 0.12; 1-year-old infants: 0.074; prenatal children: 0.047). *Total doses* estimated for each age group may be compared with the dose for each person of approximately 2.3 mSv to members of 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 2019, the dose to the 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 unchanged from 2018. The most exposed age group in 2019 was infants consuming locally produced milk at high-rates and unchanged from 2018. The most significant contributor in 2019 to the *total dose* for infants was from consumption of milk (91 per cent) and the most important radionuclides were carbon-14, strontium-90, iodine-129, and caesium-137 (29, 22, 22 and 9 per cent, respectively). All other age groups (adults, 10-year-old children and prenatal children) received a *total dose* of less than 0.005 mSv in 2019.

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

* *Dose values are rounded to two significant figures or reported as three decimal places, depending on their magnitude.*

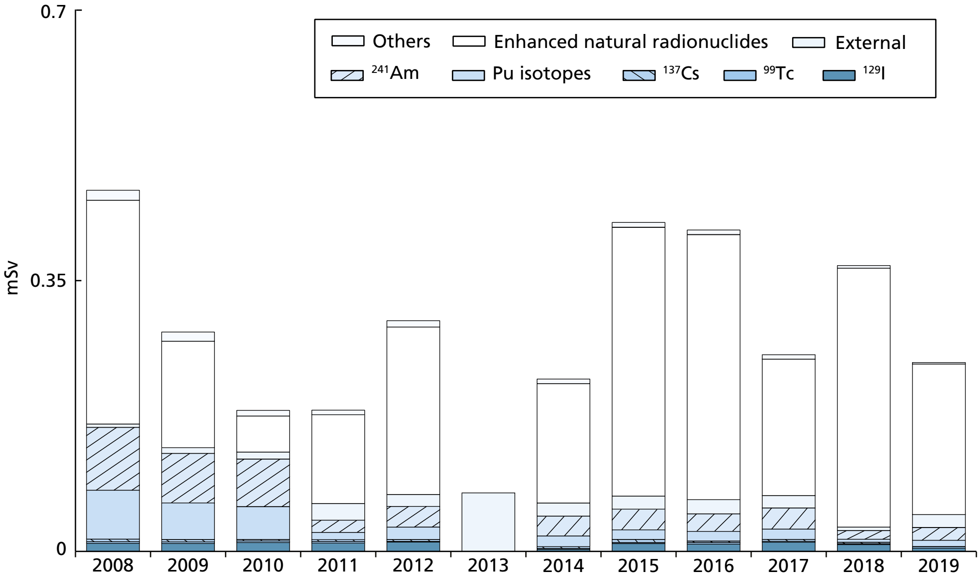


Figure 2.6. Contributions to *total dose* from all sources at Sellafield, 2008-2019 (The highest *total dose* in 2013 due to Sellafield discharges was to people living on houseboats near Barrow in Cumbria)

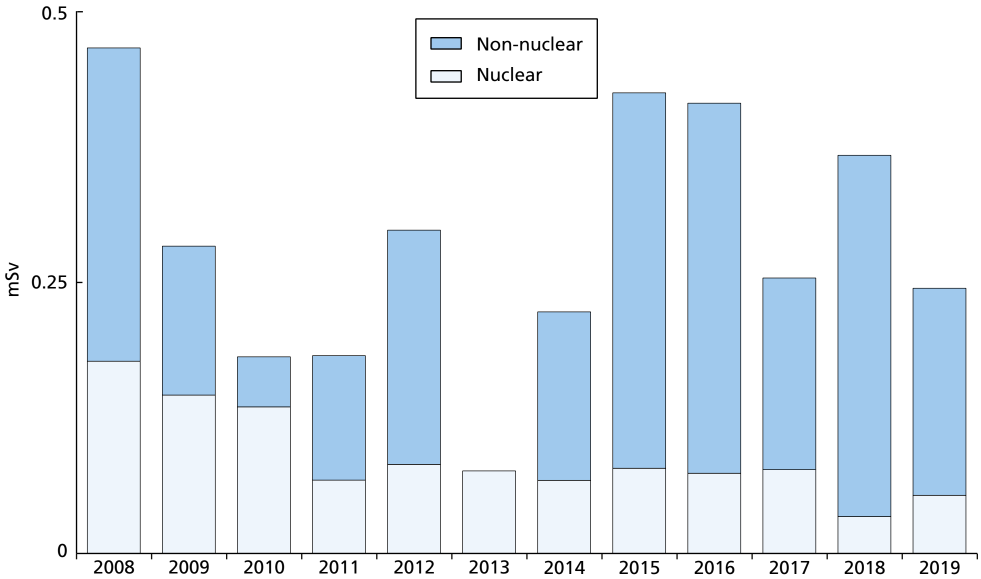


Figure 2.7. Contributions from nuclear and non-nuclear industries to *total dose* from all sources at Sellafield, 2008-2019 (The highest *total dose* in 2013 due to Sellafield discharges was to people living on houseboats near Barrow in Cumbria)

the period 2008 – 2019. 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 Agency, FSA, FSS, NIEA, NRW and SEPA, 2018). Since 2008, 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 – 2018, *total doses* were generally similar between years. The lower *total dose* values in recent years (up to 2017) was mostly due to changes in the monitoring programme in 2014 (Environment Agency, FSA, FSS, NIEA, NRW and SEPA, 2015). In 2018, the decrease in *total dose* was mostly attributed to the revision of habits information.

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.

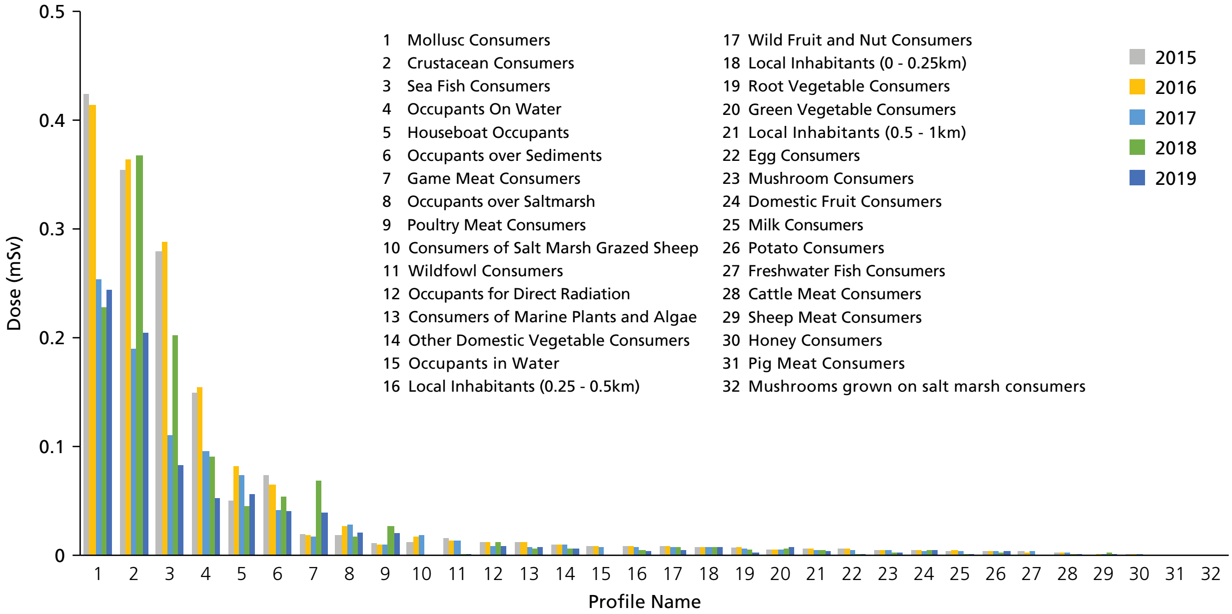


Figure 2.8. Contributions from each pathway of exposure to the *total dose* from all sources, 2015-2019

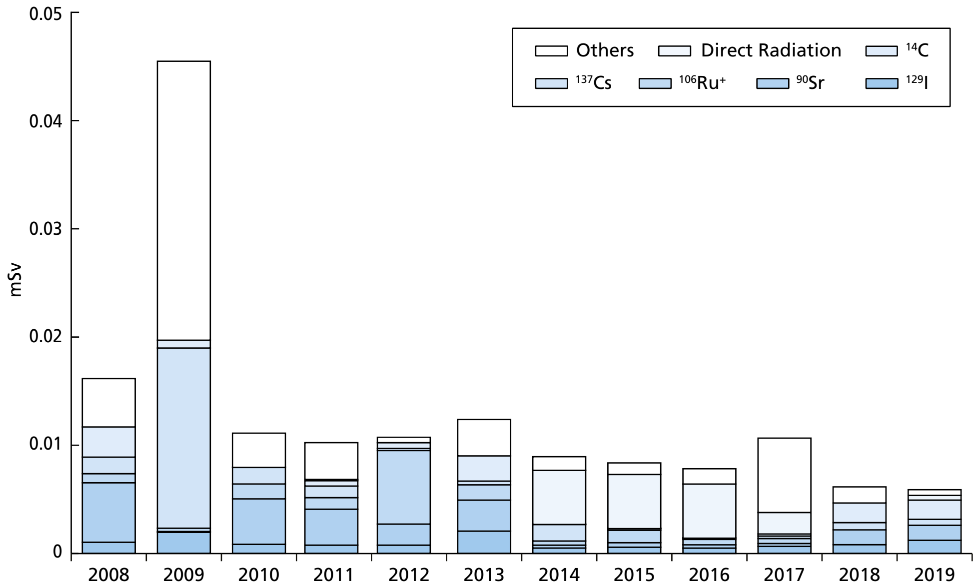


Figure 2.9. Contributions to *total dose* from gaseous discharge and direct radiation sources at Sellafield, 2008-2019 (+ based on limits of detection for concentrations in foods)

Source specific doses

Important source specific assessments of exposures, as a result of radioactive waste discharges from Sellafield, continued to be due to high-rate consumption of fish and shellfish and to external exposure from gamma rays over long periods. Other pathways were kept under review, particularly high-rate consumption of locally grown food (from gaseous 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 2019, 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 0.012 mSv in 2018 (Table 2.17), or approximately 1 per cent of the dose limit to members of the public, and increased from 2018 (0.011 mSv). Other age groups received less exposure than the infants (1-year-old) dose of 0.012 mSv in 2019 (adults: 0.009; 10-year-old children: 0.010; prenatal children: <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 (2019 habits survey). The second is based on a five-year rolling average using habits data gathered from 2015 to 2019. Some changes were found in the amounts (and mixes) of species consumed compared to those in the 2018 and the 2014 – 2018 rolling average. For crustaceans (crab, lobster, and other crustaceans), the total consumption rate increased (by a very small amount) in 2019, and small changes were reported for individual species in the 2015 – 2019 rolling average. For fish (cod, other fish), the total consumption rate decreased (by a very small amount), and small changes were reported for individual species in the 2015– 2019 rolling average. For molluscs (winkles and other molluscs), the consumption rates were similar in both 2019 and the 2015 – 2019 rolling average. The occupancy rate over sediments increased in 2019 and decreased in the 2015 – 2019 rolling average. 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.*, 2020a). 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 2019. The doses from artificial radionuclides to people who consume a large amount of seafood were 0.061 mSv (0.066 mSv in 2018) and 0.063 mSv (0.072 mSv in 2018, as amended in RIFE 24 errata) using the annual and five-year rolling average habits data, respectively. These doses each include a contribution due to external radiation exposure over sediments. Doses were similar using both sets of habits data in 2019.

The dose to a local person (high-rate consumer of seafood) due to the enhancement of concentrations of naturally occurring radionuclides resulting from discharges from the former phosphate works near Whitehaven (using maximising assumptions for the dose coefficients and the five-year rolling average habits data) is estimated to have been 0.21 mSv in 2019. Most of this was due to polonium-210 (97 per cent). The reason for the change in dose in 2019 (from 0.33 mSv in 2018) is the same as that contributing to the *total dose* for all sources, i.e. lower concentrations of polonium-210 in locally caught crabs in 2019, in comparison to those in 2018. For comparison (with the assessment using the five-year rolling average habits data), the dose from the single-year assessment for the Cumbrian coastal community seafood consumer from naturally occurring radionuclides (based on consumption rates and habits survey data in 2019) was also 0.21 mSv (Table 2.17).

Taking artificial and enhanced natural radionuclides together, the source specific doses were both 0.27 mSv for the annual and five-year rolling average habits data. These estimates are slightly larger than the estimate of *total dose* from all sources of 0.24 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 (see Appendix 1, Section 3.8).

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 2019 (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 Cumbrian coastal community 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 2019 (Table 2.16), in comparison to those in 2018. For example, in Morecambe Bay, the increase in dose to 0.024 mSv (from 0.015 mSv in 2018) was mostly due to increased gamma dose rates over sand. 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 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 2019.

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 2019 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 2019, the dose was 0.057 mSv, or less than 6 per cent of the dose limit, and up from 0.046 mSv in 2018 (see Section 5.2). Other people received lower external doses in 2019. The estimated annual dose to a high-occupancy houseboat dweller in the River Ribble was 0.024 mSv (see Section 2.2). The dose to a person who spends a long time over the marsh in the Ravenglass Estuary was 0.007 mSv in 2019, and a small decrease to that in 2018 (0.008 mSv).

The doses to people in 2019 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 2019, the doses to people from recreational use of beaches varied from less than 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 similar variation, from less than 0.005 to 0.011 mSv. 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 2019, 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 0.14 mSv and 0.077 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 2019, the dose (including contributions from Chernobyl and fallout from nuclear weapons testing) was estimated to be 0.017 mSv, which was less than 2 per cent of the dose limit for members of the public, and lower (by a small amount) than that in 2018 (0.018 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 2019 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 2019. Gaseous discharges of krypton-85, iodine-129 and carbon-14 (and most other discharges, by a small amount) decreased in 2019, in comparison to releases 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 2019 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 2019 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 gaseous discharges, detected in concentrations of tritium and carbon-14 in offal samples. 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 2019 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 gaseous discharges from Sellafield was found in some of these foods. Tritium was positively detected in locally grown apples and strontium-90 was positively detected in a number of food samples (including milk) at low concentrations. In 2019, the maximum iodine-129 and iodine-131 concentrations in milk were reported as less than values. 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 2019 are summarised in Appendix 2 (Table A2.2). In 2019, the 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 2019. Liquid discharges of iodine-129 and caesium-137 (and most other discharges, by a small amount) decreased in 2019, in comparison to releases in 2018. 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 (planned to end in 2021), and periods of planned and unplanned reprocessing plant shutdowns that occur from year to year.

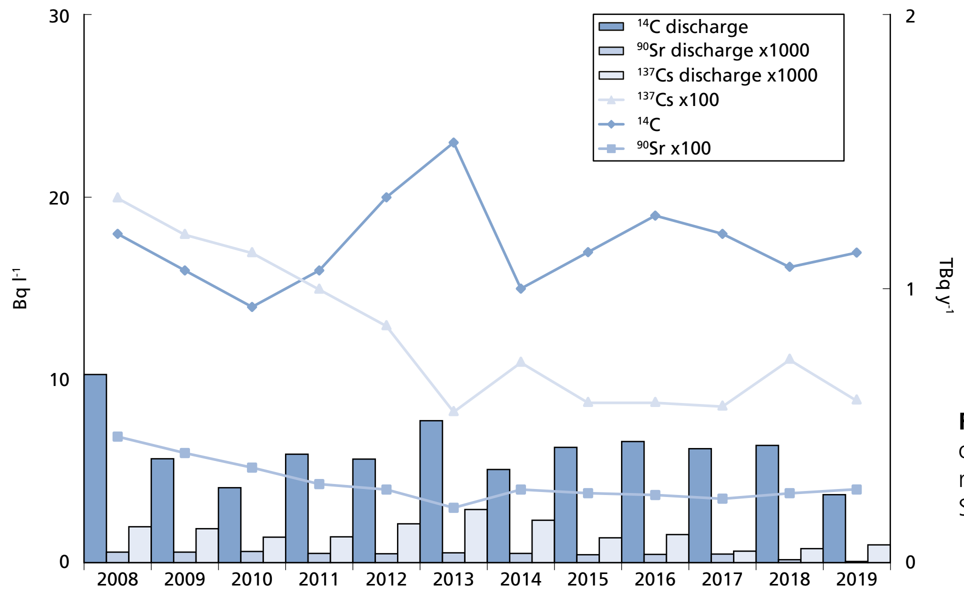


Figure 2.10. Discharges of gaseous wastes and monitoring of milk near Sellafield, 2008-2019

The downward trend of technetium-99 discharges from Sellafield is given in Figure 2.11 (2008 – 2019) and Figure 2.12 (1990 – 2019). Technetium-99 discharges have substantially reduced from the peak of 192 TBq in 1995. Further information relating to past discharges of technetium-99 is available in earlier RIFE reports (e.g. Environment Agency, FSA, FSS, NIEA, NRW and SEPA, 2019).

Monitoring of the marine environment

Regular monitoring of the marine environment near to Sellafield and further afield was conducted during 2019, 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 6.

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 2019 (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). Overall, these concentrations in shellfish have decreased over the period. The mean concentrations of plutonium-239+240 and americium-241 in crustacean shellfish, and caesium-137 in fish and shellfish, were lower in 2019, in comparison to those in 2018. The concentrations of caesium-137, plutonium-239+240 and americium-241 in Sellafield Coastal lobsters and concentrations of caesium-137 in Nethertown winkles are the lowest reported values in recent years.

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 2019, in comparison to those in 2018. Over the longer time period,

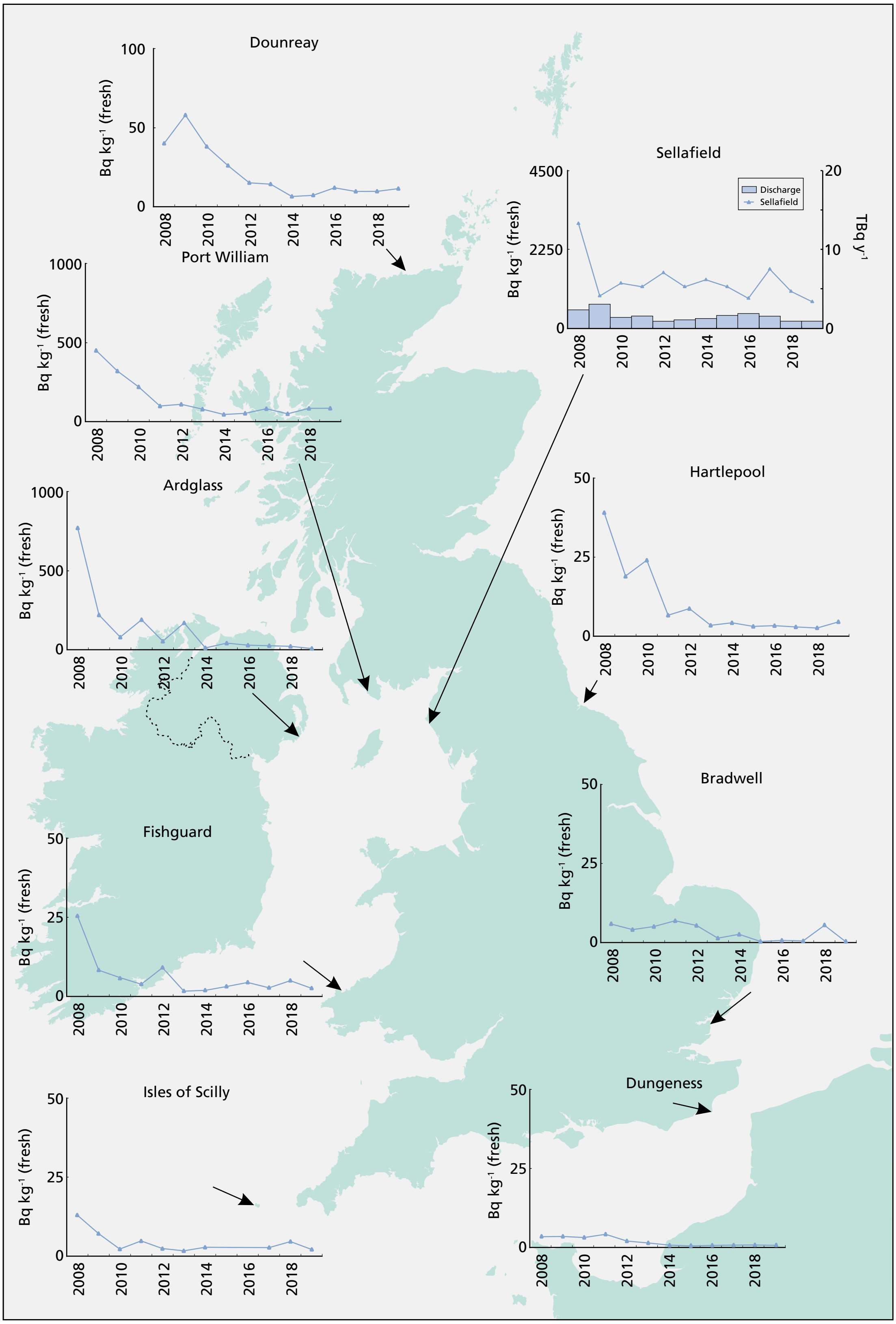


Figure 2.11. Technetium-99 in UK seaweed (*Fucus vesiculosus*) from Sellafield liquid discharges between 2008-2019 (Note different scales used for Sellafield, Ardglass, Port William and Dounreay)

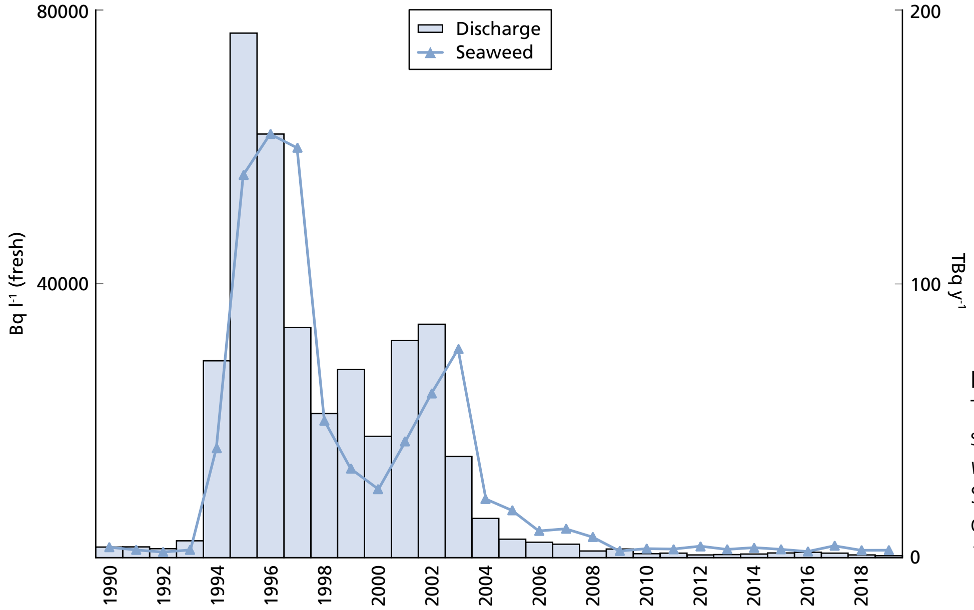


Figure 2.12. Technetium-99 in UK seaweed (*Fucus vesiculosus*) from Sellafield liquid discharges between, 1990-2019

activity concentrations in fish and shellfish appear to be generally declining (with minor variations) at a slow rate (Figure 2.18). Activity concentrations in fish (and shellfish) generally reflected progressive dilution with increasing distance from Sellafield. However, the rate of decline of caesium-137 concentrations with distance was not as marked as was the case when significant reductions in discharges were achieved in earlier decades.

Up until 2013, brown trout was sampled for analysis from the River Calder, which flows through the Sellafield site. Results for previous measured caesium-137 concentrations, and long-term trend information, are available in earlier RIFE reports (e.g. Environment Agency, FSA, NIEA, NRW and SEPA, 2014). The changes in concentrations were likely to be due 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 of about 20 Bq kg^{-1} (see Table X4.1), the data suggest a continued local enhancement of carbon-14 due to discharges from Sellafield. In 2019, carbon-14 is reported as the highest activity concentration in marine fish (plaice, 82 Bq kg^{-1}) from Whitehaven. In 2019, tritium (and organically bound tritium) values, across all species and locations, were reported as less than values (< 25 Bq kg^{-1}). Promethium-147 was detected at a very low concentration (reported as just above the less than value) in fish (plaice) in 2019.

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 (e.g. 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 2019 and 2018 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 2019 were also broadly similar (where comparisons can be made) to those in 2018.

Transuranic radionuclide data for fish and shellfish samples (chosen on the basis of potential radiological significance) in 2019 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 2019 and 2018 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 2019 (in comparison to those in 2018) at most of the north-eastern Irish Sea locations (e.g. lobsters from Sellafield coastal area). Americium-241 concentrations in mussels (near Sellafield) were also generally lower (by small amounts) in 2019, in comparison to those in 2018. Overall, plutonium-239+240 and americium-241 concentrations in lobsters (near Sellafield) were generally lower (with minor variations) in 2019, in comparison to those in recent years. The concentrations

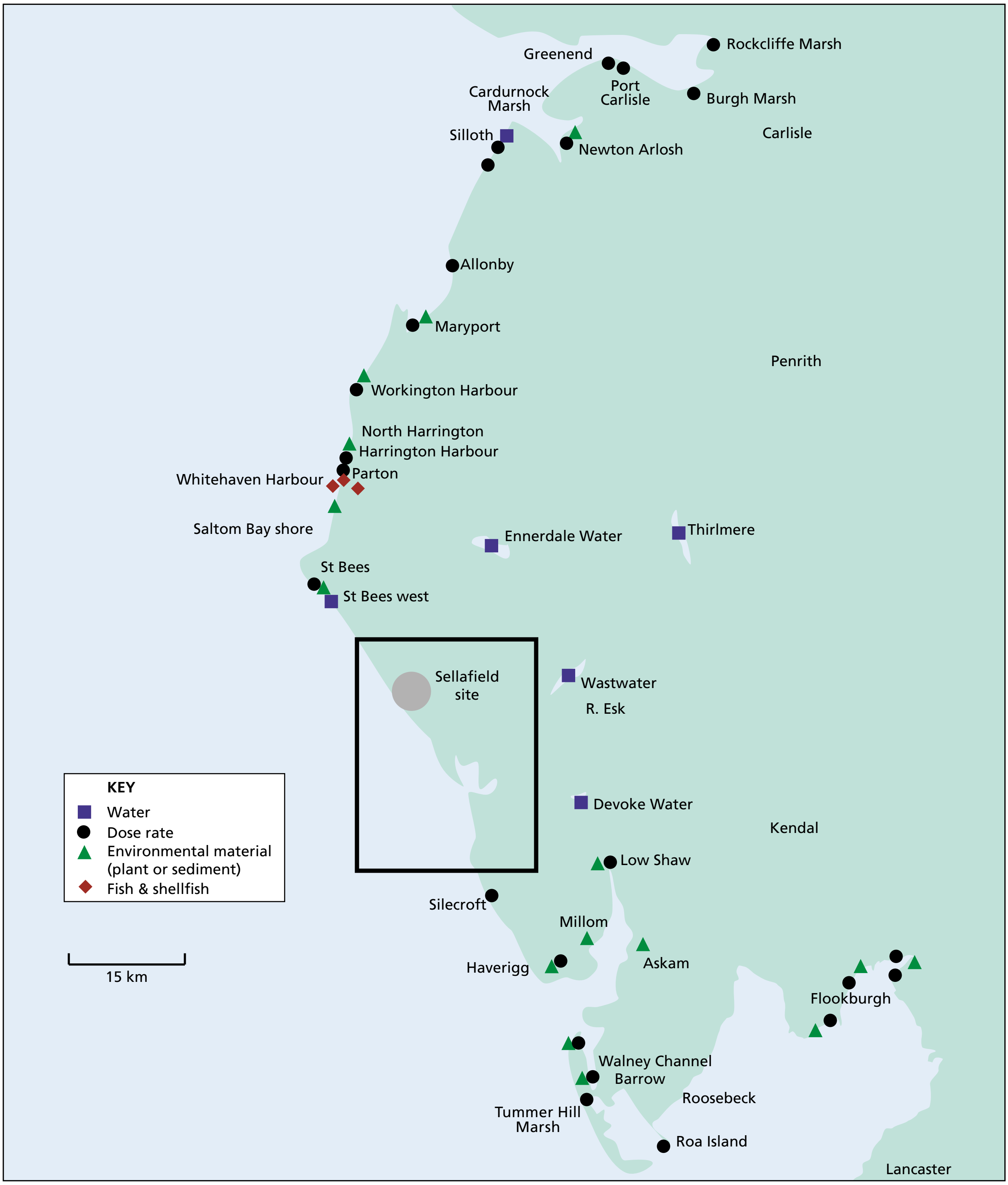


Figure 2.13. Monitoring locations in Cumbria, 2019 (not including farms)

of plutonium-239+240 and americium-241 in lobsters (Sellafield coastal area) in 2019 are the lowest reported values in recent years (Figures 2.19 and 2.20). 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 2019 are shown in Table 2.8. Radionuclides positively detected were cobalt-60, strontium-90, ruthenium-106,

Figure 2.14. Monitoring locations at Sellafield, 2019 (not including farms)

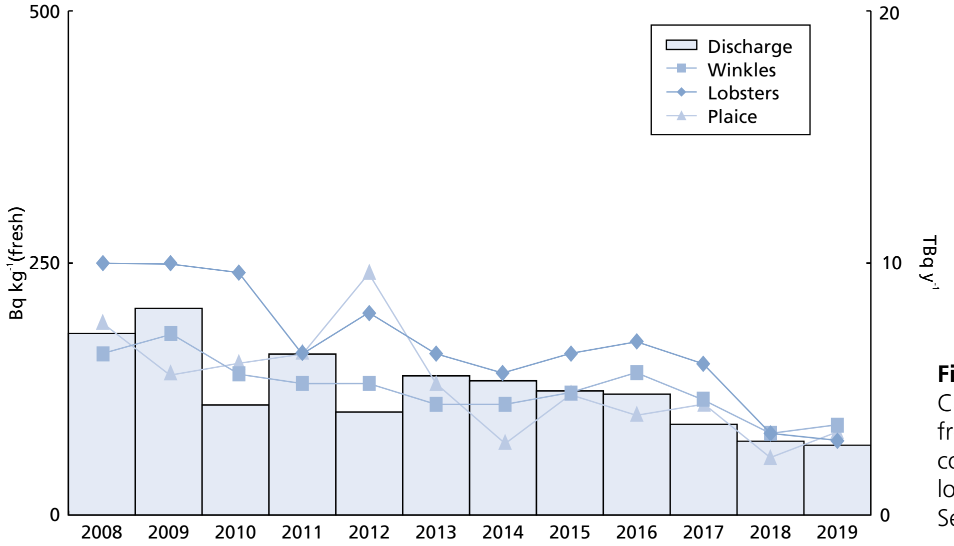


Figure 2.15. Carbon-14 liquid discharge from Sellafield and concentrations in plaice, lobsters and winkles near Sellafield, 2008-2019

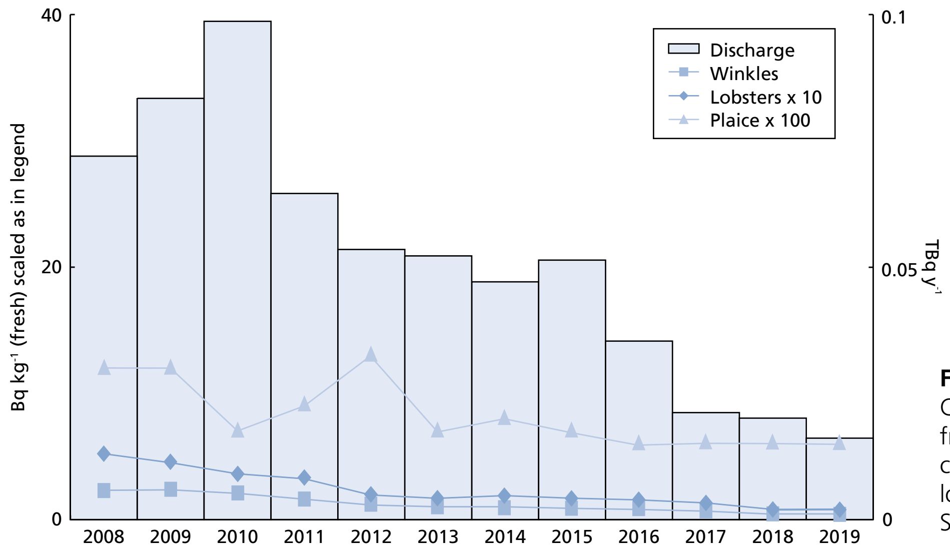


Figure 2.16. Cobalt-60 liquid discharge from Sellafield and concentrations in plaice, lobsters and winkles near Sellafield, 2008-2019

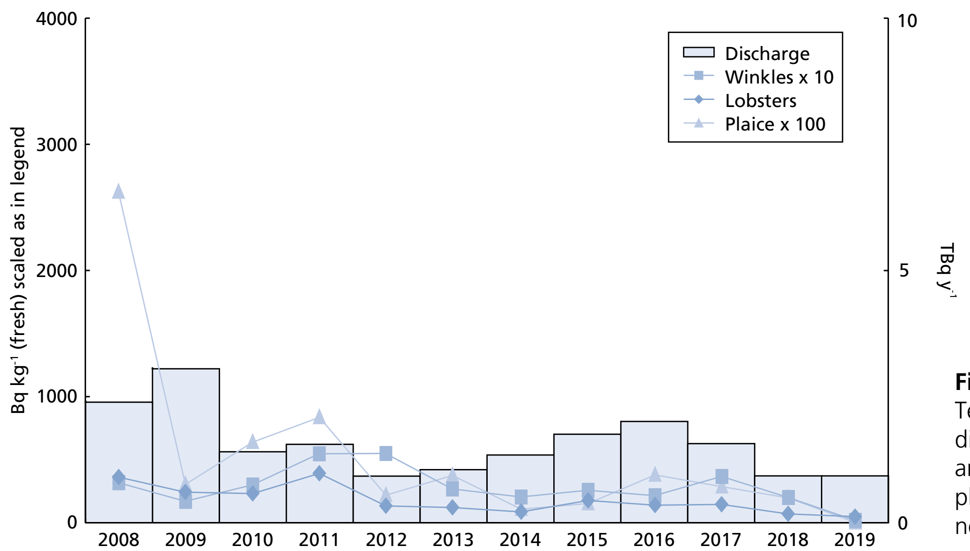


Figure 2.17. Technetium-99 liquid discharge from Sellafield and concentrations in plaice, lobsters and winkles near Sellafield, 2008-2019

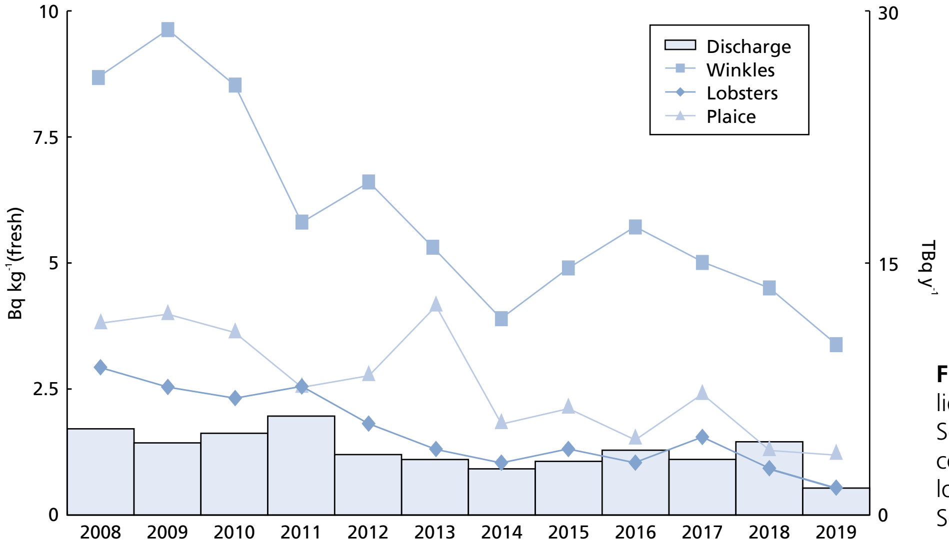


Figure 2.18. Caesium-137 liquid discharge from Sellafield and concentrations in plaice, lobsters and winkles near Sellafield, 2008-2019

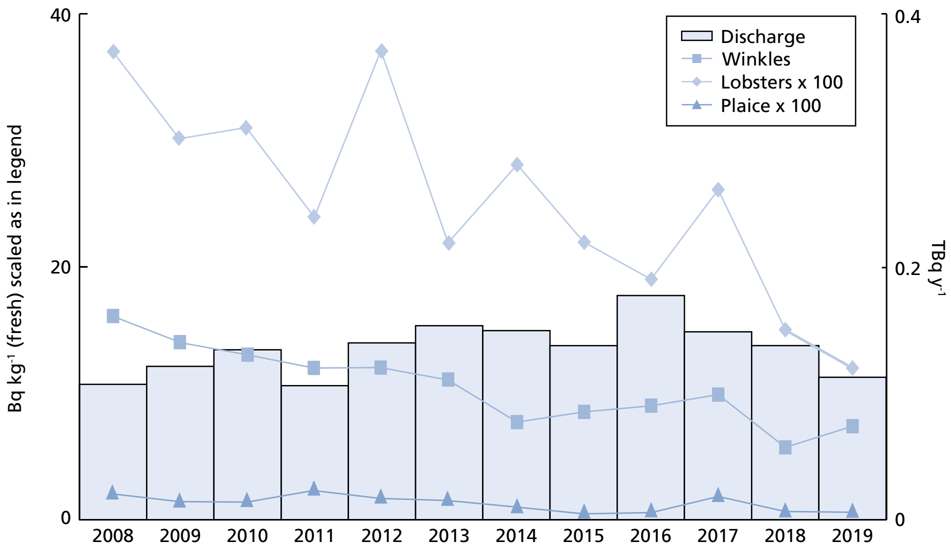


Figure 2.19. Plutonium-239+240 liquid discharge from Sellafield and concentrations in plaice, lobsters and winkles near Sellafield, 2008-2019

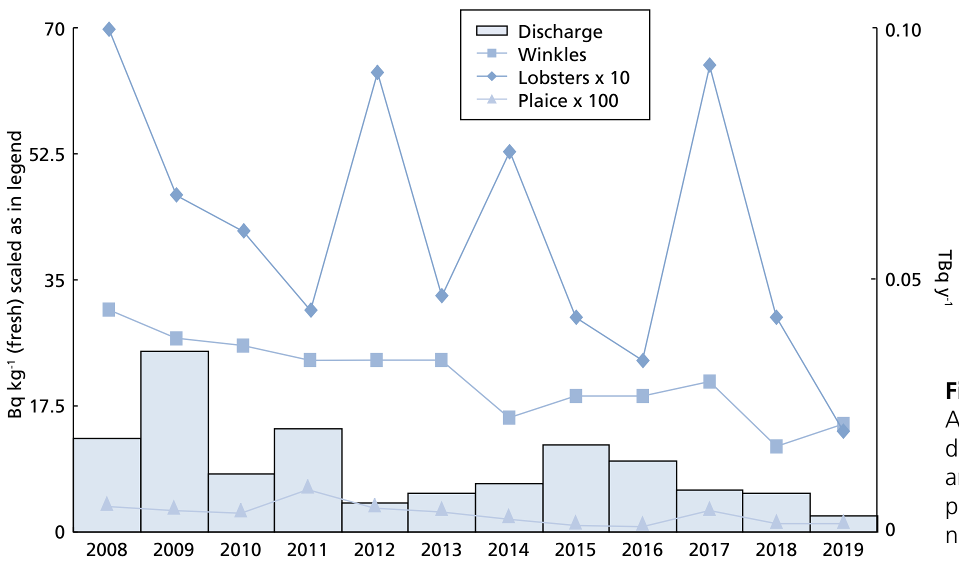


Figure 2.20. Americium-241 liquid discharge from Sellafield and concentrations in plaice, lobsters and winkles near Sellafield, 2008-2019

caesium-137, europium-154, europium-155, 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 2019, the concentrations of caesium-137, americium-241 and plutonium radionuclides were lower in the River Mite Estuary (an erosional area), in comparison to those in 2018 (reported as the highest 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 2019, in comparison to those in 2018.

The trends over time (1990 – 2019) 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 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 2019, 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 2019 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 is the lowest reported value for sediment at Carlton Marsh over the period (1998-2019). 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 2019 were generally similar to those in recent years (with small variations in comparison to those in 2018). 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 2019, 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 (2008 – 2019). 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 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

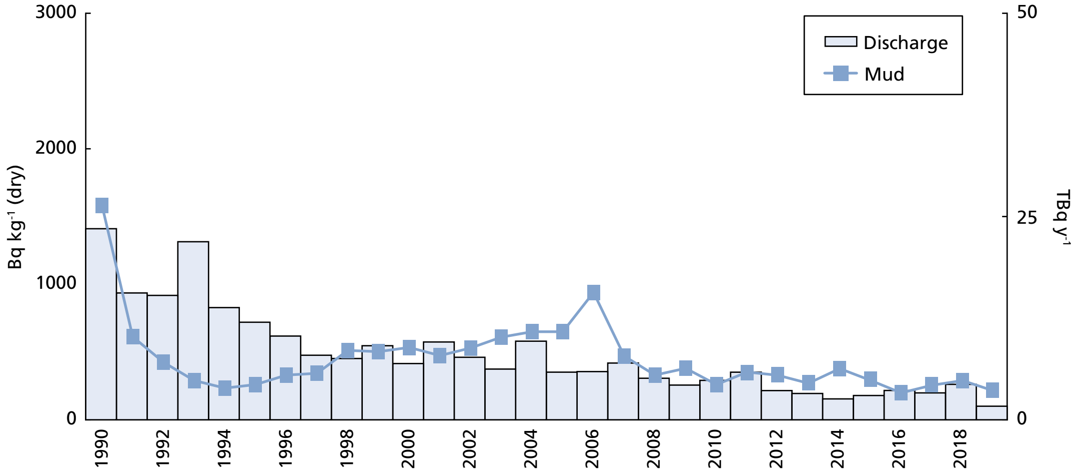


Figure 2.21. Caesium-137 liquid discharge from Sellafield and concentration in mud at Ravenglass, 1990-2019

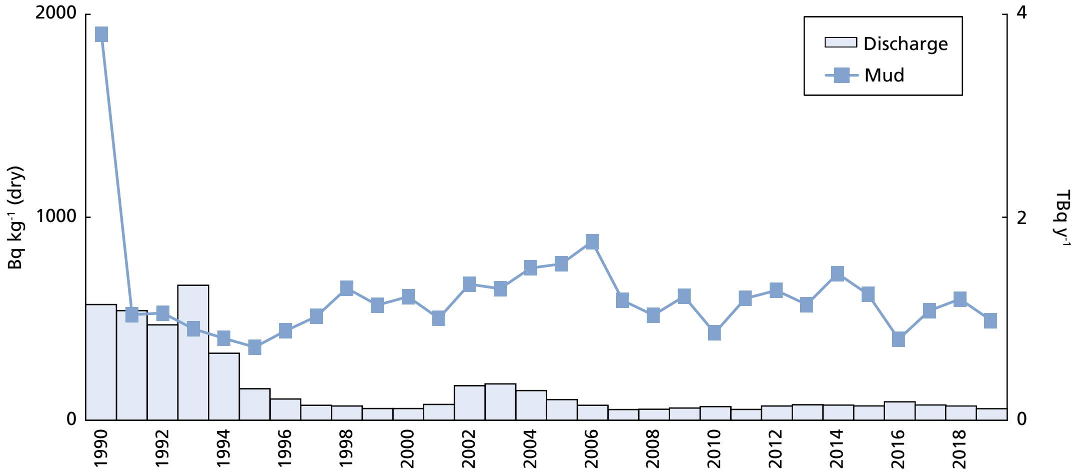


Figure 2.22. Plutonium-alpha liquid discharge from Sellafield and plutonium-239+240 concentration in mud at Ravenglass, 1990-2019

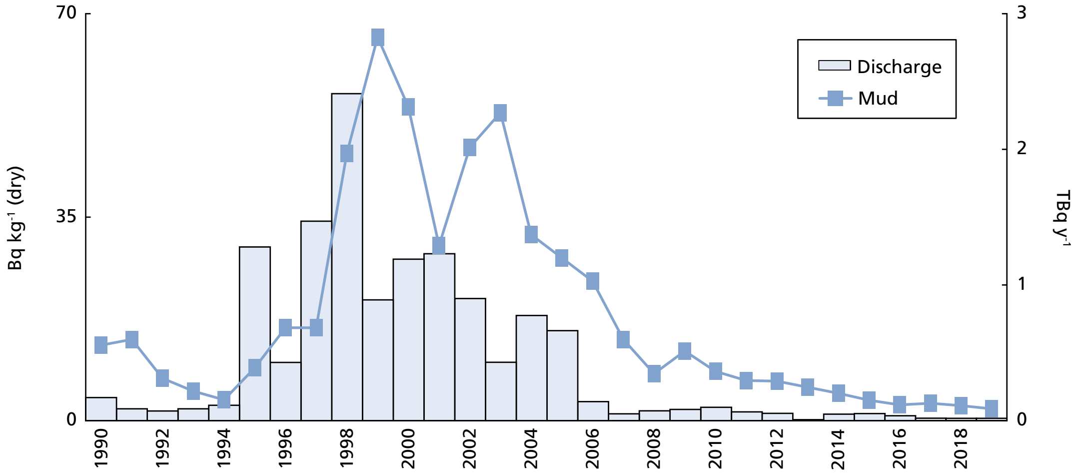


Figure 2.23. Cobalt-60 liquid discharge from Sellafield and concentration in mud at Ravenglass, 1990-2019

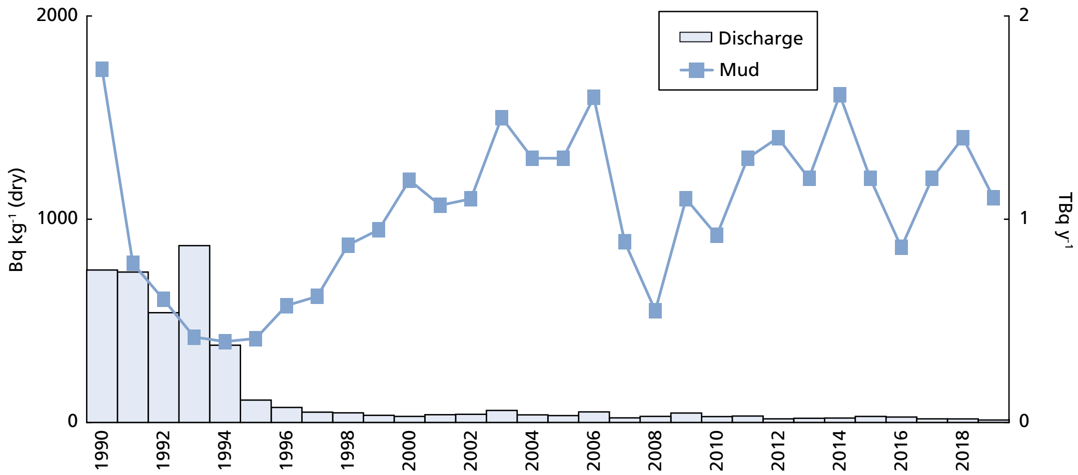


Figure 2.24. Americium-241 liquid discharge from Sellafield and concentration in mud at Ravenglass, 1990-2019

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 2019 are given in Table 2.10. Overall, where comparisons can be made, measured dose rates in 2019 were generally similar to those in 2018 (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 2019 were generally similar to those in 2018 (where comparisons can be made from similar ground types and locations). Beta dose rates in sand were higher at Whitehaven outer harbour, Sellafield beach (north of discharge point) St Bees and Tarn Bay (in comparison to those in 2018). 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 2019, 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).

Vehicle-mounted beach survey work, by the Sellafield site operator's contractors, began in 2006. The Groundhog™ Synergy system has been used (since 2009) that has a specific capability in relation to the detection of medium/high energy gamma-emitting radionuclides. The system also provides improved detection capability for low energy gamma emissions (on the original system used in 2006), increasing the ability to detect 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 2019 calendar year was completed in line with the Environment Agency's specification. A total area of 157 hectares was surveyed against a programme target of 152 hectares (Sellafield

* *"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 and 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.*

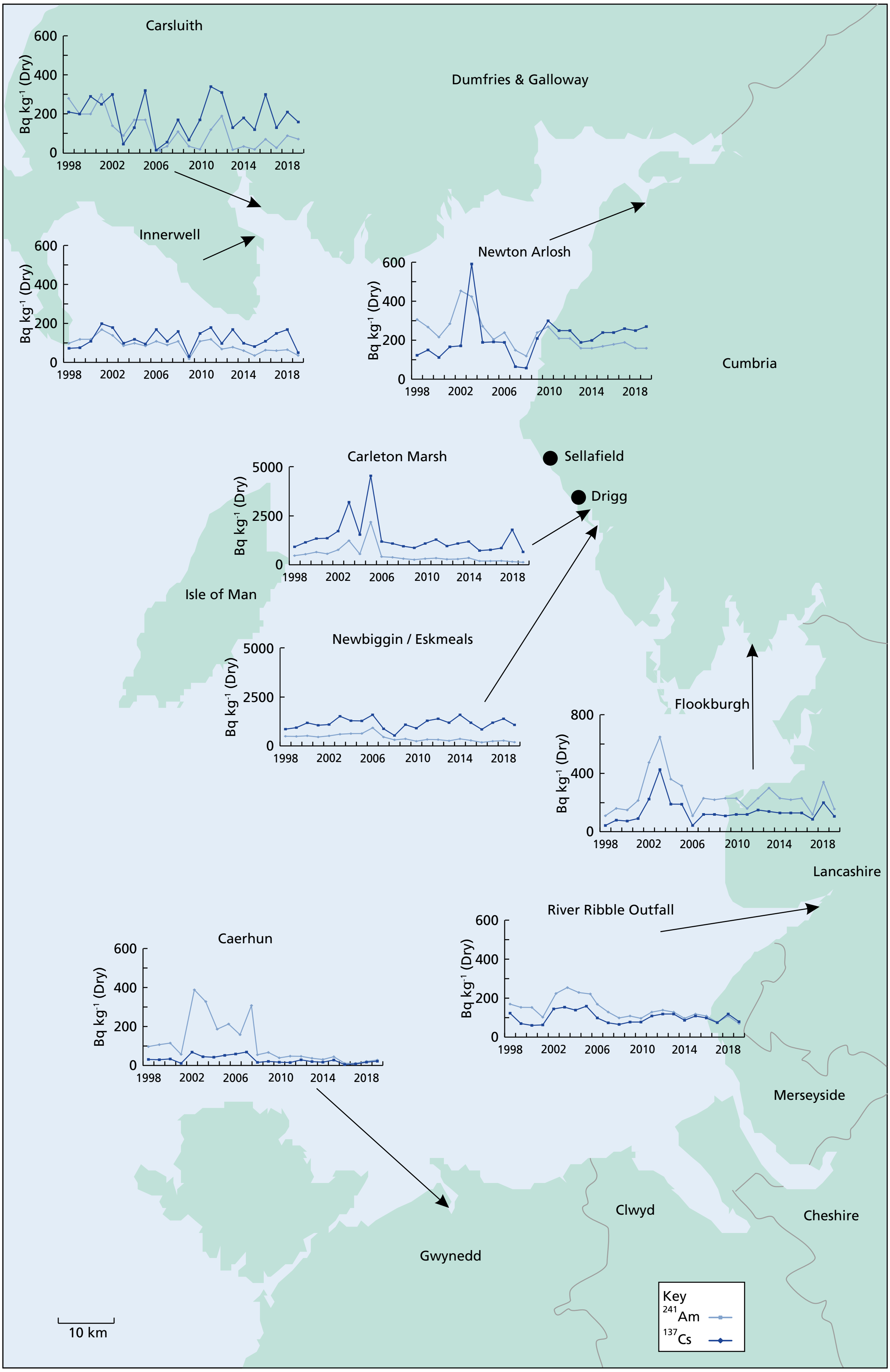


Figure 2.25. Concentrations of americium-241 and caesium-137 in coastal sediments in North West England, North Wales and South West Scotland between 1998-2019 (Note different scales used for Newbiggin and Carleton Marsh)

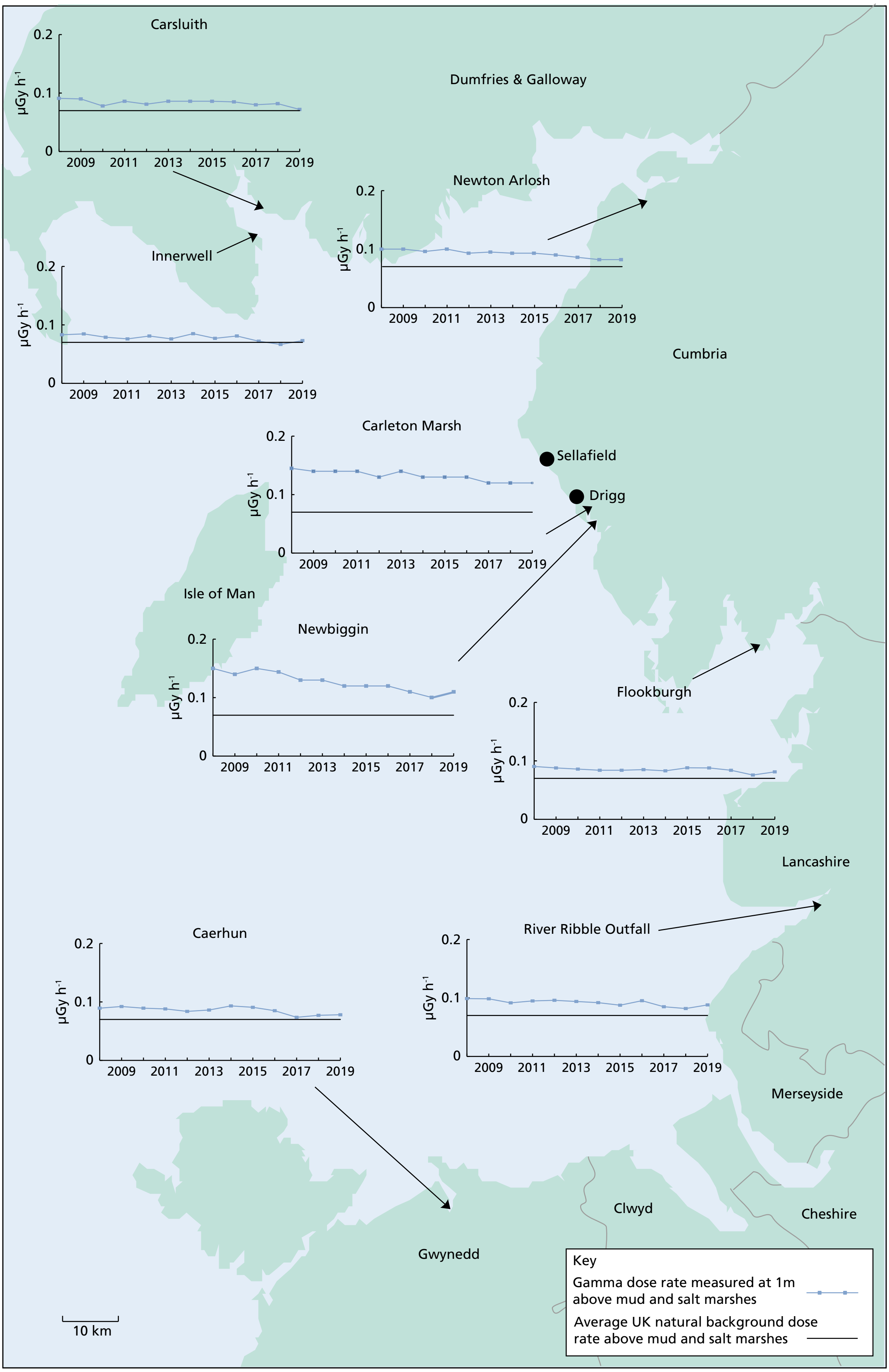


Figure 2.26. Gamma dose rates above fine coastal sediments (mud and salt marshes) in North West England, North Wales and South West Scotland between 2008-2019

Limited, 2020). In 2017, there was a change implemented to the beach finds categories in that the "stone" category is replaced by "larger 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 199 in 2019, of which approximately 95 per cent were classified as particles (less than 2 mm in size) and the remainder as larger objects. 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 2019, none 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**.

Monitoring along the Cumbrian coast will continue for 2020, with the current proposal being a further 105 hectares to be surveyed.

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 were 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. A summary report of assessing the risk to people's health from radioactive objects on beaches around the Sellafield site was published by PHE in February 2020, concluding that the risk is very low (Oatway *et al*., 2020).

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 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.

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 2019 of seaweeds from shorelines of the Cumbrian coast and further afield. Comparing 2019 and 2018 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 (2008 – 2019) and Figure 2.12 (1991 – 2019). 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 2019, in comparison to those in 2018. Over the last 5 years, small variations have been found, year on year, but technetium-99 concentrations in seaweed in 2019 were still low (Figure 2.11). At one specific location (Auchencairn, Scotland), known to have had fluctuating concentrations in previous years, technetium-99 concentrations in seaweed (*Fucus*) were similar in 2019 compared with those in 2018. The reasons behind these variations have been described in previous RIFE reports (e.g. Environment Agency, FSA, FSS, NIEA, NRW and SEPA, 2019).

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 2019, 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 2019 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). 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 7.

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 2019 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 2019, 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 2.14) 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 2019 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).

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 2019 are included in Table 2.4. The maximum caesium-137 concentration in the muscle of wood pigeon was reported as a less than value in 2019, 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 discovery of elevated concentrations in feral pigeons, 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 2019 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 increased (by small amounts) in 2019. Further information of the previously elevated concentrations (of strontium-90, caesium-137, americium-241 and plutonium radionuclides) in road drain sediments is given in earlier RIFE reports (e.g. Environment Agency, FSA, FSS, NIEA, NRW and SEPA, 2019).

Table 2.1 Individual doses – Capenhurst and Springfields, 2019

Site	Representative person[a]	Exposure, mSv per year						
		All pathways	Seafood	Other local food	External radiation from intertidal areas, river banks or fishing gear[b]	Intakes of sediment and water	Gaseous plume related pathways	Direct radiation from site
Capenhurst								
***Total dose* – all sources**	**Local child inhabitant (0–0.25km)**	**0.17[c]**	**-**	**<0.005**	**-**	**-**	**<0.005**	**0.17**
Source specific doses	Infant inhabitants and consumers of locally grown food	<0.005[c]	-	<0.005	-	-	<0.005	-
	Children playing at Rivacre Brook	0.007[c]	-	-	0.007	<0.005	-	-
Springfields								
***Total dose* – all sources**	**Adult mushroom consumers**	**0.14**	**-**	**<0.005**	**-**	**-**	**<0.005**	**0.14**
Source specific doses	Seafood consumers	0.013[c]	<0.005	-	0.012	-	-	-
	Houseboat occupants	0.024	-	-	0.024	-	-	-
	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	-	-	-
	Infant 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. Data are presented to 2 significant figures or 3 decimal places. Data below 0.005 mSv are reported as <0.005 mSv*

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

Table 2.2(a) Concentrations of radionuclides in food and the environment near Capenhurst, 2019

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		1.0					
Shrimps	Wirral	1	<25	0.27	0.60					
Mussels	Liverpool Bay	1	<25		0.52					
Cockles	Dee Estuary	1	<25	0.86	0.99	3.2				
Sediment	Rivacre Brook	2^E		190	3.4	80	170	7.3	84	<1.5
Sediment	Rivacre Brook (1.5 km downstream)	2^E		44	<1.4	<15	43	2.1	31	<1.5
Sediment	Rossmore (3.1 km downstream)	2^E		34	0.92	<13	20	<0.97	14	<1.5
Sediment	Rivacre Brook (4.3 km downstream)	2^E		14	0.62	13	15	<0.88	11	<1.5
Freshwater	Rivacre Brook	2^E	<2.7	<0.083			0.23	0.0091	0.086	<0.050
Freshwater	Rivacre Brook (1.5 km downstream)	2^E	<2.8	<0.089			0.055	<0.0028	0.025	<0.050
Freshwater	Rossmore (3.1 km downstream)	2^E	<2.8	<0.078			0.062	<0.0030	0.025	<0.050
Freshwater	Rivacre Brook (4.3 km downstream)	2^E	<2.8	<0.083			0.038	<0.0031	0.023	<0.050

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			<0.17				
Shrimps	Wirral	1	0.00057	0.0043	0.0068	*	0.000036		
Mussels	Liverpool Bay	1			1.0				
Cockles	Dee Estuary	1	0.10	0.62	1.4	*	*		
Sediment	Rivacre Brook	2^E						470	800
Sediment	Rivacre Brook (1.5km downstream)	2^E						250	630
Sediment	Rossmore (3.1km downstream)	2^E						<110	490
Sediment	Rivacre Brook (4.3km downstream)	2^E						<68	390
Freshwater	Rivacre Brook	2^E						0.26	0.54
Freshwater	Rivacre Brook (1.5km downstream)	2^E						0.063	0.31
Freshwater	Rossmore (3.1km downstream)	2^E						0.080	0.28
Freshwater	Rivacre Brook (4.3km downstream)	2^E						<0.077	0.24

Material	Location or selection[b]	No. of sampling observations[c]	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}				
			$^{3}H^{d}$	^{99}Tc	^{234}U	^{235}U	^{238}U
Terrestrial samples							
Milk		2	<4.4	<0.023	<0.0016	<0.00064	<0.0013
Milk	max			<0.028	0.0027	<0.00076	0.0023
Potato		1		<0.17	0.0040	0.00060	0.0055
Silage		1		<0.63	0.54	0.019	0.15
Grass/herbage	North of Ledsham	1^E		<2.3	0.45	<0.045	0.50
Grass/herbage	South of Capenhurst	1^E		<0.74	0.056	<0.0067	0.047
Grass/herbage	East of Capenhurst	1^E		<0.73	<0.16	<0.087	<0.13
Grass	Dunkirk Lane (0.9km South of Site)	1^E		<0.91	0.16	<0.021	0.19
Soil	North of Ledsham	1^E		<2.6	17	<1.3	20
Soil	South of Capenhurst	1^E		<2.9	20	1.0	20
Soil	East of Capenhurst	1^E		<1.8	24	1.2	24
Soil	Dunkirk Lane (0.9km South of Site)	1^E		<1.6	22	1.4	21

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

[d] *In distillate fraction of sample*

[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, 2019

Location	Ground type	No. of sampling observations	$\mu Gy\ h^{-1}$
Mean gamma dose rates at 1m over substrate			
East of railway station	Grass	1	0.078
Dunkirk Lane	Herbage and Mud	1	0.084
Near Lower Brook Farm	Grass	1	0.074
Rivacre Brook Plant outlet	Grass	1	0.084
Rivacre Brook Plant outlet	Grass and herbage	1	0.083
Rivacre Brook 1.5 km downstream	Grass	2	0.076
Rossmore Road West 3.1 km downstream	Grass	1	0.073
Rossmore Road West 3.1 km downstream	Grass and herbage	1	0.075
Rivacre Brook 4.3 km downstream	Sand and stones	2	0.080
North of Ledsham	Grass	1	0.078

Table 2.3(a) Concentrations of radionuclides in food and the environment near Springfields, 2019

Material	Location	No. of sampling observ-ations	Mean radioactivity concentration (fresh)[a], 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						2.1				
Grey Mullet	Ribble Estuary	1						2.0				
Shrimps[b]	Ribble Estuary	1		31		<0.18		1.1	0.015	0.0027	0.0011	
Mussels[c]	Ribble Estuary	1						0.11	0.17	0.078	0.036	
Wildfowl	Ribble Estuary	1	<3.5	23	<0.041		<0.97	0.65		0.0065	<0.00091	
Samphire	Marshside Sands	1				<0.066		0.16				
Sediment	River Ribble outfall	4[E]						72	23	35	22	34
Sediment	Lea Gate	2[E]						160	42	68	36	<53
Sediment	Lower Penwortham Park	4[E]						150	36	64	33	75
Sediment	Penwortham road bridge - West bank	2[E]						130	38	67	36	85
Sediment	Lytham Yacht Club	1[E]						110	32	48	31	44
Sediment	Becconsall	4[E]						63	24	45	26	33
Sediment	Freckleton	1[E]						190	39	74	39	56
Sediment	Hutton Marsh	1[E]						410	64	260	35	<22
Sediment	Longton Marsh	1[E]						460	41	280	51	<29
Grass (washed)	Hutton Marsh	1[E]				<0.39						
Grass (unwashed)	Hutton Marsh	1[E]				0.74						
Soil	Hutton Marsh	1[E]				34						

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							<0.14		
Grey Mullet	Ribble Estuary	1							<0.17		
Shrimps[b]	Ribble Estuary	1				0.000048	0.00063	0.0048	0.010		
Mussels[c]	Ribble Estuary	1					0.067	0.44	0.72		
Wildfowl	Ribble Estuary	1					0.0013	0.0086	0.015		
Samphire	Marshside Sands	1							0.11		
Sediment	River Ribble outfall	4[E]	20	<1.2	18				81	380	900
Sediment	Lea Gate	2[E]	31	<1.6	32				170	770	1200
Sediment	Lower Penwortham Park	4[E]	28	<1.8	28				160	540	1100
Sediment	Penwortham road bridge - West bank	2[E]	23	<1.1	25				140	560	1000
Sediment	Lytham Yacht Club	1[E]	23	1.1	24				120	410	870
Sediment	Becconsall	4[E]	21	<1.4	20				71	290	790
Sediment	Freckleton	1[E]	28	2.3	32				180	630	1200
Sediment	Hutton Marsh	1[E]	32	1.8	35				380	790	1600
Sediment	Longton Marsh	1[E]	32	<1.8	34				390	1000	1300

Table 2.3(a) continued

Material	Location or selection[d]	No. of sampling observ-ations[e]	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}								
			^{3}H	^{14}C	^{90}Sr	^{129}I	^{137}Cs	Total Cs	^{230}Th	^{232}Th	^{234}Th
Terrestrial samples											
Beetroot		1	<1.6	13	0.049	<0.017	<0.06	<0.061	0.0041	0.0025	
Sediment	Deepdale Brook	2[E]					<0.73				59
Silage		1	<3.8	17	0.13	<0.0080	<0.04	<0.044	0.021	0.020	
Freshwater[f]	Ulnes Walton	1[E]	<2.9				<0.23		<0.00094	<0.00064	

Material	Location or selection[b]	No. of sampling observ-ations[e]	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
Terrestrial samples											
Milk		2	<0.00039	<0.00039	<0.00039						
Milk	max		0.0031	0.00038	0.0036	<0.00018	0.00023	<0.42	0.00056		
Beetroot		1	0.0031	0.00038	0.0036	<0.00011	0.00016	<0.45	0.00015		
Sediment	Deepdale Brook	2[E]	59	2.7	56					350	820
Silage		1	0.029	0.00083	0.033	0.000076	0.00057	0.086	0.00079		
Grass	Opposite site entrance	1[E]	0.30	<0.038	0.22						
Grass	Opposite windmill	1[E]	1.5	0.062	1.5						
Grass	Deepdale Brook	1[E]	0.57	<0.043	0.53						
Grass	N of Lea Town	1[E]	<0.11	<0.077	0.14						
Soil	Opposite site entrance	1[E]	75	3.3	69						
Soil	Opposite windmill	1[E]	85	3.8	76						
Soil	Deepdale Brook	1[E]	98	4.5	94						
Soil	N of Lea Town	1[E]	43	2.7	40						
Freshwater	Deepdale Brook	4[E]	0.34	0.018	0.34					0.64	0.60
Freshwater[f]	Ulnes Walton	1[E]	0.014	<0.0012	0.014					<0.046	0.31

[a] *Except for milk and freshwater where units are Bq l^{-1} and for sediment and soil where dry concentrations apply*
[b] *The concentrations of ^{242}Cm and $^{243+244}Cm$ were not detected by the method used*
[c] *The concentrations of ^{242}Cm and $^{243+244}Cm$ were not detected and 0.00080 Bq kg^{-1}, respectively*
[d] *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*
[e] *The number of farms from which milk is sampled. The number of analyses is greater than this and depends on the bulking regime*
[f] *The concentration of ^{228}Th was <0.0028 Bq l^{-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, 2019

Location	Material or ground type	No. of sampling observations	μGy h^{-1}
Mean gamma dose rates at 1m over substrate			
Lytham Yacht Club	Salt marsh	1	0.095
Warton Salt Marsh	Salt marsh	2	0.090
Warton Salt Marsh	Salt marsh[a]	2	0.094
Freckleton	Salt marsh	1	0.079
Naze Point	Salt marsh	2	0.095
Banks Marsh (alternative)[b]	Salt marsh	2	0.10
Banks Marsh (alternative)[b]	Salt marsh[a]	2	0.10
Becconsall Boatyard	Salt marsh	4	0.080
Longton Marsh	Salt marsh	1	0.11
Hutton Marsh	Salt marsh	1	0.11
River Ribble outfall	Mud	2	0.086
River Ribble outfall	Mud and sand	1	0.091
River Ribble outfall	Salt marsh	1	0.086
Savick Brook, confluence with Ribble	Salt marsh	2	0.089
Savick Brook, Lea Gate	Grass	1	0.095
Savick Brook, Lea Gate	Salt marsh	1	0.089
South bank opposite outfall	Salt marsh	1	0.093
Penwortham road bridge	Mud	2	0.082
Lower Penwortham Park	Grass	3	0.075
Lower Penwortham Park	Grass and herbage	1	0.072
River Darwen	Grass	3	0.080
River Darwen	Grass and herbage	1	0.080
Riverbank Angler Location 1	Grass	3	0.077
Riverbank Angler Location 2	Grass and herbage	1	0.072
Ulnes Walton, BNFL area survey	Grass	3	0.078
Mean beta dose rates			μSv h^{-1}
Banks Marsh (alternative)[b]	Salt marsh	2	0.092
Warton Salt Marsh	Salt marsh	2	0.082

[a] *15cm above substrate*
[b] *As in 2018, no monitoring was undertaken at Banks Marsh in 2019 (as reported in earlier RIFE reports)*

Table 2.4 Concentrations of radionuclides in terrestrial food and the environment near Sellafield, 2019

Material	Location or selection[a]	No. of sampling observ-ations[b]	Mean radioactivity concentration (fresh)[c], Bq kg^{-1}										
			Organic ^{3}H	^{3}H	^{14}C	^{60}Co	^{90}Sr	^{99}Tc	^{106}Ru	^{125}Sb	^{129}I	^{131}I	^{134}Cs
Milk		9	<2.9	<3.0	17	<0.04	<0.040	<0.011	<0.33	<0.09	<0.0055	<0.0024	<0.04
Milk	max		<4.7	<4.7	19	<0.05	0.053		<0.39	<0.11	<0.022	<0.0040	<0.05
Apple		1	7.9	7.9	20	<0.07	0.067	<0.061	<0.50	<0.14	<0.021		<0.06
Beef kidney		1	<9.2	<9.2	20	<0.10	0.025	<0.094	<1.2	<0.30			<0.12
Beef liver		1	<6.5	<6.5	31	<0.04	<0.017	<0.15	<0.29	<0.08	<0.013		<0.03
Beef muscle		1	19	19	35	<0.04	0.029	<0.064	<0.30	<0.09	<0.015		<0.03
Beetroot		1	<2.3	<2.3	14	<0.05	0.093	<0.064	<0.38	<0.10	<0.016		<0.05
Cabbage		1	<2.2	<2.2	12	<0.06	0.16		<0.45	<0.12	<0.025		<0.06
Carrots		1	<2.0	<2.0	11	<0.04	0.031		<0.28	<0.09	<0.017		<0.03
Eggs		1	<2.9	<2.9	36	<0.04	0.021		<0.25	<0.08	<0.019		<0.03
Mushrooms		1	<3.0	<3.0	17	<0.03	0.017		<0.23	<0.06	<0.017		<0.03
Pheasant		1	<9.9	<9.9	49	<0.05	<0.041	<0.063	<0.29	<0.08	<0.0080		<0.03
Potatoes		1	<2.4	<2.4	18	<0.07	<0.026		<0.50	<0.13	<0.023		<0.07
Rabbit		1	<6.3	<6.3	40	<0.06	<0.042	<0.064	<0.45	<0.11	<0.0080		<0.06
Sheep muscle		2	<3.0	<3.1	37	<0.05	<0.049	<0.063	<0.29	<0.09	<0.017		<0.04
Sheep muscle	max		<3.1	<3.3	41		<0.052	<0.065	<0.30				
Sheep offal		2	<7.1	<7.1	27	<0.04	<0.023	<0.12	<0.26	<0.08	<0.020		<0.03
Sheep offal	max		<7.5	<7.5	29		<0.025		<0.27				
Wood pigeon muscle		2	<5.2	<5.3	34	<0.06	<0.043		<0.40	<0.11	<0.013		<0.05
Wood pigeon muscle	max		<5.8	<5.8					<0.48	<0.12	<0.018		<0.06
Grass	Braystones	1[E]		<13	20		2.3		<9.1	<5.1			
Grass	River Calder (upstream)	1[E]		<14	<4.3		0.61		<6.3	<3.8			
Grass	River Calder (downstream)	1[E]		<16	30		<0.48		<9.1	<5.1			
Grass	WAMAC Access gate	1[E]		<21	23		3.6		<7.1	<4.1			
Soil[d]		1	<2.0	<2.0	7.6	<0.19	<2.0	<0.96	<1.7	<0.56	<0.010		<0.21
Soil	Braystones	1[E]		<8.8	<3.9		<0.95		<4.4	<2.5			
Soil	River Calder (upstream)	1[E]		<8.5	<3.8		<0.88		<3.9	<2.2			
Soil	WAMAC Access gate	1[E]		<9.2	8.1		<0.69		<3.4	<1.9			

Table 2.4 continued

Material	Location or selection[a]	No. of sampling observ-ations[b]	Mean radioactivity concentration (fresh)[c], 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	<0.09	<0.088				<0.000062	<0.000044	<0.21	<0.000025
Milk	max		0.16	0.16				<0.000072	<0.000075	<0.22	<0.000043
Apple		1	0.16	0.16				0.00022	0.00054	<0.29	0.0012
Beef kidney		1	0.46	0.46	<0.00035	0.00037	0.0023	0.000025	0.00014	<0.46	0.00038
Beef liver		1	0.15	0.15				0.000042	0.00070	<0.24	0.00083
Beef muscle		1	<0.07	0.55				0.000085	0.000068	<0.35	0.00015
Beetroot		1	<0.07	<0.066							<0.26
Cabbage		1	0.05	0.053				0.000030	0.000093	0.10	0.00017
Carrots		1	0.07	0.067	0.016	0.00048	0.014	0.000046	0.00026	<0.28	0.00020
Eggs		1	<0.06	<0.062				0.000077	0.00013	<0.31	0.000095
Mushrooms		1	0.26	0.26				0.0017	0.011	0.16	0.021
Pheasant		1	<0.05	<0.053				<0.00012	<0.00012	<0.46	0.00019
Potatoes		1	<0.06	<0.061	0.094	0.0033	0.082				<0.14
Rabbit		1	2.8	2.8				<0.00016	0.000024	<0.46	0.00018
Sheep muscle		2	0.64	0.64				<0.000097	<0.00010	<0.35	0.000067
Sheep muscle	max		0.75	0.75				<0.00011	<0.00012	<0.37	0.00011
Sheep offal		2	0.33	0.33	0.0069	0.00062	0.0060	0.00024	0.0024	<0.16	0.0016
Sheep offal	max		0.40	0.40	0.011		0.0082	0.00028	0.0029	<0.26	0.0020
Wood pigeon muscle		2	<0.06	<0.057				<0.00014	0.000094	<0.42	0.00015
Wood pigeon muscle	max		<0.08	<0.078				<0.00019	0.00011	<0.46	0.00020
Grass	Braystones	1[E]	2.8					0.032	0.19	<22	<1.3
Grass	River Calder (upstream)	1[E]	1.5					<0.18	<0.18	<8.1	<0.87
Grass	River Calder (downstream)	1[E]	<1.2					0.22	0.81	<13	<1.3
Grass	WAMAC Access gate	1[E]	1.7					<0.090	0.083	<6.8	<0.94
Soil[d]		1	18	18				0.055	0.93	21	0.48
Soil	Braystones	1[E]	51					0.77	6.1	<55	5.1
Soil	River Calder (upstream)	1[E]	47					<0.98	12	45	3.8
Soil	WAMAC Access gate	1[E]	89					0.48	11	<39	15

[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 from which milk is sampled. The number of analyses is greater than this and depends on the bulking regime*
[c] *Except for milk where units are Bq l^{-1}*
[d] *The concentration of ^{226}Ra was 20 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 2.5 Beta/gamma radioactivity in fish from the Irish Sea vicinity and further afield, 2019

Location	Material	No. of sampling observ-ations	Mean radioactivity concentration (fresh), Bq kg^{-1}							
			Organic ^{3}H	^{3}H	^{14}C	^{59}Fe	^{60}Co	^{90}Sr	^{95}Nb	^{95}Zr
Cumbria										
Parton	Cod[a]	1			41		<0.09	<0.024	<0.19	<0.22
Whitehaven	Cod[a]	1			51		<0.04	<0.025	<0.08	<0.10
Whitehaven	Plaice[a,b]	2	<25	<25	82		<0.04	<0.023	<0.06	<0.08
Ravenglass	Plaice[a,c]	2	<25	<25	77		<0.06	0.025	<0.10	<0.11
Lancashire and Merseyside										
Morecambe Bay (Morecambe)	Flounder	2	<25	<25	47		<0.07	0.048	<0.12	<0.15
Ribble Estuary	Flounder	1					<0.04		<0.20	<0.16
Ribble Estuary	Grey Mullet	1					<0.05		<0.19	<0.17
Liverpool Bay	Dab	1		<25			<0.06		<0.05	<0.10
Scotland										
Shetland	Fish meal (salmon)	1[S]				<0.38	<0.15		<0.20	<0.28
Shetland	Fish meal (herring)	1[S]				<0.41	<0.15		<0.20	<0.29
Shetland	Fish oil (salmon)	1[S]				<0.25	<0.10		<0.14	<0.20
Shetland	Fish oil (herring)	1[S]				0.19	<0.10		<0.12	<0.18
Ardrossan South Bay	Mackerel	1[S]				<0.61	<0.11		<0.36	<0.34
Ardrossan South Bay	Salmon	1[S]				<0.29	<0.10		<0.18	<0.20
Kirkcudbright	Plaice	2[S]			18	<0.42	<0.10		<0.26	<0.24
Wales										
North Anglesey	Dab	1	<25	<25	29		<0.03		<0.16	<0.09
Northern Ireland										
North coast	Lesser spotted dogfish	2[N]					<0.09		<0.30	<0.27
North coast	Nursehound	1[N]					<0.11		<1.1	<0.59
North coast	Spurdog	1[N]					<0.11		<0.16	<0.22
Ardglass	Herring	2[N]					<0.08		<2.6	<0.63
Kilkeel	Cod	4[N]			20		<0.05		<0.11	<0.12
Kilkeel	Plaice	4[N]					<0.05		<0.12	<0.13
Kilkeel	Skates / rays	4[N]					<0.06		<0.29	<0.21
Kilkeel	Haddock	4[N]					<0.05		<0.13	<0.11
Further afield										
Norwegian Sea	Haddock	2					<0.05		<0.10	<0.17

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[a]	1	<0.27	<0.40	<0.10	<0.05	1.4	<0.23	
Whitehaven	Cod[a]	1	<0.16	<0.35	<0.12	<0.04	1.9	<0.26	
Whitehaven	Plaice[a,b]	2	2.4	<0.36	<0.12	<0.04	1.2	<0.35	97
Ravenglass	Plaice[a,c]	2	4.1	<0.37	<0.11	<0.04	1.3	<0.34	440
Lancashire and Merseyside									
Morecambe Bay (Morecambe)	Flounder	2	0.46	<0.47	<0.17	<0.08	2.9	<0.36	
Ribble Estuary	Flounder	1		<0.40	<0.12	<0.04	2.1	<0.30	
Ribble Estuary	Grey Mullet	1		<0.51	<0.16	<0.06	2.0	<0.59	
Liverpool Bay	Dab	1		<0.44	<0.15	<0.05	1.0	<0.30	
Scotland									
Shetland	Fish meal (salmon)	1[S]		<1.1	<0.37	<0.14	0.11	<0.69	
Shetland	Fish meal (herring)	1[S]		<1.2	<0.36	<0.14	0.18	<0.66	
Shetland	Fish oil (salmon)	1[S]		<0.84	<0.26	<0.10	<0.10		
Shetland	Fish oil (herring)	1[S]		<0.76	<0.24	<0.10	<0.10	<0.46	
Ardrossan South Bay	Mackerel	1[S]		<0.92	<0.27	<0.10	0.86	<0.49	
Ardrossan South Bay	Salmon	1[S]		<0.63	<0.20	<0.10	0.13	<0.40	
Kirkcudbright	Plaice	2[S]	<0.18	<0.62	<0.18	<0.10	0.10	<0.35	
Wales									
North Anglesey	Dab	1		<0.32	<0.09	<0.04	0.89	<0.22	
Northern Ireland									
North coast	Lesser spotted dogfish	2[N]		<0.77	<0.23	<0.13	0.56	<0.50	
North coast	Nursehound	1[N]		<1.0	<0.29	<0.11	0.70	<0.68	
North coast	Spurdog	1[N]		<0.89	<0.28	<0.10	0.70	<0.55	
Ardglass	Herring	2[N]		<0.76	<0.19	<0.08	0.37	<0.53	
Kilkeel	Cod	4[N]		<0.40	<0.12	<0.05	0.67	<0.40	
Kilkeel	Plaice	4[N]		<0.45	<0.13	<0.06	0.26	<0.29	
Kilkeel	Skates / rays	4[N]		<0.52	<0.14	<0.06	0.67	<0.31	
Kilkeel	Haddock	4[N]		<0.40	<0.12	<0.05	0.34	<0.32	
Further afield									
Norwegian Sea	Haddock	2		<0.44	<0.11	<0.05	<0.09	<0.23	

[a] *Data for natural radionuclides for some of these samples may be available in Table 6.6*
[b] *The concentrations of ^{129}I and ^{147}Pm were <0.98 Bq kg^{-1} and 0.019 Bq kg^{-1} respectively*
[c] *The concentrations of ^{129}I and ^{147}Pm were <1.0 Bq kg^{-1} and <0.013 Bq kg^{-1} respectively*
Measurements are made on behalf of the Foods Standards Agency unless labelled "N" or "S"
[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, 2019

Location	Material	No. of sampling observ-ations	Mean radioactivity concentration (fresh), Bq kg^{-1}								
			Organic ^{3}H	^{3}H	^{14}C	^{60}Co	^{65}Zn	^{90}Sr	^{95}Nb	^{95}Zr	^{99}Tc
Cumbria											
Parton	Crabs[a]	2			89	<0.10	<0.09	0.10	<0.12	<0.26	3.4
Parton	Lobsters[a]	2			87	<0.07	<0.15	0.020	<0.13	<0.13	37
Parton	Winkles[a]	2			60	0.22	<0.19	0.41	<0.11	<0.16	18
Whitehaven	*Nephrops*[a,b]	2	<25	<25	60	<0.04	<0.14	0.052	<0.14	<0.09	23
Whitehaven outer harbour	Mussels[a]	2			66	<0.10	<0.13	0.18	<0.10	<0.13	15
Nethertown	Winkles[a,c]	4	<25	<27	87	0.41	<0.18	1.5	<0.12	<0.16	19
Sellafield coastal area	Crabs[a,d]	2	<25	<25	61	<0.04	<0.11	0.089	<0.11	<0.11	3.6
Sellafield coastal area	Lobsters[a]	2	<25	29	73	<0.05	<0.12	0.027	<0.14	<0.14	49
Ravenglass	Winkles[a]	2			64	0.19	<0.22	0.27	<0.16	<0.16	7.4
Seascale Area	Common prawns[d]	1	<25	<25	86	<0.06	<0.14	0.019	<0.13	<0.14	0.16
Lancashire and Merseyside											
Morecambe Bay (Morecambe)	Shrimps	2	<25	<25	51	<0.06	<0.11	<0.053	<0.10	<0.11	<0.21
Morecambe Bay (Morecambe)	Mussels	2	110	140	63	<0.07	<0.24	0.18	<0.02	<0.26	41
Morecambe Bay (Middleton Sands)	Winkles	2	260	240	43	<0.07	<0.23	0.22	<0.13	<0.27	9.5
Ribble Estuary	Shrimps	1			31	<0.06	<0.13		<0.18	<0.29	<0.18
Ribble Estuary	Mussels	1				<0.08	<0.10		<0.06	<0.09	
Liverpool Bay	Mussels	1		<25		<0.08	<0.18		<0.09	<0.14	
Dee Estuary	Cockles	1		<25		<0.10	<0.27		<0.27	<0.28	0.86
Wirral	Shrimps	1		<25		<0.04	<0.11		<0.09	<0.07	0.27
Scotland											
Kinlochbervie	Crabs	2[S]				<0.10	<0.19		<0.55	<0.35	0.90
Lewis	Mussels	1[S]				<0.10	<0.27		<0.50	<0.40	
Skye	Lobsters	1[S]				<0.10	<0.28		<0.96	<0.58	1.6
Skye	Mussels	1[S]				<0.10	<0.27		<1.0	<0.58	
Islay	Crabs	1[S]				<0.10	<0.22		<0.68	<0.42	
Islay	Scallops	1[S]				<0.10	<0.33		<0.87	<0.61	
Kirkcudbright	Crabs[a]	2[S]			34	<0.10	<0.14	<0.10	<0.17	<0.17	0.43
Kirkcudbright	Lobsters[a]	2[S]			26	<0.10	<0.13	<0.10	<0.17	<0.17	22
Kirkcudbright	Scallops	2[S]				<0.10	<0.11		<0.12	<0.11	0.26
Kirkcudbright	Queens	2[S]				<0.10	<0.16		<0.18	<0.18	<0.19
Cutters Pool	Limpets[a]	1[S]				<0.10	<0.10		<0.15	<0.14	
Cutters Pool	Winkles	1[S]				<0.10	<0.14		<0.32	<0.23	
Southerness	Winkles	2[S]		<5.0		<0.10	<0.21	0.38	<0.61	<0.40	8.1
North Solway coast	Mussels	2[S]		<5.0	35	<0.10	<0.23	0.37	<0.58	<0.41	14
Inner Solway	Shrimps	2[S]		<5.0		<0.10	<0.14	<0.10	<0.20	<0.18	<0.18
Wales											
North Anglesey	Crabs	1	<25	<25	33	<0.06	<0.15		<0.10	<0.09	
North Anglesey	Lobsters	1	<25	<25	48	<0.05	<0.17		<0.12	<0.19	23
Northern Ireland											
Ballycastle	Lobsters	2[N]				<0.10	<0.26		<0.35	<0.31	8.1
County Down	Scallops	2[N]				<0.06	<0.11		<0.09	<0.10	
Kilkeel	Crabs	4[N]				<0.05	<0.13		<0.14	<0.14	
Kilkeel	Lobsters	4[N]				<0.05	<0.17		<0.16	<0.13	8.9
Kilkeel	*Nephrops*	4[N]				<0.08	<0.22		<0.25	<0.23	5.0
Minerstown	Toothed winkles	1[N]				<0.04	<0.13		<0.10	<0.11	
Minerstown	Winkles	3[N]				<0.07	<0.17		<0.10	<0.14	
Carlingford Lough	Mussels	2[N]				<0.11	<0.30		<0.30	<0.25	3.0
Further afield											
Cromer	Crabs	2				<0.06	<0.14		<0.10	<0.13	
Southern North Sea	Cockles	2				<0.03	<0.08		<0.07	<0.12	

Table 2.6 continued

Location	Material	No. of sampling observ-ations	Mean radioactivity concentration (fresh), Bq kg^{-1}							
			^{106}Ru	^{110m}Ag	^{125}Sb	^{134}Cs	^{137}Cs	^{144}Ce	^{147}Pm	Gross beta
Cumbria										
Parton	Crabs[a]	2	<0.60	<0.10	<0.17	<0.07	0.76	<0.32		110
Parton	Lobsters[a]	2	<0.48	<0.08	<0.13	<0.05	1.0	<0.44		150
Parton	Winkles[a]	2	<0.49	<0.08	<0.19	<0.06	2.8	<0.31		140
Whitehaven	*Nephrops*[a,b]	2	<0.31	<0.06	<0.10	<0.04	1.6	<0.24	0.050	130
Whitehaven outer harbour	Mussels[a]	2	<0.75	<0.06	<0.11	<0.04	0.80	<0.25		110
Nethertown	Winkles[a,c]	4	<1.5	<0.11	<0.22	<0.05	3.4	<0.46	0.38	160
Sellafield coastal area	Crabs[a,d]	2	<0.39	<0.06	<0.12	<0.04	0.44	<0.28	<1.1	87
Sellafield coastal area	Lobsters[a]	2	<0.42	<0.07	<0.11	<0.05	0.56	<0.24		120
Ravenglass	Winkles[a]	2	<1.1	<0.09	<0.26	<0.06	2.1	<0.41		110
Seascale Area	Common prawns[a]	1	<0.48	<0.08	<0.12	<0.05	1.1	<0.28		96
Lancashire and Merseyside										
Morecambe Bay (Morecambe)	Shrimps	2	<0.40	<0.07	<0.12	<0.04	1.7	<0.27		
Morecambe Bay (Morecambe)	Mussels	2	<0.62	<0.10	<0.18	<0.08	1.6	<0.48		120
Morecambe Bay (Middleton Sands)	Winkles	2	<0.55	<0.10	<0.18	<0.07	2.4	<0.53		120
Ribble Estuary	Shrimps	1	<0.47	<0.08	<0.12	<0.05	1.1	<0.28		
Ribble Estuary	Mussels	1	<0.42	<0.07	<0.14	<0.05	0.11	<0.31		
Liverpool Bay	Mussels	1	<0.66	<0.11	<0.21	<0.08	0.52	<0.88		
Dee Estuary	Cockles	1	<0.93	<0.16	<0.28	<0.10	0.99	<0.96		
Wirral	Shrimps	1	<0.36	<0.06	<0.11	<0.04	0.60	<0.26		
Scotland										
Kinlochbervie	Crabs	2[S]	<0.63	<0.10	<0.18	<0.10	<0.10	<0.36		
Lewis	Mussels	1[S]	<0.92	<0.13	<0.25	<0.10	<0.10	<0.54		
Skye	Lobsters	1[S]	<0.95	<0.15	<0.27	<0.11	<0.10	<0.61		
Skye	Mussels	1[S]	<0.93	<0.13	<0.26	<0.10	<0.10	<0.54		
Islay	Crabs	1[S]	<0.71	<0.11	<0.20	<0.10	<0.10	<0.43		
Islay	Scallops	1[S]	<0.90	<0.13	<0.27	<0.11	<0.10	<0.79		
Kirkcudbright	Crabs[a]	2[S]	<0.50	<0.10	<0.15	<0.10	0.13	<0.29		
Kirkcudbright	Lobsters[a]	2[S]	<0.49	<0.10	<0.15	<0.10	<0.59	<0.29		
Kirkcudbright	Scallops	2[S]	<0.29	<0.10	<0.10	<0.10	0.20	<0.19		
Kirkcudbright	Queens	2[S]	<0.51	<0.10	<0.15	<0.10	0.28	<0.31		
Cutters Pool	Limpets[a]	1[S]	<0.39	<0.10	<0.12	<0.10	1.7	<0.24		
Cutters Pool	Winkles	1[S]	<0.50	<0.11	<0.16	<0.10	1.4	<0.29		
Southerness	Winkles	2[S]	<0.84	<0.16	<0.25	<0.10	1.8	<0.46		
North Solway coast	Mussels	2[S]	<0.89	<0.14	<0.26	<0.10	1.2	<0.54		
Inner Solway	Shrimps	2[S]	<0.46	<0.10	<0.14	<0.10	<0.10	<0.28		
Wales										
North Anglesey	Crabs	1	<0.50	<0.08	<0.13	<0.06	0.13	<0.31		
North Anglesey	Lobsters	1	<0.41	<0.07	<0.11	<0.05	0.39	<0.23		130
Northern Ireland										
Ballycastle	Lobsters	2[N]	<1.1	<0.17	<0.38	<0.10	<0.13	<0.84		
County Down	Scallops	2[N]	<0.32	<0.06	<0.10	<0.04	0.15	<0.34		
Kilkeel	Crabs	4[N]	<0.45	<0.08	<0.14	<0.05	0.14	<0.32		
Kilkeel	Lobsters	4[N]	<0.45	<0.07	<0.18	<0.05	0.19	<0.28		
Kilkeel	*Nephrops*	4[N]	<0.63	<0.11	<0.17	<0.07	0.53	<0.36		
Minerstown	Toothed winkles	1[N]	<0.48	<0.06	<0.11	<0.04	0.17	<0.27		
Minerstown	Winkles	3[N]	<0.58	<0.10	<0.17	<0.06	<0.17	<0.46		
Carlingford Lough	Mussels	2[N]	<0.87	<0.14	<0.21	<0.10	0.47	<0.43		
Further afield										
Cromer	Crabs	2	<0.52	<0.08	<0.15	<0.06	<0.06	<0.34		
Southern North Sea	Cockles	2	<0.26	<0.04	<0.08	<0.03	<0.07	<0.24		

[a] *Data for natural radionuclides for some of these samples may be available in Table 6.6*
[b] *The concentration of ^{129}I was <1.0 Bq kg^{-1}*
[c] *The concentration of ^{129}I was <1.2 Bq kg^{-1}*
[d] *The concentration of ^{129}I was <0.94 Bq kg^{-1}*
Measurements are made on behalf of the Foods Standards Agency unless labelled "N" or "S"
[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, 2019

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	1		0.00026	0.0018	<0.41	0.0033	*	*
Parton	Crabs	2		0.034	0.19	0.98	0.92	*	0.0015
Parton	Lobsters	2		0.018	0.11	0.58	1.0	*	*
Parton	Winkles	2		0.64	3.8	18	7.9	*	*
Whitehaven	Cod	1		0.00029	0.0016	0.063	0.0035	*	0.0000032
Whitehaven	Plaice	2	0.000039	0.00090	0.0057	0.092	0.012	*	*
Whitehaven	*Nephrops*	2	0.00065	0.032	0.20	1.0	1.4	*	0.0037
Whitehaven outer harbour	Mussels	2		0.35	2.0	9.9	4.6	*	0.0065
Nethertown	Winkles	4	0.013	1.3	7.4	35	15	*	0.035
Sellafield coastal area	Crabs	2	0.00049	0.017	0.098	0.68	0.45	*	*
Sellafield coastal area	Lobsters	2		0.020	0.12	0.92	1.4	*	*
Ravenglass	Plaice	2	0.000065	0.00087	0.0056	0.071	0.011	*	0.000034
Ravenglass	Winkles	2		0.50	3.0	14	6.8	*	*
Seascale	Prawns	1		0.00019	0.0016	<0.82	0.011	*	*
Lancashire and Merseyside									
Morecambe Bay (Morecambe)	Flounder	2		0.00036	0.0021		0.0039	*	*
Morecambe Bay (Morecambe)	Shrimps	2		0.0046	0.030		0.055	*	*
Morecambe Bay (Morecambe)	Mussels	2		0.28	1.7	7.4	2.7	*	*
Morecambe Bay (Middleton Sands)	Winkles	2		0.43	2.6	11	5.2	0.0060	0.0044
Ribble Estuary	Flounder	1					<0.14		
Ribble Estuary	Mullet	1					<0.17		
Ribble Estuary	Shrimps	1	0.000048	0.00063	0.0048		0.010	*	*
Ribble Estuary	Mussels	1		0.067	0.44		0.72	*	0.00080
Liverpool Bay	Dab	1					<0.17		
Liverpool Bay	Mussels	1					1.0		
Dee Estuary	Cockles	1		0.10	0.62		1.4	*	*
Wirral	Shrimps	1		0.00057	0.0043		0.0068	*	0.000036
Scotland									
Shetland	Fish meal (salmon)	1[S]		0.035	0.038		0.029		
Shetland	Fish meal (herring)	1[S]		0.015	0.015		0.021		
Shetland	Fish oil (salmon)	1[S]		0.0013	0.0073		0.0044		
Shetland	Fish oil (herring)	1[S]		0.00076	0.00094		0.0065		
Kinlochbervie	Crabs	2[S]		0.0056	0.023		0.12		
Lewis	Mussels	1[S]					<0.13		
Skye	Lobsters	1[S]					<0.12		
Skye	Mussels	1[S]					<0.12		
Islay	Crabs	1[S]					<0.10		
Islay	Scallops	1[S]					<0.39		
Ardrossan South Bay	Mackerel	1[S]		0.0035	0.0046		0.015		
Ardrossan South Bay	Salmon	1[S]		0.0036	0.0048		0.0095		
Kirkcudbright	Plaice	2[S]		0.0012	0.00078		0.0031		
Kirkcudbright	Scallops	2[S]		0.015	0.085		0.030		
Kirkcudbright	Queens	2[S]		0.011	0.068		0.12		
Kirkcudbright	Crabs	2[S]		0.13	0.38		0.33		

Table 2.7 continued									
Location	Material	No. of sampling observ-ations	Mean radioactivity concentration (fresh), Bq kg^{-1}						
			^{237}Np	^{238}Pu	$^{239}Pu+$ ^{240}Pu	^{241}Pu	^{241}Am	^{242}Cm	$^{243}Cm+$ ^{244}Cm
Kirkcudbright	Lobsters	2[S]		0.0043	0.0032		0.21		
Cutters Pool	Limpets	1[S]					6.5		
Cutters Pool	Winkles	1[S]					5.4		
Southerness	Winkles	2[S]		0.13	0.87		1.7		
North Solway coast	Mussels	2[S]		0.39	2.4		7.0		
Inner Solway	Shrimps	2[S]		0.0040	0.0038		0.0066		
Wales									
North Anglesey	Dab	1					<0.11		
North Anglesey	Crabs	1					<0.06		
North Anglesey	Lobsters	1		0.0051	0.030	0.40	0.11	*	*
Northern Ireland									
North coast	Lesser spotted dogfish	2[N]					<0.39		
North coast	Nursehound	1[N]					<0.29		
North coast	Spurdog	1[N]					<0.29		
Ballycastle	Lobsters	2[N]					<0.41		
County Down	Scallops	2[N]					<0.17		
Ardglass	Herring	2[N]					<0.18		
Kilkeel	Cod	4[N]					<0.14		
Kilkeel	Plaice	4[N]					<0.17		
Kilkeel	Skates / rays	4[N]					<0.13		
Kilkeel	Haddock	4[N]					<0.14		
Kilkeel	Crabs	4[N]					<0.14		
Kilkeel	Lobsters	4[N]					<0.13		
Kilkeel	*Nephrops*	4[N]		0.0025	0.015		0.091	*	0.000046
Minerstown	Toothed winkles	1[N]					0.19		
Minerstown	Winkles	3[N]		0.027	0.17		0.11	*	*
Carlingford Lough	Mussels	2[N]					0.18		
Further afield									
Norwegian Sea	Haddock	2					<0.10		
Cromer	Crabs	2					<0.23		
Southern North Sea	Cockles	2		0.0018	0.15		0.0079	*	0.000035

* *Not detected by the method used*
Measurements are made on behalf of the Foods Standards Agency unless labelled "N" or "S"
[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, 2019

Location	Material	No. of sampling observ-ations	Mean radioactivity concentration (dry), Bq kg^{-1}								
			^{60}Co	^{90}Sr	^{95}Zr	^{95}Nb	^{106}Ru	^{125}Sb	^{134}Cs	^{137}Cs	^{144}Ce
Cumbria											
Newton Arlosh	Sediment	2	<1.1		<2.4	<0.90	<8.4	<4.3	<1.1	160	<4.5
Maryport Outer Harbour	Sediment	2	<0.42		<0.61	<0.36	<2.6	<1.4	<0.38	54	<1.8
Workington Harbour	Sediment	2	<0.38		<0.67	<0.44	<2.6	<1.5	<0.40	23	<2.1
Harrington Harbour	Sediment	2	<0.54		<0.85	<0.52	<3.5	<1.9	<0.51	74	<2.0
Whitehaven Outer Harbour	Sediment	4	<0.48	<3.6	<0.66	<0.38	<2.9	<1.6	<0.41	53	<1.6
St Bees beach	Sediment	4	<0.44	<1.4	<0.59	<0.29	<2.6	<1.5	<0.37	46	<1.4
St Bees beach (RFL Identified location)	Sediment	1	<0.51	<1.3	<0.72	<0.31	<2.9	<1.6	<0.42	47	<1.5
Ehen spit	Sediment	3	<0.52		<0.68	<0.44	<3.2	<1.7	<0.44	89	<1.9
Sellafield beach, S of former pipeline	Sediment	4	<0.45		<0.60	<0.27	<2.5	<1.4	<0.36	32	<1.3
River Calder – downstream	Sediment	4	<0.42		<0.57	<0.34	<2.6	<1.4	<0.36	52	<1.7
River Calder – upstream	Sediment	4	<0.67		<0.92	<0.56	<3.6	<2.0	<0.66	35	<2.2
Seascale beach	Sediment	4	<0.37		<0.51	<0.25	<2.1	<1.2	<0.33	21	<1.4
Ravenglass – Carleton Marsh	Sediment	4	<1.0	53	<1.4	<0.64	<6.1	<3.2	<0.84	160	<3.0
River Mite Estuary (erosional)	Sediment	4	<1.5	50	<2.2	<0.9	<10	<5.3	<1.3	320	<4.8
Ravenglass - Raven Villa	Sediment	4	<0.78		<0.87	<0.49	<4.8	<2.2	<0.60	140	<2.1
Newbiggin (Eskmeals)	Sediment	4	2.0	49	<1.0	<0.58	<5.0	<2.6	<0.63	220	<2.5
Haverigg	Sediment	2	<0.51		<0.72	<0.32	<3.0	<1.6	<0.52	28	<1.4
Millom	Sediment	2	<0.55		<0.83	<0.48	<3.6	<1.9	<0.50	82	<2.1
Askam Pier	Sediment	2	<0.50		<0.74	<0.42	<3.0	<1.6	<0.44	38	<1.8
Low Shaw	Sediment	2	<0.39		<0.56	<0.26	<2.4	<1.4	<0.35	53	<1.8
Walney Channel – N of discharge point	Sediment	2	<0.57		<0.86	<0.42	<3.7	<1.9	<0.51	91	<2.1
Sand Gate Marsh	Sediment	1	<0.50		<0.77	<0.34	<3.0	<1.6	<0.45	44	<1.8
Kents Bank	Sediment	1	<0.68		<1.2	<0.47	<4.9	<2.6	<0.67	160	<2.3
Arnside	Sediment	1	<1.2		<1.9	<0.87	<9.0	<5.1	<1.3	190	<4.3

Location	Material	No. of sampling observ-ations	Mean radioactivity concentration (dry), Bq kg^{-1}							
			^{154}Eu	^{155}Eu	^{238}Pu	^{239}Pu + ^{240}Pu	^{241}Pu	^{241}Am	Gross alpha	Gross beta
Cumbria										
Newton Arlosh	Sediment	2	<2.9	<2.0				270	800	890
Maryport Outer Harbour	Sediment	2	<1.1	<0.82				130	300	580
Workington Harbour	Sediment	2	<1.2	<0.96				28	370	750
Harrington Harbour	Sediment	2	<1.5	<0.89				46	290	780
Whitehaven Outer Harbour	Sediment	4	<1.3	<0.74	13	75	260	110	280	500
St Bees beach	Sediment	4	<1.1	<0.65	16	98	320	140	240	430
St Bees beach (RFL Identified location)	Sediment	1	<1.5	<0.68	16	97	380	150	230	330
Ehen spit	Sediment	3	<1.4	<0.85				72	280	920
Sellafield beach, S of former pipeline	Sediment	4	<1.2	<0.63				120	230	440
River Calder – downstream	Sediment	4	<1.3	<1.1				87	250	570
River Calder – upstream	Sediment	4	<1.8	<1.7					290	1400
Seascale beach	Sediment	4	<0.98	<0.63				100	160	390
Ravenglass – Carleton Marsh	Sediment	4	<1.9	<1.4	53	300	1400	690	1200	1000
River Mite Estuary (erosional)	Sediment	4	<3.5	<2.3	100	650	2200	1300	1900	1300
Ravenglass - Raven Villa	Sediment	4	<1.5	<1.0				600	970	880
Newbiggin (Eskmeals)	Sediment	4	2.5	<1.8	84	490	1900	1100	1500	1000
Haverigg	Sediment	2	<1.4	<0.67				130	220	480
Millom	Sediment	2	<1.5	<0.94				360	580	800
Askam Pier	Sediment	2	<1.3	<0.82				120	250	630
Low Shaw	Sediment	2	<.01	<0.79				110	240	570
Walney Channel – N of discharge point	Sediment	2	<1.6	<0.91				240	590	850
Sand Gate Marsh	Sediment	1	<1.4	<0.79				63	250	560
Kents Bank	Sediment	1	<1.9	<1.1				110	380	720
Arnside	Sediment	1	<3.5	<2.1				130	660	860

Table 2.8 continued

Location	Material	No. of sampling observ-ations	Mean radioactivity concentration (dry), Bq kg^{-1}						
			^{60}Co	^{95}Zr	^{95}Nb	^{106}Ru	^{125}Sb	^{134}Cs	^{137}Cs
Lancashire									
Morecambe	Sediment	2	<0.36						25
Half Moon Bay	Sediment	2	<0.48						46
Red Nab Point	Sediment	1	<0.37						16
Potts Corner	Sediment	2	<0.46						13
Shore adjecant to Northern Outfall	Sediment	1	<0.49						49
Sunderland Point	Sediment	1	<0.39	<0.69	<0.37	<2.6	<1.4	<0.39	39
Conder Green	Sediment	1	<0.42	<0.78	<0.44	<3.0	<1.7	<0.45	57
Hambleton	Sediment	1	<0.57	<0.97	<0.53	<4.2	<2.3	<0.59	180
Skippool Creek	Sediment	1	<0.70	<1.3	<0.64	<4.7	<2.6	<0.65	110
Fleetwood	Sediment	1	<0.46	<0.74	<0.29	<2.5	<1.4	<0.40	5.0
Blackpool	Sediment	1	<0.31	<0.54	<0.22	<1.9	<1.1	<0.28	1.5
Crossens Marsh	Sediment	1	<1.3	<2.5	<0.97	<9.6	<5.3	<1.3	170
Ainsdale	Sediment	1	<0.32	<0.56	<0.22	<2.0	<0.99	<0.30	2.8
Rock Ferry	Sediment	1	<0.41	<0.65	<0.36	<2.6	<1.4	<0.37	51

Location	Material	No. of sampling observ-ations	Mean radioactivity concentration (dry), Bq kg^{-1}							
			^{144}Ce	^{154}Eu	^{155}Eu	^{238}Pu	$^{239}Pu+^{240}Pu$	^{241}Am	Gross alpha	Gross beta
Lancashire										
Morecambe	Sediment	2						36		
Half Moon Bay	Sediment	2				7.6	43	80		
Red Nab Point	Sediment	1						13		
Potts Corner	Sediment	2						18		
Shore adjecant to Northern Outfall	Sediment	1						93		
Sunderland Point	Sediment	1	<2.2	<0.99	<0.94			65	200	670
Conder Green	Sediment	1	<2.5	<1.1	<1.1			85	400	720
Hambleton	Sediment	1	<3.2	<1.5	<1.4			220	540	1100
Skippool Creek	Sediment	1	<2.3	<2.0	<1.0			150	560	980
Fleetwood	Sediment	1	<1.2	<1.2	<0.54			8.4	87	300
Blackpool	Sediment	1	<1.1	<0.81	<0.47			3.2	<66	170
Crossens Marsh	Sediment	1	<4.5	<4.0	<2.1			170	400	1100
Ainsdale	Sediment	1	<1.1	<0.84	<0.51			2.5	110	200
Rock Ferry	Sediment	1	<2.0	<1.0	<1.1			43	200	700

Table 2.8 continued

Location	Material	No. of sampling observ-ations	Mean radioactivity concentration (dry), Bq kg^{-1}							
			^{54}Mn	^{60}Co	^{95}Zr	^{95}Nb	^{106}Ru	^{125}Sb	^{134}Cs	^{137}Cs
Scotland										
Campbeltown	Sediment	1[S]	<0.10	<0.10	<0.10	<0.10	<0.27	<0.10	<0.10	4.8
Garlieston	Sediment	1[S]	<0.10	<0.10	<0.10	<0.10	<0.30	<0.10	<0.10	20
Innerwell	Sediment	2[S]	<0.07	<0.07	<0.12	<0.11	<0.48	<0.18	<0.08	38
Carsluith	Sediment	1[S]	<0.10	0.30	<0.39	<0.32	<1.1	<0.38	<0.14	72
Skyreburn	Sediment	2[S]	<0.10	<0.10	<0.26	<0.28	<0.77	<0.24	<0.11	19
Kirkcudbright	Sediment[a]	2[S]	<0.10	0.26	<0.42	<0.60	<1.0	<0.36	<0.14	75
Rascarrel Bay	Sediment[a]	1[S]	<0.10	0.12	<0.17	<0.19	<0.70	<0.26	<0.10	47
Palnackie Harbour	Sediment	2[S]	<0.10	0.28	<0.29	<0.48	<1.2	<0.46	<0.14	130
Gardenburn	Sediment	2[S]	<0.10	0.18	<0.26	<0.37	<0.80	<0.38	<0.11	120
Kippford Slipway	Sediment	2[S]	<0.10	0.37	<0.32	<0.50	1.6	<0.41	<0.13	130
Kippford Merse	Sediment	1[S]	<0.10	0.40	<0.38	<0.65	<0.99	<0.61	<0.17	230
Kirkconnell Merse	Sediment	1[S]	<0.10	<0.10	<0.18	<0.23	<0.65	<0.23	<0.10	34
Southerness	Sediment	1[S]	<0.10	<0.10	<0.22	<0.25	<0.70	<0.24	<0.10	26

Location	Material	No. of sampling observ-ations	Mean radioactivity concentration (dry), Bq kg^{-1}							
			^{144}Ce	^{154}Eu	^{155}Eu	^{238}Pu	$^{239}Pu+^{240}Pu$	^{241}Am	Gross alpha	Gross beta
Scotland										
Campbeltown	Sediment	1[S]	<0.27	<0.10	0.64			0.76		
Garlieston	Sediment	1[S]	<0.29	<0.10	0.68	3.8	21	35		
Innerwell	Sediment	2[S]	<0.55	<0.14	1.3	5.8	35	53		
Carsluith	Sediment	1[S]	<1.2	<0.29	1.2	13	84	160	240	1900
Skyreburn	Sediment	2[S]	<0.77	<0.21	0.86	2.1	17	27	<0.77	
Kirkcudbright	Sediment[a]	2[S]	<1.0	<0.21	1.9			160		
Rascarrel Bay	Sediment[a]	1[S]	<0.78	<0.22	0.96			75		
Palnackie Harbour	Sediment	2[S]	<1.1	<0.33	1.1	19	120	250	<1.1	
Gardenburn	Sediment	2[S]	<0.99	<0.23	0.85	18	120	240	<0.88	
Kippford Slipway	Sediment	2[S]	<1.0	0.53	<0.88	22	140	270	<1.1	
Kippford Merse	Sediment	1[S]	<1.3	0.62	0.97	9.8	76	150		
Kirkconnell Merse	Sediment	1[S]	<0.66	<0.17	<0.34	2.9	20	39	120	1400
Southerness	Sediment	1[S]	<0.76	<0.20	0.67	4.2	31	55		

Table 2.8 continued

Location	Material	No. of sampling observ-ations	Mean radioactivity concentration (dry), Bq kg^{-1}								
			^{54}Mn	^{60}Co	^{95}Zr	^{95}Nb	^{106}Ru	^{125}Sb	^{134}Cs	^{137}Cs	^{144}Ce
Wales											
Rhyl	Sediment	1		<0.72	<0.92	<0.62	<4.0	<2.2	<0.62	53	<2.3
Llandudno	Sediment	1		<0.43	<0.59	<0.30	<2.4	<1.3	<0.39	1.4	<1.2
Caerhun	Sediment	1		<0.44	<0.62	<0.40	<2.7	<1.5	<0.41	31	<1.9
Llanfairfechan	Sediment	1		<0.45	<0.59	<0.30	<2.6	<1.4	<0.42	6.0	<1.4
Northern Ireland											
Carrichue	Sandy mud	1[N]	<0.36	<0.18	<1.8	<2.8	<1.9	<0.46	<0.47	2.1	<3.1
Carrichue	Shells & sand	1[N]	<0.15	<0.13	<1.5	<0.97	<1.3	<0.40	<0.15	0.96	<1.3
Portrush	Sand	2[N]	<0.22	<0.16	<0.89	<1.3	<1.6	<0.42	<0.19	0.54	<1.2
Oldmill Bay	Mud	2[N]	<0.37	<0.23	<1.3	<0.64	<2.1	<0.65	<0.41	25	<2.4
Ballymacormick	Mud	2[N]	<0.28	<0.19	<0.78	<0.61	<1.7	<0.53	<0.33	11	<2.2
Strangford Lough - Nicky's Point	Mud	2[N]	<0.38	<0.21	<2.3	<4.2	<2.1	<0.59	<0.36	13	<1.7
Dundrum Bay	Sandy mud	1[N]	<0.36	<0.20	<2.3	<4.6	<2.0	<0.48	<0.51	4.6	<2.7
Dundrum Bay	Mud	1[N]	<0.32	<0.18	<1.2	<1.5	<1.7	<0.55	<0.44	4.3	<2.9
Carlingford Lough	Mud	2[N]	<0.55	<0.26	<3.4	<6.5	<2.9	<0.86	<0.67	34	<4.0

Location	Material	No. of sampling observ-ations	Mean radioactivity concentration (dry), Bq kg^{-1}								
			^{154}Eu	^{155}Eu	^{238}Pu	^{239}Pu+ ^{240}Pu	^{241}Am	^{242}Cm	^{243}Cm+ ^{244}Cm	Gross alpha	Gross beta
Wales											
Rhyl	Sediment	1	<1.9	<1.1			47			380	930
Llandudno	Sediment	1	<1.2	<0.58			1.7			<89	200
Caerhun	Sediment	1	<1.1	<0.89			25			260	690
Llanfairfechan	Sediment	1	<1.3	<0.64			6.0			170	380
Northern Ireland											
Carrichue	Sandy mud	1[N]	<0.59	<0.60	0.090	0.71	1.4	*	*		
Carrichue	Shells & sand	1[N]	<0.38	<0.52			<1.3				
Portrush	Sand	2[N]	<0.51	<0.52			1.10				
Oldmill Bay	Mud	2[N]	<0.74	<0.91			7.9				
Ballymacormick	Mud	2[N]	<0.59	<0.87			12				
Strangford Lough - Nicky's Point	Mud	2[N]	<0.65	<1.2			5.5				
Dundrum Bay	Sandy mud	1[N]	<0.64	<1.2			2.8				
Dundrum Bay	Mud	1[N]	<0.60	<1.5			2.5				
Carlingford Lough	Mud	2[N]	<0.84	<1.9	1.9	12	8.5	*	*		

Measurements are made on behalf of the Foods Standards Agency unless labelled "N" or "S"

* *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 6.6*

Table 2.9 Gamma radiation dose rates over areas of the Cumbrian coast and further afield, 2019

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	0.071
Burgh Marsh	Salt marsh	2	0.072
Port Carlisle 1	Mud and sand	2	0.079
Port Carlisle 2	Salt marsh	2	0.076
Newton Arlosh	Salt marsh	2	0.082
Silloth harbour	Pebbles and sand	2	0.089
Allonby	Sand	2	0.080
Maryport harbour	Sand	2	0.083
Workington harbour	Pebbles	1	0.095
Workington harbour	Shingle	1	0.11
Harrington harbour	Pebbles and sand	1	0.099
Harrington harbour	Sand	1	0.090
Cumbria, Whitehaven-Drigg			
Whitehaven - outer harbour	Pebbles and sand	1	0.085
Whitehaven - outer harbour	Sand	3	0.086
St Bees	Sand	4	0.069
Nethertown beach	Pebbles	1	0.10
Nethertown beach	Shingle	3	0.12
Ehen spit	Pebbles and sand	3	0.11
Braystones	Grass	1	0.093
Braystones beach	Pebbles	1	0.10
Braystones beach	Sand and shingle	1	0.10
Braystones beach	Shingle	2	0.11
WAMAC Access gate	Grass	1	0.099
Sellafield dunes	Grass	4	0.093
North of former pipeline on foreshore	Sand	3	0.072
North of former pipeline on foreshore	Sand and stones	1	0.090
South of former pipeline on foreshore	Sand	3	0.072
South of former pipeline on foreshore	Sand and stones	1	0.095
River Calder downstream of site	Grass	4	0.083
River Calder upstream of site	Grass	1	0.096
Seascale beach	Sand	4	0.073
Cumbria, Ravenglass-Askam			
Ravenglass - Carleton Marsh	Salt marsh	4	0.12
Ravenglass - River Mite estuary (erosional)	Salt marsh	4	0.12
Ravenglass - Raven Villa	Salt marsh	4	0.12
Ravenglass - boat area	Pebbles and sand	2	0.10
Ravenglass - boat area	Sand	1	0.098
Ravenglass - boat area	Sand and stones	1	0.096
Ravenglass - ford	Sand	4	0.089
Muncaster Bridge	Grass	2	0.11
Muncaster Bridge	Salt marsh	2	0.11
Ravenglass - salmon garth	Mud and sand	1	0.096
Ravenglass - salmon garth	Sand and stones	1	0.10
Ravenglass - salmon garth	Sand	2	0.11
Ravenglass - Eskmeals Nature Reserve	Salt marsh	3	0.099
Newbiggin/Eskmeals Bridge	Salt marsh	4	0.11
Newbiggin/Eskmeals viaduct	Salt marsh	4	0.11
Tarn Bay	Sand	4	0.069
Silecroft	Pebbles	1	0.11
Silecroft	Shingle	1	0.12

Table 2.9 continued

Location	Ground type	No. of sampling observations	Mean gamma dose rate in air at 1m, μGy h^{-1}
Haverigg	Mud and sand	1	0.079
Haverigg	Sand	1	0.061
Millom	Mud and sand	1	0.089
Millom	Pebbles and sand	1	0.094
Low Shaw	Salt marsh	2	0.070
Askam	Sand	4	0.066
Askam Pier	Mud and sand	3	0.076
Askam Pier	Sand and mud	1	0.088
Cumbria, Walney-Arnside			
Walney Channel, N of discharge point	Mud and sand	3	0.077
Walney Channel, N of discharge point	Sand	1	0.093
Tummer Hill Marsh	Salt marsh	2	0.099
Roa Island	Mud	1	0.085
Roa Island	Sand	1	0.083
Sand Gate Marsh	Salt marsh	2	0.076
Kents Bank 2	Salt marsh	2	0.075
Arnside 2	Salt marsh	2	0.081
Lancashire and Merseyside			
Morecambe Central beach	Sand	2	0.074
Half Moon Bay	Mud and sand	1	0.085
Half Moon Bay	Sand	1	0.084
Pipeline (Heysham)	Sand	1	0.072
Red Nab Point	Sand	1	0.066
Middleton Sands	Sand	2	0.081
Sunderland Point	Mud and sand	1	0.085
Sunderland Point	Sand	1	0.080
Colloway Marsh	Salt marsh	2	0.10
Lancaster	Grass	1	0.079
Aldcliffe Marsh	Salt marsh	2	0.087
Conder Green	Salt marsh	2	0.084
Pilling Marsh	Salt marsh	2	0.085
Knott End	Sand	2	0.075
Height o' th' hill - River Wyre	Salt marsh	2	0.092
Hambleton	Salt marsh	2	0.089
Skippool Creek 1	Salt marsh	2	0.10
Skippool Creek 2	Salt marsh	2	0.096
Fleetwood shore 1	Sand	2	0.075
Fleetwood shore 2	Salt marsh	2	0.11
Blackpool	Sand	2	0.061
Crossens Marsh	Salt marsh	2	0.086
Ainsdale	Sand	2	0.060
Rock Ferry	Mud and sand	2	0.078
West Kirby	Sand	2	0.069
Scotland			
Piltanton Burn	Sand	2^{S}	0.053
Garlieston	Sediment	1^{S}	0.057
Innerwell	Sediment	2^{S}	0.073
Bladnoch	Salt marsh	2^{S}	0.061
Carsluith	Stones	2^{S}	0.072
Skyreburn Bay (Water of Fleet)	Sediment	2^{S}	0.062
Kirkcudbright	Salt marsh	2^{S}	0.056

Table 2.9 continued

Location	Ground type	No. of sampling observations	Mean gamma dose rate in air at 1m, µGy h^{-1}
Cutters Pool	Winkle bed	2^{S}	0.066
Cutters Pool	Sediment	2^{S}	0.068
Rascarrel Bay	Salt marsh	2^{S}	0.078
Gardenburn	Sediment	2^{S}	0.062
Palnackie Harbour	Sediment	2^{S}	0.058
Kippford - Slipway	Sand	2^{S}	0.081
Kippford - Merse	Salt marsh	2^{S}	0.070
Kirkconnell Marsh	Salt marsh	2^{S}	0.063
Southerness	Rocks	1^{S}	0.054
Southerness	Sand	1^{S}	0.049
Wales			
Flint 1	Mud	2	0.085
Flint 2	Salt marsh	2	0.085
Rhyl	Salt marsh	2	0.078
Llandudno	Sand and shingle	1	0.083
Llandudno	Shingle	1	0.092
Caerhun	Grass	1	0.078
Caerhun	Salt marsh	1	0.078
Llanfairfechan	Sand and shells	2	0.073
Northern Ireland			
Lisahally	Mud	1^{N}	0.058
Donnybrewer	Shingle	1^{N}	0.048
Carrichue	Mud	1^{N}	0.067
Bellerena	Mud	1^{N}	0.057
Benone	Sand	1^{N}	0.057
Castlerock	Sand	1^{N}	0.056
Portstewart	Sand	1^{N}	0.055
Portrush, Blue Pool	Sand	1^{N}	0.054
Portrush, White Rocks	Sand	1^{N}	0.053
Portballintrae	Sand	1^{N}	0.052
Giant's Causeway	Sand	1^{N}	0.050
Ballycastle	Sand	1^{N}	0.053
Half Way House	Sand	1^{N}	0.053
Ballygally	Sand	1^{N}	0.051
Drains Bay	Sand	1^{N}	0.055
Larne	Sand	1^{N}	0.056
Whitehead	Sand	1^{N}	0.058
Carrickfergus	Sand	1^{N}	0.057
Jordanstown	Sand	1^{N}	0.058
Helen's Bay	Sand	1^{N}	0.060
Groomsport	Sand	1^{N}	0.068
Millisle	Sand	1^{N}	0.065
Ballywalter	Sand	1^{N}	0.060
Ballyhalbert	Sand	1^{N}	0.063
Cloghy	Sand	1^{N}	0.064
Portaferry	Shingle and sand	1^{N}	0.082
Kircubbin	Sand	1^{N}	0.082
Greyabbey	Sand	1^{N}	0.089
Ards Maltings	Mud	1^{N}	0.076
Island Hill	Mud	1^{N}	0.070
Nicky's Point	Mud	1^{N}	0.089
Strangford	Shingle and stones	1^{N}	0.093

Table 2.9 continued

Location	Ground type	No. of sampling observations	Mean gamma dose rate in air at 1m, μGy h⁻¹
Kilclief	Sand	1[N]	0.072
Ardglass	Mud	1[N]	0.084
Killough	Mud	1[N]	0.079
Ringmore Point	Sand	1[N]	0.075
Tyrella	Sand	1[N]	0.077
Dundrum	Sand	1[N]	0.090
Newcastle	Sand	1[N]	0.11
Annalong	Sand	1[N]	0.11
Cranfield Bay	Sand	1[N]	0.084
Mill Bay	Sand	1[N]	0.098
Greencastle	Sand	1[N]	0.081
Rostrevor	Sand	1[N]	0.11
Narrow Water	Mud	1[N]	0.090

All other measurements are made on behalf of the Environment Agency unless labelled "N" or "S"
[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 2.10 Beta radiation dose rates on contact with fishing gear on vessels operating off Sellafield, 2019

Vessel or location	Type of gear	No. of sampling observations	Mean beta dose rate in tissue, μSv h⁻¹
104	Nets	2	<0.092
106	Nets	1	<0.086
111	Nets	1	<0.082
116	Nets	1	0.091
South 1	Lobster pots	1	<0.094
South 2	Lobster pots	1	<0.095
South 3	Lobster pots	1	<0.11
South 4	Lobster pots	1	<0.14

Table 2.11 Beta radiation dose rates over intertidal areas of the Cumbrian coast, 2019

Location	Ground type	No. of sampling observations	Mean beta dose rate in tissue, μSv h⁻¹
Whitehaven - outer harbour	Pebbles and sand	1	0.14
Whitehaven - outer harbour	Sand	3	0.16
St Bees	Sand	4	0.17
Sellafield beach, N of discharge point	Sand	3	0.15
Sellafield beach, N of discharge point	Sand and stones	1	0.11
Ravenglass - Raven Villa	Salt marsh	4	0.17
Tarn Bay	Sand	4	0.16

Table 2.12 Concentrations of radionuclides in aquatic plants from the Cumbrian coast and further afield, 2019

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
Silloth	Seaweed	2	<1.0			<1.3	<0.68	130	<5.9	<0.99	<3.4
Harrington Harbour	Seaweed	2	<0.80			<1.0	<0.49	120	<4.5	<0.75	<2.6
St Bees[a]	Seaweed	2	<0.96		0.87	<1.1	<0.60	210	<5.5	<0.90	<3.1
Sellafield[b]	Seaweed	2	<0.89		2.3	<1.1	<0.58	770	<5.0	<0.86	<2.8
Ravenglass	Samphire	1[F]	<0.05	<0.18		<0.28	<0.19	1.1	<0.41	<0.07	<0.12
Ravenglass[c]	Seaweed	2	<0.98		3.4	<1.3	<0.64	110	<5.8	<0.97	<3.3
Lancashire											
Half Moon Bay[d]	Seaweed	2	<0.57			<0.69	<0.37	130	<3.3	<0.54	<1.9
Marshside Sands	Samphire	1[F]	<0.02	<0.04		<0.05	<0.05	<0.066	<0.15	<0.03	<0.05
Scotland											
Lerwick	*Fucus vesiculosus*	1[S]	<0.10	<0.28		<0.55	<1.1	5.4	<0.76	<0.11	<0.19
Kinlochbervie	*Fucus vesiculosus*	2[S]	<0.10	<0.19		<0.32	<0.50	15	<0.62	<0.10	<0.18
Lewis	*Fucus vesiculosus*	1[S]	<0.10	<0.10		<0.11	<0.13		<0.27	<0.10	<0.10
Islay	*Fucus vesiculosus*	1[S]	<0.10	<0.18		<0.16	<0.12	48	<0.56	<0.10	<0.17
Campbeltown	*Fucus vesiculosus*	1[S]	<0.10	<0.22		<0.28	<0.34	42	<0.69	<0.11	<0.19
Port William	*Fucus vesiculosus*	4[S]	<0.10	<0.17		<0.18	<0.19	84	<0.50	<0.10	<0.14
Garlieston	*Fucus vesiculosus*	4[S]	<0.10	<0.14		<0.14	<0.15	38	<0.42	<0.10	<0.13
Auchencairn	*Fucus vesiculosus*	4[S]	<0.10	<0.22		<0.24	<0.37	170	<0.67	<0.14	<0.19
Wales											
Cemaes Bay	Seaweed	2	<0.72			<0.89	<0.47	24	<4.1	<0.67	<2.5
Porthmadog	Seaweed	2	<0.72			<0.88	<0.50	<1.1	<4.4	<0.71	<2.4
Lavernock Point	Seaweed	2	<0.83			<1.0	<0.53	2.9	<4.6	<0.78	<2.6
Fishguard	Seaweed	2	<0.39			<0.55	<0.27	2.8	<2.4	<0.41	<1.4
Northern Ireland											
Portrush	*Fucus* spp.	2[N]	<0.07	<0.23		<0.12	<0.11		<0.46	<0.09	<0.13
Portrush	*Fucus serratus*	2[N]	<0.06	<0.19		<0.11	<0.11		<0.46	<0.07	<0.13
Portaferry[e]	*Rhodymenia* spp.	4[N]	<0.08	<0.20		<0.24	<0.26	0.29	<0.59	<0.10	<0.15
Ardglass	*Ascophyllum nodosum*	2[N]	<0.05	<0.15		<0.09	<0.06		<0.36	<0.06	<0.10
Ardglass	*Fucus vesiculosus*	2[N]	<0.04	<0.14		<0.23	<0.13	8.9	<0.31	<0.06	<0.09
Carlingford Lough	*Fucus vesiculosus*	2[N]	<0.04	<0.15		<0.16	<0.24		<0.34	<0.06	<0.09
Carlingford Lough	*Fucus* spp.	2[N]	<0.06	<0.21		<0.26	<0.18	36	<0.48	<0.09	<0.15
Isles of Scilly	Seaweed	1	<0.63			<0.75	<0.42	<2.2	<3.9	<0.56	<2.1

Table 2.12 continued

Location	Material	No. of sampling observ-ations	Mean radioactivity concentration (fresh), Bq kg^{-1}							
			^{129}I	^{134}Cs	^{137}Cs	^{144}Ce	^{155}Eu	^{238}Pu	^{239}Pu + ^{240}Pu	^{241}Am
Cumbria										
Silloth	Seaweed	2	<1.4	<0.97	4.4	<2.2				4.7
Harrington Harbour	Seaweed	2	<1.1	<0.69	1.4	<1.8				1.4
St Bees[a]	Seaweed	2	2.3	<0.88	1.8	<2.0		0.60	3.4	2.4
Sellafield[b]	Seaweed	2	2.6	<0.79	2.7	<2.0		0.87	4.6	4.0
Ravenglass	Samphire	1[F]		<0.05	1.4	<0.26	<0.12			7.7
Ravenglass[c]	Seaweed	2	<1.9	<0.87	8.4	<2.1		1.9	11	33
Lancashire										
Half Moon Bay[d]	Seaweed	2	<0.71	<0.50	1.7	<1.4				1.0
Marshside Sands	Samphire	1[F]		<0.02	0.16	<0.11	<0.05			0.11
Scotland										
Lerwick	*Fucus vesiculosus*	1[S]		<0.10	<0.10	<0.46	<0.17			<0.11
Kinlochbervie	*Fucus vesiculosus*	2[S]		<0.10	0.15	<0.39	<0.16			<0.11
Lewis	*Fucus vesiculosus*	1[S]		<0.10	0.12	<0.18	<0.10			<0.10
Islay	*Fucus vesiculosus*	1[S]		<0.10	0.25	<0.36	<0.14			<0.10
Campbeltown	*Fucus vesiculosus*	1[S]		<0.10	0.41	<0.38	<0.17			<0.12
Port William	*Fucus vesiculosus*	4[S]		<0.10	0.49	<0.31	<0.15			0.50
Garlieston	*Fucus vesiculosus*	4[S]		<0.10	3.0	<0.26	<0.13			6.3
Auchencairn	*Fucus vesiculosus*	4[S]		<0.10	1.9	<0.41	<0.17			2.7
Wales										
Cemaes Bay	Seaweed	2		<0.64	<0.52	<1.9				<0.57
Porthmadog	Seaweed	2		<0.68	<1.1	<1.8				<0.60
Lavernock Point	Seaweed	2		<0.71	<0.56	<1.8	<0.87			<0.61
Fishguard	Seaweed	2		<0.34	<0.30	<1.1				<0.35
Northern Ireland										
Portrush	*Fucus* spp.	2[N]		<0.06	<0.07	<0.27	<0.19			<0.25
Portrush	*Fucus serratus*	2[N]		<0.09	0.07	<0.41	<0.13			<0.23
Portaferry[e]	*Rhodymenia* spp.	4[N]		<0.07	0.36	<0.37	<0.13	0.058	0.39	0.78
Ardglass	*Ascophyllum nodosum*	2[N]		<0.05	0.21	<0.30	<0.12			<0.13
Ardglass	*Fucus vesiculosus*	2[N]		<0.06	0.33	<0.21	<0.10			<0.12
Carlingford Lough	*Fucus vesiculosus*	2[N]		<0.04	0.25	<0.31	<0.19			<0.18
Carlingford Lough	*Fucus* spp.	2[N]		<0.06	0.26	<0.33	<0.21			<0.22
Isles of Scilly	Seaweed	1		<54	<0.44	<1.6	<0.73			<0.51

[a] *The concentrations of ^{14}C was 48 Bq kg^{-1}*
[b] *The concentrations of ^{14}C was 59 Bq kg^{-1}*
[c] *The concentrations of ^{14}C was <13 Bq kg^{-1}*
[d] *The concentrations of ^{35}S was 5.1 Bq kg^{-1}*
[e] *The concentrations of ^{242}Cm and $^{243+244}Cm$ were not detected by the method used and 0.0025 Bq kg^{-1}, respectively*
[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*
Measurements are made on behalf of the Environment Agency unless specifically labelled

Table 2.13 Concentrations of radionuclides in terrestrial food and the environment near Ravenglass, 2019

Material and selection[a]		No. of sampling observ-ations[b]	Mean radioactivity concentration (fresh)[c], Bq kg^{-1}											
			Organic ^{3}H	^{3}H	^{14}C	^{60}Co	^{90}Sr	^{95}Nb	^{95}Zr	^{99}Tc	^{106}Ru	^{125}Sb	^{129}I	^{134}Cs
Milk		3		<3.8	18	<0.05	<0.037	<0.05	<0.08	<0.011	<0.35	<0.10	<0.0042	<0.04
Milk	max						0.056	<0.06	<0.09		<0.36		<0.0065	
Beef kidney		1				<0.08	0.024	<0.15	<0.19		<0.84	<0.24		<0.09
Beef liver		1		<3.3	31	<0.04	0.014	<0.05	<0.05	<0.11	<0.27	<0.08	<0.028	<0.03
Beef muscle		1		<3.5	18	<0.05	<0.019	<0.13	<0.16	<0.064	<0.29	<0.09	<0.018	<0.04
Blackberries		1	<6.7	<6.7	19	<0.03	0.078	<0.03	<0.08		<0.22	<0.06	<0.0080	<0.03
Sheep muscle		2		<3.0	26	<0.06	<0.029	<0.11	<0.14	<0.063	<0.44	<0.12	<0.015	<0.05
Sheep muscle	max				27		<0.041	<0.12	<0.17	<0.064			<0.016	
Sheep offal		2		<3.1	28	<0.04	<0.044	<0.06	<0.08	<0.15	<0.33	<0.09	<0.019	<0.04
Sheep offal	max			<3.2	32		<0.059			<0.16	<0.34		<0.021	

Material and selection[a]		No. of sampling observ-ations[b]	Mean radioactivity concentration (fresh)[c], 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	<0.08		<0.29				<0.000044	<0.000045	<0.21	0.000017
Milk	max		<0.11		<0.31							
Beef kidney		1	0.42	0.42	<0.58	0.062	0.0022	0.053	0.0011	0.0070	0.28	0.075
Beef liver		1	0.19	0.19	<0.17				0.0059	0.034	0.30	0.033
Beef muscle		1	0.40	0.40	<0.19				0.00011	0.00055	0.17	0.0025
Blackberries		1	0.09	0.094	<0.18				0.00043	0.011	<0.34	0.0061
Sheep muscle		2	3.6	3.6	<0.30				<0.000071	0.00010	<0.30	0.000090
Sheep muscle	max		5.6	5.6					<0.000099	0.00013	<0.32	0.00010
Sheep offal		2	1.7	1.7	<0.32				<0.00016	0.00066	<0.23	0.00058
Sheep offal	max		2.3	2.3	<0.33				<0.00021	0.00084	<0.29	

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

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

Table 2.14 Concentrations of radionuclides in surface waters from West Cumbria, 2019

Location	No. of sampling observ-ations	Mean radioactivity concentration, Bq l^{-1}									
		^{3}H	^{60}Co	^{90}Sr	^{99}Tc	^{134}Cs	^{137}Cs	^{238}Pu	^{239}Pu + ^{240}Pu	Gross alpha	Gross beta
Ehen Spit beach	4	100	<0.31	<0.021	<0.35	<0.30	<0.26	<0.0026	<0.0025	<2.7	11
River Ehen (100m downstream of sewer outfall)	4	<3.6	<0.32	<0.071		<0.30	<0.25	<0.0029	<0.0028	<0.13	0.86
River Calder (downstream)	4	<3.0	<0.30	<0.016	<0.088	<0.30	<0.24	<0.0022	<0.0016	<0.024	0.16
River Calder (upstream)	4	<3.0	<0.30	<0.012	<0.082	<0.30	<0.25	<0.0091	<0.016	<0.029	0.037
River Ehen (upstream of site and tidal confluence)	4	<3.1	<0.34	<0.012		<0.34	<0.27	<0.0029	<0.0020	<0.021	0.061
Wast Water	1	<2.5	<0.34				<0.27			<0.018	0.014
Ennerdale Water	1	<2.6	<0.12			<0.12	<0.09			<0.028	0.020
Sellafield Tarn	1	<3.0		<0.017	<0.094		<0.29	<0.0023	<0.0014		
Devoke Water	1	<2.6	<0.12			<0.11	<0.09			<0.020	0.029
Thirlmere	1	<2.7	<0.32				<0.27			<0.022	0.015

Table 2.15 Concentrations of radionuclides in road drain sediments from Whitehaven and Seascale, 2019

Location	No. of sampling observations	Mean radioactivity concentration (dry), Bq kg^{-1}						
		^{60}Co	^{90}Sr	^{134}Cs	^{137}Cs	^{238}Pu	$^{239}Pu+^{240}Pu$	^{241}Am
Seascale SS 204	1	<1.2	<1.4	<1.1	97	2.4	17	21
Seascale SS 233	1	<0.65	<1.8	<0.53	50	1.6	11	21
Seascale SS 209	1	<0.46	<2.9	<0.42	12	1.7	9.5	12
Seascale SS 232	1	<0.45	<1.2	<0.42	20	0.70	4.2	14
Seascale SS 231	1	<1.5	<0.39	<1.5	28	2.9	18	32

Table 2.16 Doses from artificial radionuclides in the Irish Sea, 2007-2019

Group	Exposure, mSv per year												
	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
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	0.010
Dumfries and Galloway	0.060	0.047	0.047	0.040	0.040	0.046	0.044	0.045	0.038	0.044	0.035	0.029	0.031
Whitehaven	0.009	0.009	0.011	0.010	0.010	0.013	0.010	0.012	0.017	0.016	0.017	0.018	0.014
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	0.072	0.063
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	0.024
North Wales	0.014	0.018	0.015	0.013	0.014	0.014	0.013	0.018	0.014	0.015	0.014	0.014	0.012

Table 2.17 Individual radiation exposures, Sellafield, 2019

Representative person[a]	Exposure, mSv per year							
	Total	Seafood (nuclear industry discharges)[b]	Seafood (other discharges)[c]	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
***Total dose* – maximum effect of all sources**								
Adult mollusc consumers	**0.24[e]**	**0.035**	**0.19**	**-**	**0.018**	**-**	**-**	**-**
***Total dose* – maximum effect of gaseous release and direct radiation sources**								
Infant milk consumers	**0.006**	**-**	**-**	**0.005**	**<0.005**	**-**	**<0.005**	**<0.005**
***Total dose* – maximum effect of liquid release source**								
Adult mollusc consumers	**0.24[e]**	**0.035**	**0.19**	**-**	**0.018**	**-**	**-**	**-**
Source specific doses								
Seafood consumers								
Local seafood consumers (habits averaged 2015-19)	0.27[f]	0.035	0.21	-	0.027	-	-	-
Local seafood consumers (habits for 2019)	0.27[g]	0.033	0.21	-	0.028	-	-	-
Whitehaven seafood consumers	0.014	0.014	-	-	-	-	-	-
Dumfries and Galloway seafood and wildfowl consumers	0.031	0.026	-	-	<0.005	-	-	-
Morecambe Bay seafood consumers	0.024	0.007	-	-	0.017	-	-	-
Northern Ireland seafood consumers	0.010	0.008	-	-	<0.005	-	-	-
North Wales seafood consumers	0.012	0.007	-	-	<0.005	-	-	-
Other groups								
Ravenglass Estuary, marsh users	0.007	-	-	-	0.006	<0.005	-	-
Fishermen handling nets or pots[h]	0.14	-	-	-	0.14	-	-	-
Bait diggers and shellfish collectors[h]	0.077	-	-	-	0.077	-	-	-
Ribble Estuary houseboats	0.024	-	-	-	0.024	-	-	-
Barrow Houseboats	0.055	-	-	-	0.055	-	-	-
Local infant consumers of locally grown food at Ravenglass	0.017[i]	-	-	0.017	-	-	-	-
Local infant consumers of locally grown food at LLWR near Drigg	0.005[i]	-	-	0.005	-	-	-	-
Infant inhabitants and consumers of locally grown food	0.012[i]	-	-	0.012	-	-	<0.005	-
Groups with average consumption or exposure								
Average seafood consumer in Cumbria	<0.005	<0.005	-	-	-	-	-	-
Average consumer of locally grown food[j]	<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	0.006	-	-	-	0.006	-	-	-
North Wales	0.007	-	-	-	0.007	-	-	-

Table 2.17 continued

Representative person[a]	Exposure, mSv per year							
	Total	Seafood (nuclear industry discharges)[b]	Seafood (other discharges)[c]	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
Recreational user of mud/saltmarsh areas								
Dumfries and Galloway	<0.005	-	-	-	<0.005	-	-	-
North Cumbria	<0.005	-	-	-	<0.005	-	-	-
Sellafield	0.011	-	-	-	0.011	-	-	-
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. Data are presented to 2 significant figures or 3 decimal places. Data below 0.005 mSv are reported as <0.005 mSv*

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

[c] *Enhanced naturally occurring radionuclides from Whitehaven*

[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)*

[e] *The dose due to nuclear industry discharges was 0.052 mSv*

[f] *The dose due to nuclear industry discharges was 0.063 mSv*

[g] *The dose due to nuclear industry discharges was 0.061 mSv*

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

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

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

3. Nuclear power stations

Key points

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

Berkeley, Gloucestershire and Oldbury, South Gloucestershire

- *Total dose* for the representative person was less than 0.005 mSv and unchanged in 2019
- Liquid discharges of tritium, caesium-137 and "other radionuclides" decreased from Oldbury in 2019

Bradwell, Essex

- *Total dose* for the representative person was less than 0.005 mSv and decreased in 2019

Chapelcross, Dumfries and Galloway

- *Total dose* for the representative person was 0.007 mSv and decreased in 2019
- Gaseous discharges of "all other radionuclides" increased in 2019

Dungeness, Kent

- *Total dose* for the representative person was 0.037 mSv and increased in 2019
- Gaseous discharges of tritium, carbon-14, sulphur-35 and argon-41 decreased from Dungeness B in 2019. Liquid discharges of "other radionuclides" increased from Dungeness A, and tritium and sulphur-35 decreased from Dungeness B in 2019

Hartlepool, County Durham

- *Total dose* for the representative person was 0.013 mSv and increased in 2019
- Gaseous discharges of carbon-14 increased, and liquid discharges of tritium and sulphur-35 decreased, in 2019

Heysham, Lancashire

- *Total dose* for the representative person was 0.018 mSv and increased in 2019
- Gaseous discharges of carbon-14 increased from Heysham 1, and tritium and carbon-14 discharges increased from Heysham 2, in 2019

Hinkley Point, Somerset

- *Total dose* for the representative person was 0.021 mSv and decreased in 2019
- Gaseous discharges of carbon-14 increased from Hinkley Point B in 2019

Hunterston, North Ayrshire

- *Total dose* for the representative person was less than 0.005 mSv and unchanged in 2019
- Gaseous discharges of carbon-14 from Hunterston B decreased in 2019
- Liquid discharges of "alpha" from Hunterston A, and tritium from Hunterston B, decreased in 2019

Sizewell, Suffolk

- *Total dose* for the representative person was 0.010 mSv and decreased in 2019
- Gaseous discharges of carbon-14 and liquid discharges of tritium increased from Sizewell B in 2019

Torness, East Lothian

- *Total dose* for the representative person was less than 0.005 mSv and unchanged in 2019
- Liquid discharges of sulphur-35 increased in 2019

Trawsfynydd, Gwynedd

- *Total dose* for the representative person was 0.005 mSv and decreased in 2019

Wylfa, Isle of Anglesey

- *Total dose* for the representative person was less than 0.005 mSv and decreased in 2019
- Liquid discharges of tritium decreased in 2019

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 (both operating stations and decommissioning sites). 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).

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 decommissioning. De-fuelling of the remaining two Magnox sites was completed in 2019 (Wylfa in Wales and Calder Hall on the Sellafield site). All of the first-generation nuclear reactors are now fuel free. In April

2020, the NDA published its annual business plan (2020 – 2023). The plan summarises the programme of work at each of the sites (NDA, 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 Research Sites Restoration Limited (RSRL)). Thereafter, the ten Magnox sites were re-licensed 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 September 2019, Magnox Limited became a wholly owned subsidiary of the NDA (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.

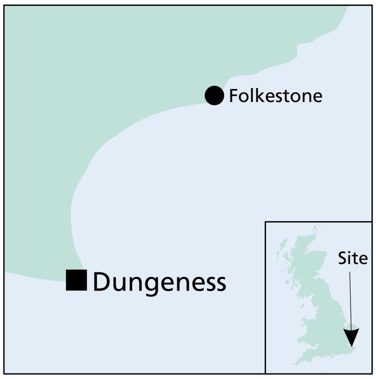
Seven AGR power stations and one PWR power station are owned and operated by EDF Energy Nuclear Generation Limited in 2019; these are Dungeness B, Hartlepool, Heysham 1 and 2, Hinkley Point B, Sizewell B Power Stations in England, and Hunterston B and Torness Power Stations in Scotland. All these power stations generated electricity during 2019.

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 2019, 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 2019 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.

In this section, sites are grouped according to their status of power generation (operating and decommissioning power stations). Dungeness, Hartlepool, Heysham, Hinkley Point, Hunterston, Sizewell and Torness sites are included under operating power stations (Section 3.1). Berkeley, Bradwell, Chapelcross, Hinkley Point, Hunterston, Oldbury, Trawsfynydd, and Wylfa sites are included under decommissioning power stations (Section 3.2). Power stations that have both operating and decommissioning sites (Dungeness, Hinkley Point, Hunterston and Sizewell) are considered under operating sites because, for the purposes of environmental monitoring, the effects from sites contribute to the same area.

3.1 Operating sites

3.1.1 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 is currently undergoing decommissioning. Dungeness B is expected to continue electricity generation until 2028.

Between June and July 2019, a habits survey was conducted to determine the consumption and occupancy rates by members of the public (Greenhill *et al*., 2020). A large decrease in both the fish consumption and occupancy (over sand and mud) rates have been observed, together with increases in the rates of crustacean and mollusc consumption, in comparison with those of the previous survey undertaken in 2010. Unlike in 2010, occupancy rates over other ground types were also observed in 2019. The activity of living on houseboats was not identified in the recent habits survey as a significant pathway of exposure from radioactivity. Revised figures for consumption rates of fish, together with occupancy rates, are provided in Appendix 1 (Table X2.2).

Doses to the public

In 2019, the *total dose* from all pathways and sources of radiation was 0.037 mSv (Table 3.1), or less than 4 per cent of the dose limit of 1 mSv, and up from 0.022 mSv (in 2018). 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 increase in *total dose* (from 2018) was mostly attributable to a higher estimate of direct radiation in 2019 (Table 1.1). The trend in *total dose* over the period 2008 – 2019 is given in Figure 3.1. *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).

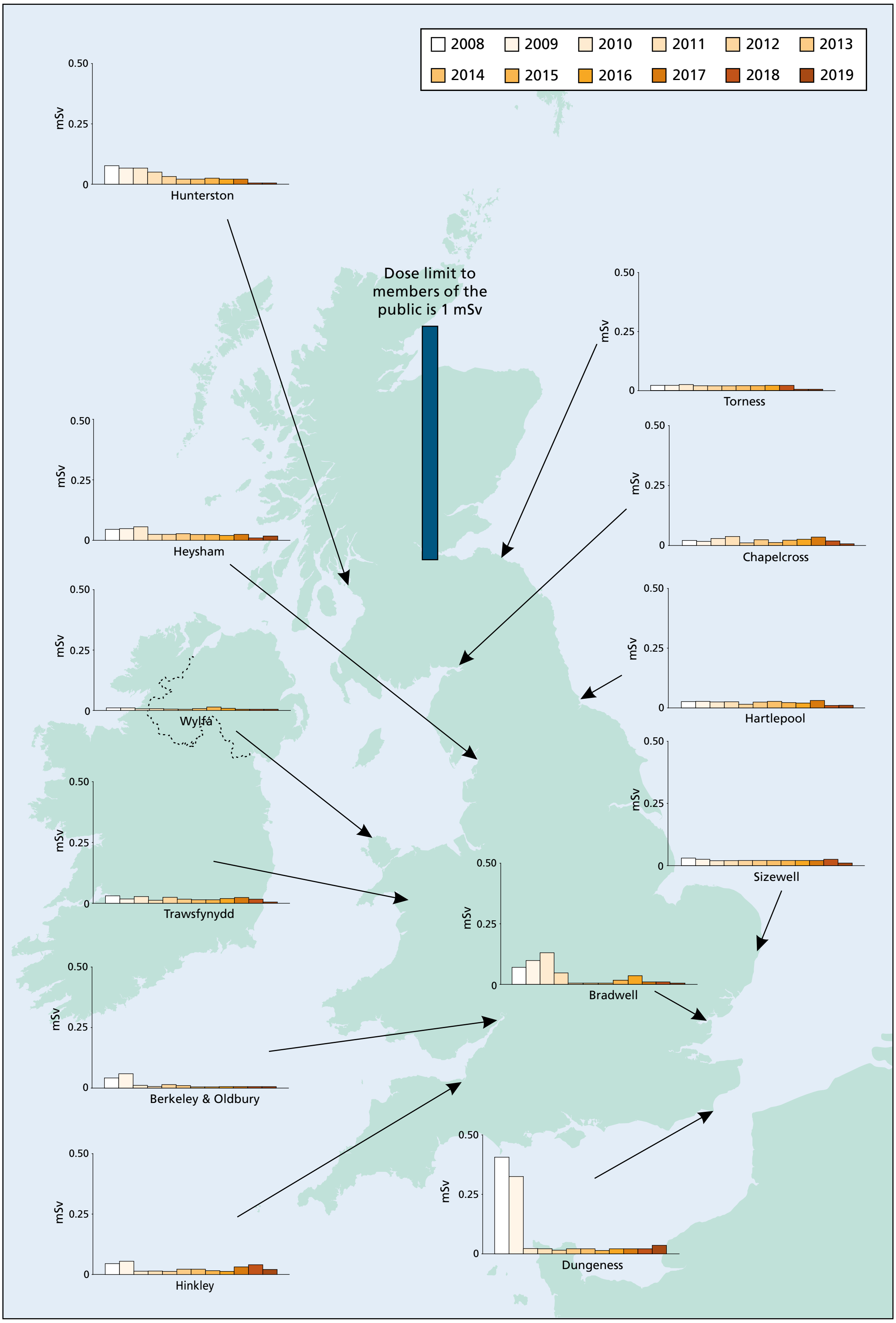


Figure 3.1. *Total dose* at nuclear power stations, 2008-2019
(Small doses less than or equal to 0.005 mSv are recorded as being 0.005 mSv)

Source specific assessments for a high-rate consumer of locally grown foodstuffs and 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) give exposures that were less than the *total dose* in 2019 (Table 3.1) and both source specific doses were less than 0.005 mSv. The estimation of dose for a houseboat occupant (from external exposure) was not required in 2019 (consistent with information identified in the habits survey).

Gaseous discharges and terrestrial monitoring

Gaseous wastes are discharged via separate stacks to the local environment. Discharges of tritium, carbon-14, sulphur-35 and argon-41 decreased from Dungeness B in 2019, in comparison to releases in 2018. The reduction in gaseous (and liquid) discharges from Dungeness B was due to a decrease in power generation during 2019 (in comparison to that in 2018). 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 2019 are given in Table 3.2(a). Activity concentrations in many terrestrial foods are reported as less than values (or close to the less than value). Unlike in recent years, sulphur-35 was not positively detected in local terrestrial food samples in 2019. Carbon-14 concentration in wheat increased in 2019, in comparison to that in 2018. In 2019, tritium concentrations in all terrestrial food are reported as less than values. 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 "other radionuclides" increased from Dungeness A, and discharges of tritium and sulphur-35 decreased significantly from Dungeness B in 2019, in comparison to releases in 2018. Marine monitoring included gamma dose rate measurements, and analysis of seafood and sediments. The results of monitoring for 2019 are given in Tables 3.2(a) and (b). The caesium-137 concentrations in seafood is attributable to discharges from the stations, to 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 2019. Caesium-137 concentrations in sediment have remained low over the last decade (Figure 3.2) and reported as less than values in recent years; the apparent increase in 2010 was due to the reporting of a relatively high less than value (< 5.8 Bq kg^{-1}). Gamma dose rates were generally difficult to distinguish from the natural background.

3.1.2 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 0.013 mSv in 2019 (Table 3.1), which was approximately 1 per cent of the dose limit, and up from 0.012 mSv in 2018. The small increase in *total dose* was attributed to higher gamma dose rates over local beaches (despite a lower estimate of direct radiation from the site) in 2019, in comparison to that in 2018. The representative person was adults spending time over sand and a change from that in 2018 (adults living in the vicinity of the site). The trend in *total dose* over the period 2008 – 2019 is given in Figure 3.1. *Total doses* remained broadly similar, from year to year, and were low.

A source specific assessment for high-rate consumers of locally grown foodstuffs gave an exposure that was less than the *total dose* in 2019 (Table 3.1). The dose to a local fish and shellfish consumer (including external radiation but excluding naturally occurring radionuclides) was 0.015 mSv in 2019, and up from 0.011 mSv in 2018. The reason for the increase in dose was because gamma dose rates were measured over different ground types from one year to next.

In 2019, a source specific assessment was not undertaken to determine the exposure from naturally occurring radionuclides, as a consequence of reported polonium-210 concentrations in mollusc samples. In previous years, winkle samples collected from South Gare (inside the Tees Estuary entrance) included some winkles taken 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 a potential reason for enhanced

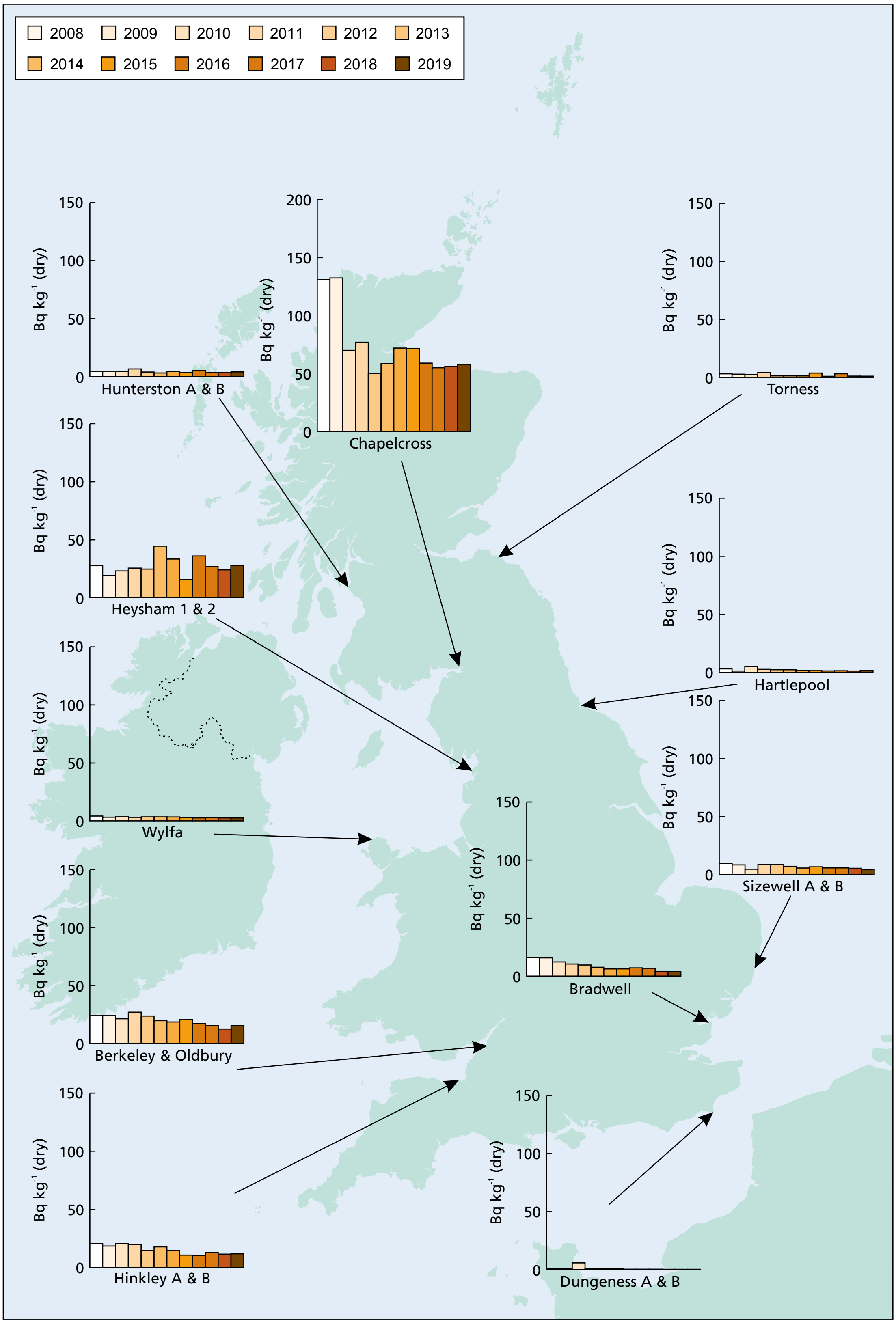


Figure 3.2. Caesium-137 concentration in marine sediments near nuclear power stations between 2008-2019

naturally occurring radionuclides in molluscs. Unlike in previous years, a winkle sample was not collected from Paddy's Hole in 2019. 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 2019.

Gaseous discharges and terrestrial monitoring

Gaseous radioactive waste is discharged via stacks to the local environment. Discharges of carbon-14 increased in 2019, in comparison to those in 2018. The increase in carbon-14 discharges to the atmosphere in 2019 was believed to be associated with increased nitrogen gas in-leakage through the reactor safety shut-down valves. Analyses of tritium, carbon-14, sulphur-35 and gamma-emitting radionuclides were carried out in milk and crop samples. Samples of water were also taken from a borehole. Data for 2019 are given in Table 3.3(a). The effects of gaseous disposals from the site were not easily detectable in foodstuffs, although a small enhancement of carbon-14 concentrations was measured in food (wheat) and a grass sample close to the site (0.6 km NE) in 2019. Carbon-14 was detected in locally produced milk at concentrations close to the default value used to represent background. 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

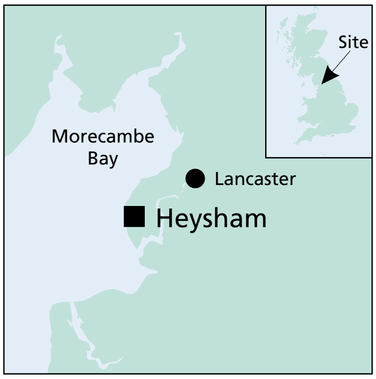
Regulated discharges of radioactive liquid effluent are made to Hartlepool Bay with a minor component being discharged directly to the River Tees. Liquid discharges of tritium and sulphur-35 decreased in 2019, in comparison to those in 2018. The decrease in sulphur-35 in 2019 was likely to be associated with the on-going effect of reduced Carbonyl Sulphide (COS) injection implemented in 2017. The decrease in tritium was associated with maintenance work on gas drier drains at the end of 2019, that necessitated temporary storage of tritiated water rather than routine discharges in the aquatic environment. Results of the aquatic monitoring programme conducted in 2019 are shown in Tables 3.3(a) and (b). As in previous years, a small enhancement of the carbon-14 concentration, above the expected background, was observed in mollusc samples. These enhancements are unlikely to result from carbon-14 discharges from the site since carbon-14 discharges from the power station are low. Carbon-14 concentrations in fish and crustaceans were generally similar in 2019, in comparison to those in 2018.

The analysis of technetium-99 in seaweed is used as a specific indication of the far-field effects of disposals to sea from Sellafield. As in recent years, technetium-99 in seaweed was low and much less than the concentrations observed in 2008 (see Figure 2.11, Environment Agency, FSA, FSS, NIEA, NRW and SEPA, 2018). Technetium-99 concentrations in seaweed 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 2019. 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 3.2). Overall, gamma dose rates over intertidal sediment in 2019 were generally similar (where comparisons can be made from similar ground types and locations), to those observed in 2018.

In 2019, the reported polonium-210 and lead-210 concentrations in winkles from South Gare are values expected due to naturally occurring sources (given in Table X4.1). A winkle sample was not collected from the estuary entrance near Paddy's Hole in 2019.

3.1.3 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 of two separate nuclear power stations, Heysham 1 and Heysham 2, each powered by two AGRs. Heysham 1 commenced operation in 1983 and Heysham 2 began operating in 1988. 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 Heysham 1 permit was varied and updated in 2019 to incorporate the requirements of "GRR" guidance. The consolidated permit also included changes arising from EPR 18 (for implementation of BSSD 13). No environmental discharge limits were changed as part of the variation process. 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 0.018 mSv in 2019 (Table 3.1), or less than 2 per cent of the dose limit for members of the public, and up from 0.010 mSv in 2018. In 2019, the representative person was adults spending time over sediments. The increase in *total dose* in 2019 was mostly due to higher gamma dose rates over sand, in comparison to those in 2018.

The trend in *total dose* over the period 2008 – 2019 is given in Figure 3.1. Any changes in *total doses* from 2008 – 2010 were attributed to natural 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 in the rate of mollusc consumption (from the revised habits data) and lower concentrations of plutonium radionuclides and americium-241 in molluscs. In 2017 and 2018, 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 2019 (Table 3.1). The estimated doses for terrestrial food consumption and from turf cutting were less than 0.005 mSv and 0.006 mSv, respectively, in 2019. The decrease in dose (from 0.005 mSv in 2018) for the terrestrial food consumption was mostly attributed to lower concentrations of carbon-14 in milk in 2019. The reason for the small increase in dose from turf cutting in 2019 (from less than 0.005 mSv in 2018) was because higher gamma dose rates were measured over saltmarsh, in comparison to those in 2018. The dose to a local fisherman, who was considered to consume a large amount of seafood and was exposed to external radiation over intertidal areas, was 0.024 mSv in 2019, which was approximately 2 per cent of the dose limit for members of the public of 1 mSv (Table 3.1). The dose in 2018 was 0.015 mSv. The increase in dose was also attributed to higher gamma dose rates over sand in 2019 (in comparison to those in 2018).

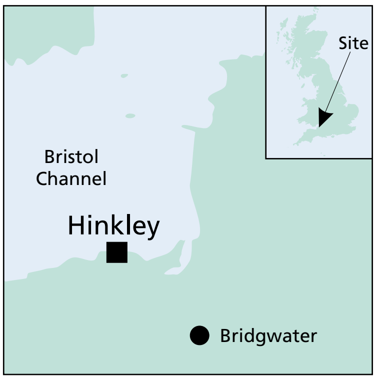
Gaseous discharges and terrestrial monitoring

Both stations discharge gaseous radioactive waste via stacks to the atmosphere. In 2019, carbon-14 discharges increased from Heysham 1, and tritium and carbon-14 discharges increased from Heysham 2, in comparison to releases in 2018. The monitoring programme for the effects of gaseous disposals was similar to that for other power stations. Data for 2019 are given in Table 3.4(a). The effects of gaseous disposals from the site were not easily detectable in foodstuffs, although a sulphur-35 concentration was enhanced (reported as above the less than value) in silage in 2019. Carbon-14 concentrations in milk were below the default value used to represent background in 2019. 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. 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 2019 are given in Tables 3.4(a) and (b). In general, activity concentrations in 2019 were similar (in comparison to those in 2018) 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 these reported concentrations originated as a result of discharges from Heysham. Plutonium radionuclides and americium-241 concentrations in mussels were slightly higher in 2019, in comparison to those in 2018, but similar to values in previous years. Concentrations of technetium-99 in marine samples originating from Sellafield discharges were similar to those in recent years. In 2019, strontium-90 was detected at low concentrations (reported as just above, or close to, the less than value) in food samples. Overall, gamma dose rates were higher in 2019 (in comparison to 2018) including those measured over sand (Morecambe central beach, Half Moon Bay and Middleton sands).

3.1.4 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. 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).

The construction of the twin EPR™ reactors continues at Hinkley point C. 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 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, 2019). Latest information can be found at: **https://www.gov.uk/government/collections/hinkley-point**.

Doses to the public

In 2019, the *total dose* from all pathways and sources of radiation was 0.021 mSv (Table 3.1), or approximately 2 per cent of the dose limit, and down from 0.041 mSv in 2018. The representative person was adults spending time over sediments. The decrease in *total dose* was mostly due to lower gamma dose rates (over mud) in 2019, in comparison to those in 2018.

The trend in *total dose* over the period 2008 – 2019 is given in Figure 3.1. 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* from 2017 to 2018 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 2019 (Table 3.1). The dose to this consumer of locally grown food was less than 0.005 mSv in 2019. The decrease in dose (from 0.005 mSv in 2018) was mostly due to lower carbon-14 concentrations in milk in 2019. The dose to the local fisherman was 0.014 mSv in 2019, or approximately 1 per cent of the dose limit for members of the public of 1 mSv. The reason for the decrease in dose from 0.025 mSv (in 2018) was mostly due to lower gamma dose rate over mud. This dose estimate also includes the effects of discharges (historical) of tritium from the GE Healthcare Limited plant at Cardiff and uses an increased dose coefficient (see Appendix 1, Annex 3). The estimated dose for a houseboat occupant was 0.012 mSv in 2019. This estimate is determined as a cautious value (due to direct measurements beneath houseboats not being available) and therefore not included in the *total dose* assessment.

Gaseous discharges and terrestrial monitoring

Gaseous radioactive waste is discharged via separate stacks to the local environment. Discharges of carbon-14 increased from Hinkley Point B in 2019, in comparison to releases in 2018. Analyses of milk, fruit, honey and crops were undertaken to measure activity concentrations of tritium, carbon-14, sulphur-35 and gamma-emitting radionuclides. Local reservoir water samples were also analysed. Data for 2019 are given in Table 3.5(a). Activity concentrations of tritium and gamma-emitting radionuclides (including caesium-137) in terrestrial materials are reported as less than values (or close to the less than value). Sulphur-35 from Hinkley Point B was detected at low concentrations in some of the food samples (blackberries and wheat). Carbon-14 concentrations in locally produced milk were lower in 2019 (in comparison to 2018) and the maximum concentration was that expected from natural background. Carbon-14 was detected in blackberries (as in previous years) above the expected background value in 2019. 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 2019 are given in Tables 3.5(a) and (b). Activity concentrations observed in seafood and other materials from the Bristol Channel were generally similar to those in recent years. In 2019, tritium concentrations in shellfish (shrimps) were lower, in comparison to those in 2018, 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 continuing evidence to suggest that caesium-137 concentrations in sediment have been generally decreasing over the reported years (Figure 3.2). Overall, gamma dose rates over intertidal sediment in 2019 were generally similar (where comparisons can be made for similar ground types and locations), although the dose rates over mud (at Stolford) decreased, in comparison to those observed in 2018.

3.1.5 Hunterston, North Ayrshire

Hunterston Power Station is located on the Ayrshire coast near West Kilbride and consists of 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 decommissioning 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 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.

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. Reactor 4 was authorised to operate between August and December 2019. The unit was then shut down, pending further safety case approval.

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 2019 (Table 3.1), which was less than 0.5 per cent of the dose limit, and unchanged from 2018. In 2019, the representative person was prenatal children of local inhabitants. The trend in *total dose* over the period 2008 – 2019 is given in Figure 3.1. The decrease in *total dose* in recent years has reflected a downward trend in the reported direct radiation.

Source specific assessments for a high-rate consumer of locally grown food, and of local seafood, give exposures that were higher (by a small amount) than the *total dose* in 2019 (Table 3.1). The estimated dose for seafood consumption was 0.006 mSv in 2019, and similar to that in 2018 (0.005 mSv). The small increase in dose was mostly attributable to higher concentrations of americium-241 in molluscs and crustaceans. The estimated dose to a terrestrial food consumer was 0.007 mSv in 2019, which was approximately 0.5 per cent of the dose limit for members of the public of 1 mSv. The reason for the decrease in dose from 0.013 mSv (in 2018) was mostly due to a lower maximum concentration of carbon-14 in milk in 2019.

Gaseous discharges and terrestrial monitoring

Gaseous discharges are made via separate discharge points from the Hunterston A and Hunterston B stations. Due to shutdowns of Reactors 3 and 4 in 2019, carbon-14 discharges (and to a lesser extent, other discharges) decreased from Hunterston B, in comparison to those releases 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 2019 are given in Tables 3.6(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). Concentrations of sulphur-35 were positively detected in grass (and in the maximum concentration in soil) and europium-155 was detected in soil samples (reported as just above the less than value) in 2019. As in 2018, carbon-14 concentrations in a number of foodstuffs were found to be higher than values used to represent background values (apples, eggs, and rosehips). Tritium, gross alpha and gross beta concentrations in freshwater were well below the investigation levels for drinking water in the European Directive 2013/51. Activity concentrations in air at locations near to the site (Table 3.6(c)) are reported as less than values (or close to the less than value). The number of observations at one of the sampling locations (Low Ballees) was very low in 2019, because of necessary renovation works undertaken on the air sampling unit.

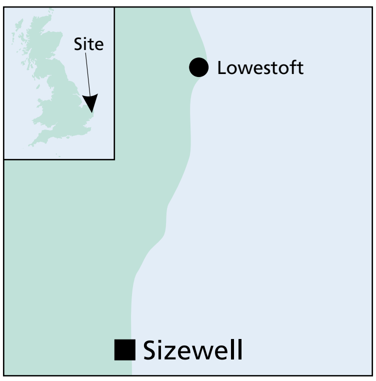
Solid waste transfers in 2019 are also given in Appendix 2 (Table A2.4).

Liquid waste discharges and aquatic monitoring

Authorised liquid discharges from both Hunterston stations are made to the Firth of Clyde via the Hunterston B station's cooling water outfall. Discharges of "alpha" decreased from Hunterston A in 2019, in comparison to those releases in 2018. Discharges of tritium (and to a lesser extent, sulphur-35) decreased from Hunterston B, due to shutdowns of Reactors 3 and 4 in 2019. 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 2019 are shown in Tables 3.6(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 2019 and were generally similar to those reported in 2018. Small concentrations (reported as just above the less than value) of activation products (manganese-54 and cobalt-60) were detected in seaweed and sediment, and also in 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). Americium-241 concentrations in mollusc (scallop) and crustacean (lobster) samples collected in 2019 were generally higher than those observed in 2018. Gamma dose rates were generally similar in 2019, in comparison to those in 2018. Measurements of the beta dose rates over sand are reported as less than values in 2019. Caesium-137 concentrations in sediment have remained low over the last decade (Figure 3.2).

3.1.6 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.

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. The most recent habits survey was conducted in 2015 (Garrod *et al*., 2016). NNB GenCo is developing its plans for a twin EPR^{TM} reactor-based station at the site (Sizewell C) and applied to the Environment Agency for a radioactive substances disposal permit and the Planning Inspectorate for a Development Consent Order (DCO) in May 2020. NNB Genco applied to the ONR for a nuclear site licence in June 2020.

Doses to the public

The *total dose* from all pathways and sources of radiation was 0.010 mSv in 2019 (Table 3.1) or 1 per cent of the dose limit, and down from 0.026 mSv in 2018. 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 decrease in *total dose* (from 2018) was mostly attributed to a lower estimate of direct radiation in 2019 (Table 1.1). The trend in *total dose* over the period 2008 – 2019 is given in Figure 3.1. 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 six), 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 2019 (Table 3.1).

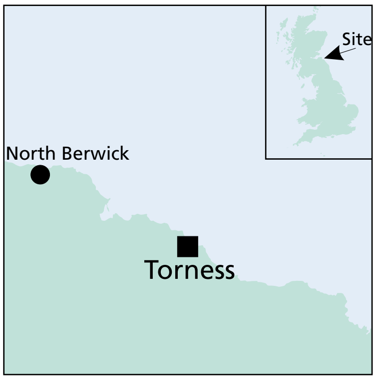
Gaseous discharges and terrestrial monitoring

Gaseous wastes are discharged via separate stacks to the local environment. Discharges of carbon-14 increased (by a small amount) from Sizewell B in 2019, in comparison to releases in 2018. The results of the terrestrial monitoring in 2019 are shown in Table 3.7(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 2019. Sulphur-35 was positively detected at a very low concentration in one sample (barley) in 2019. Tritium concentrations in local freshwater were all reported as less than values, including those measured at the Leisure Park (positively detected in previous years). Tritium, gross alpha and gross beta concentrations in surface water were below the investigation levels for drinking water in the European Directive 2013/51.

Liquid waste discharges and aquatic monitoring

Regulated discharges of radioactive liquid effluent are made via outfalls to the North Sea. Discharges of tritium increased from Sizewell B in 2019, in comparison to those in 2018. 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 2019 are given in Tables 3.7(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 are generally decreasing with time (Figure 3.2). Overall, gamma radiation dose rates over intertidal areas were difficult to distinguish from the natural background and were similar to those reported in 2018.

3.1.7 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. 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 2019. The gaseous and liquid discharges from the site are given in Appendix 2 (Table A2.1). Solid waste transfers in 2019 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 2019, the *total dose* from all pathways and sources of radiation was less than 0.005 mSv (Table 3.1), or less than 0.5 per cent of the dose limit, and unchanged from 2018. In 2019, the representative person was prenatal children of local inhabitants living near the site and a change from that in 2018 (prenatal children consuming wild fruits and nuts). The trend in *total dose* over the period 2008 – 2019 is given in Figure 3.1. 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 2019 (Table 3.1). The estimated dose to a terrestrial food consumer was 0.006 mSv in 2019, which was approximately 0.5 per cent of the dose limit for members of the public of 1 mSv, and similar to that in 2018 (0.007 mSv).

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 2019 are given in Tables 3.8(a) and (c). Activity concentrations in many terrestrial foods are reported as less than values (or close to the less than value). The carbon-14 concentrations in locally produced milk were close to the default value used to represent background. In 2019, the effects of sulphur-35 discharges from the power station were detected in terrestrial foods (honey, lamb, pigeon and rabbit) and in the maximum concentration in an environmental indicator material (grass). Caesium-137 in honey was positively detected at a low concentration (3.6 Bq kg^{-1}) in 2019, but similar to the value reported in 2018 (2.0 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 2019. 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 2019 (Table 3.8(c)). Solid waste transfers in 2019 are also given in Appendix 2 (Table A2.4).

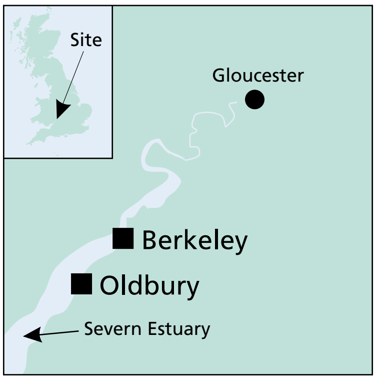
Liquid waste discharges and aquatic monitoring

Discharges of authorised liquid radioactive wastes are made to the Firth of Forth. Discharges of sulphur-35 increased in 2019, in comparison to those releases in 2018 (due to general operational variability between years). Seafood, seaweed, sediment, and seawater samples were collected in 2019. 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 2019 are shown in Tables 3.8(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, cobalt-60 (in environmental indicator samples) and silver-110m (in winkles) were detected 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 2018. Overall, caesium-137 concentrations in sediments have remained low over the last decade (Figure 3.2). Gamma dose rates over intertidal areas were generally indistinguishable from natural background and were similar to those measured in recent years. Measurements of the contact beta dose rate on fishermen's pots are reported as less than values in 2019.

3.2 Decommissioning sites

3.2.1 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 small amounts of radioactive wastes are still generated by these operations.

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.

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 2019, the *total dose* from all pathways and sources of radiation was less than 0.005 mSv (Table 3.1), or less than 0.5 per cent of the dose limit, and unchanged from 2018. The representative person was prenatal children of local inhabitants living near the site and a change from that in 2018 (infants consuming milk). The trend in the *total dose* over the period 2008 – 2019 is given in Figure 3.1. Any longer-term variations in *total doses* with time are attributable to changes in the contribution from direct radiation.

The source specific assessments for a high-rate consumer of locally grown foods, and of fish and shellfish, in the vicinity of the Berkeley and Oldbury sites, give exposures that were also less than 0.005 mSv in 2019 (Table 3.1). 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 a higher dose coefficient for organically bound tritium (see Appendix 1). The dose for houseboat dwellers was 0.009 mSv in 2019. The reason for the small decrease in estimated dose for houseboat dwellers (from 0.013 mSv in 2018) was because gamma dose rates were measured over a different ground type (at Sharpness, over salt marsh and mud), in comparison to those in 2018. 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

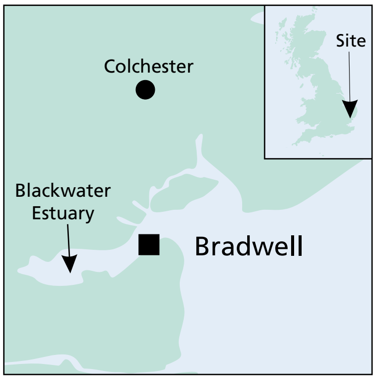
The Berkeley and Oldbury sites discharge gaseous radioactive wastes via separate stacks to the atmosphere. The focus of the terrestrial sampling was for the analyses of tritium, carbon-14 and sulphur-35 in milk and crops. Local freshwater samples were also analysed. Data for 2019 are given in Table 3.9(a). Sulphur-35 was detected at very low concentrations in two terrestrial food samples (carrot and barley) in 2019. Carbon-14 concentrations in foodstuffs (including milk) decreased in 2019 in comparison to those in 2018. The maximum concentration in milk was close to the default value used to represent background. 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. 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. In 2019, discharges of tritium (and to a lesser extent, caesium-137 and "other radionuclides") decreased from Oldbury in 2019, in comparison to releases in 2018.

Analyses of seafood and marine indicator materials and measurements of external radiation were conducted over muddy intertidal areas. Data for 2019 are given in Tables 3.9(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, 2008 – 2019 (Figure 3.2). As in recent years, the tritium concentrations in fish, shellfish and seawater are reported as less than values in 2019. 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 similar to those in 2018 (where comparisons can be made).

3.2.2 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. In November 2017, Magnox Limited applied to the Environment Agency to vary its environmental permit. The revised permit, effective from the 1st 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).

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 less than 0.005 mSv in 2019 (Table 3.1), or less than 0.5 per cent of the dose limit for members of the public of 1 mSv, and down from 0.011 mSv in 2018. The representative person was adults living in a houseboat and was a change from 2018 (prenatal children of local inhabitants). The decrease in *total dose* (from 2018) was mostly attributed to a lower estimate of direct radiation in 2019 (Table 1.1). The trend in *total dose* over the period 2008 – 2019 is given in Figure 3.1. 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 also less than 0.005 mSv per year.

Gaseous discharges and terrestrial monitoring

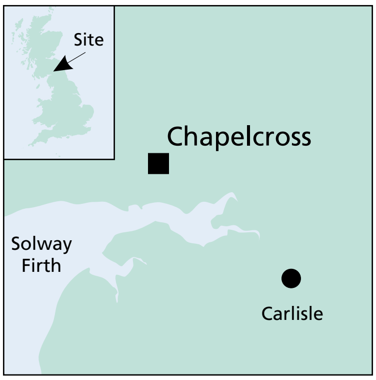
The power station is permitted to discharge gaseous wastes to the local environment via stacks to the atmosphere. Terrestrial sampling is similar to that for other power stations including analyses of milk and crop samples. Samples of water are also taken from a coastal ditch. Data for 2019 are given in Table 3.10(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. As in recent years, strontium-90 was detected at a low concentration in one coastal ditch sample. The gross beta activities (and gross alpha in 2019) 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 lower in 2019 (in comparison to those in recent years) and are all reported as less than values (and 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. The source of this effluent is rainwater which is discharged to the estuary via the main drains pit at Bradwell site. The main drains pit is sampled at quarterly intervals. The site is also permitted to discharge non-radioactive effluent from the turbine hall voids to the main drains pit, and from there to the estuary, however no effluent from this source was discharged in 2019. Effluent was last discharged to the estuary via Bradwell site's active effluent system in September 2017. This route has been decommissioned and was removed from the site's permit when the permit was varied in 2019.

Aquatic sampling was directed at the consumption of locally caught fish and shellfish and external exposure over intertidal sediments. Seaweeds were also analysed as an environmental indicator material. Data for 2019 are given in Tables 3.10(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. There is an overall decline in caesium-137 concentrations in sediments over the last decade (Figure 3.2). The caesium-137 concentration observed in the sediment samples collected in 2019 were amongst the lowest reported values in recent years. Gamma dose rates on beaches were difficult to distinguish from natural background and generally similar to those in 2018.

3.2.3 Chapelcross, Dumfries and Galloway



Chapelcross was Scotland's first commercial nuclear power station. It has four Magnox reactors and is 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 since 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.

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 0.007 mSv in 2019 (Table 3.1), which was less than 1 per cent of the dose limit, and down from 0.019 mSv in 2018. As in recent years, the representative person was infants consuming locally produced milk at high-rates. The decrease in *total dose* (from 2018) was mostly due to the exclusion from the assessment of americium-241 concentration in terrestrial foods. In line with the rules on use of the results for dose calculations, americium-241 was not included in the 2019 assessment because no detectable activity of americium-241 was observed in any terrestrial samples. The trend in *total dose* over the period 2008 – 2019 is given in Figure 3.1.

Source specific assessments for a high-rate consumer of locally grown food, for a seafood consumer (crustaceans), and for a seafood (fish and mollusc) and wildfowl consumer, give exposures that were less than the *total dose* in 2019 (Table 3.1). The dose for the terrestrial food consumer was estimated to be 0.006 mSv in 2019. The reason for the decrease in dose from 0.014 mSv (in 2018) is the same as that contributing to the maximum *total dose*. The dose for the seafood and wildfowl consumer was 0.006 mSv in 2019, and down from 0.011 mSv in 2018. The decrease in dose in 2019 was mostly due to not including a contribution for americium-241 in cockles in 2019 (sample not collected), in comparison to that 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" increased in 2019, in comparison to releases in 2018.

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 2019 are given in Tables 3.11(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. Americium-241 concentrations in all terrestrial food, soil and grass samples are reported as less than values.

In recent years, tritium results have shown the effects of discharges in some terrestrial samples from Chapelcross. In 2019, tritium was positively detected (just above the less than value) in food samples (beef, cabbage and rosehips) and in an indicator material (maximum concentration in grass). 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 3.11(c)) are reported as less than values (or close to the less than value). Solid waste transfers in 2019 are also given in Appendix 2 (Table A2.4).

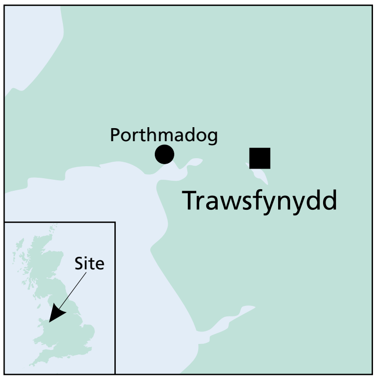
Liquid waste discharges and aquatic monitoring

Radioactive liquid effluents are discharged to the Solway Firth. As in previous years, discharges continued at very low rates in 2019 (most reported as < 1 per cent of the annual limit). 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 2019 are given in Tables 3.11(a) and (b). Unlike in recent years, salmon and cockle samples were not collected in 2019. 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.

As in previous years, concentrations of caesium-137, plutonium radionuclides and americium-241 were enhanced in sediment samples taken close to the pipeline in 2019. Technetium-99 concentrations in seaweed were generally similar, in comparison to those in 2018, whilst concentrations in fish and shrimps are both reported as less than values in 2019. Concentrations of caesium-137 in sediments, largely due to Sellafield, are generally in decline over the last decade (Figure 3.2). In 2019, gamma dose rates over intertidal sediment (where comparisons can be made) were generally similar, although the dose rates over sand (at Dornoch Brow) decreased (by small amounts), in comparison to those in 2018. Measurements of the contact beta dose rate on stake nets and sediment are reported as less than values in 2019.

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 2019 (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.

3.2.4 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 most recent habits survey was undertaken in 2018 (Greenhill *et al*., 2019).

Doses to the public

The *total dose* from all pathways and sources of radiation was 0.005 mSv in 2019 (Table 3.1), which was 0.5 per cent of the dose limit, and down from 0.017 mSv in 2018. The representative person in 2019 was adults exposed to external radiation over lake sediments. The decrease in *total dose* was mostly attributed to a lower caesium-137 concentration in the lake shore sediment sample included in the assessment in 2019 (in comparison to those in 2018). The trend in *total dose* over the period 2008 – 2019 is given in Figure 3.1. In 2018, the decrease in *total dose* can be attributed to the revised habits information. *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 0.006 mSv in 2019 (Table 3.1), which was approximately 0.5 per cent of the dose limit for members of the public of 1 mSv. The decrease in dose (from 0.018 mSv in 2018) was the same as that contributing to the maximum *total dose*. The observed activity concentration(s) 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 0.041 mSv, or approximately 4 per cent of the dose limit. The dose in 2018 was 0.025 mSv, and the increase was mostly due to a higher reported less than value for americium-241 in milk in 2019.

Gaseous discharges and terrestrial monitoring

The results of the terrestrial programme, for local food (including milk) and silage samples in 2019, are shown in Table 3.12(a). Results from surveys, providing 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. Tritium concentrations in all milk samples are reported as less than values. Carbon-14 concentrations in milk were generally similar in 2019 (in comparison to those in 2018) 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 2019. 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 2019, 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 direct evidence of re-suspension of activity in sediment from the lake shore contributing to increased exposure from transuranic radionuclides in 2019.

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 caesium-137 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 caesium-137 concentrations than indigenous fish.

Data for 2019 are given in Tables 3.12(a) and (b). The majority of activity concentrations in fish and sediments result from historical discharges. Rainbow trout samples were collected (but not a brown trout sample) in 2019. The most recent brown trout sample to be collected was in 2015 and the concentration of caesium-137 was the lowest reported value for fish indigenous to the lake (Environment Agency, FSA, FSS, NIEA, NRW and SEPA, 2016). As in previous years, caesium-137 concentrations in water samples are reported as less than values in 2019. 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 lower than those in 2018 (where comparison can be made). In 2019, the highest caesium-137 concentration was in a sediment sample collected near the lake shore (130 Bq kg^{-1}), but lower than in 2018 (410 Bq kg^{-1}). Plutonium-239+240 was also positively detected in the same sediment sample. 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 2019 were generally similar to those in recent years. Strontium-90 and transuranic concentrations in fish continued to be very low in 2019 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 2019 and were generally similar (with some small variations, where comparison can be made) to those in 2018. The predominant radionuclide was caesium-137. The time trends of concentrations of caesium-137 in sediments and discharges are shown in Figure 3.3. 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 have generally decreased again from the small peak in discharge in 2012, with the lowest concentrations reported in 2016.

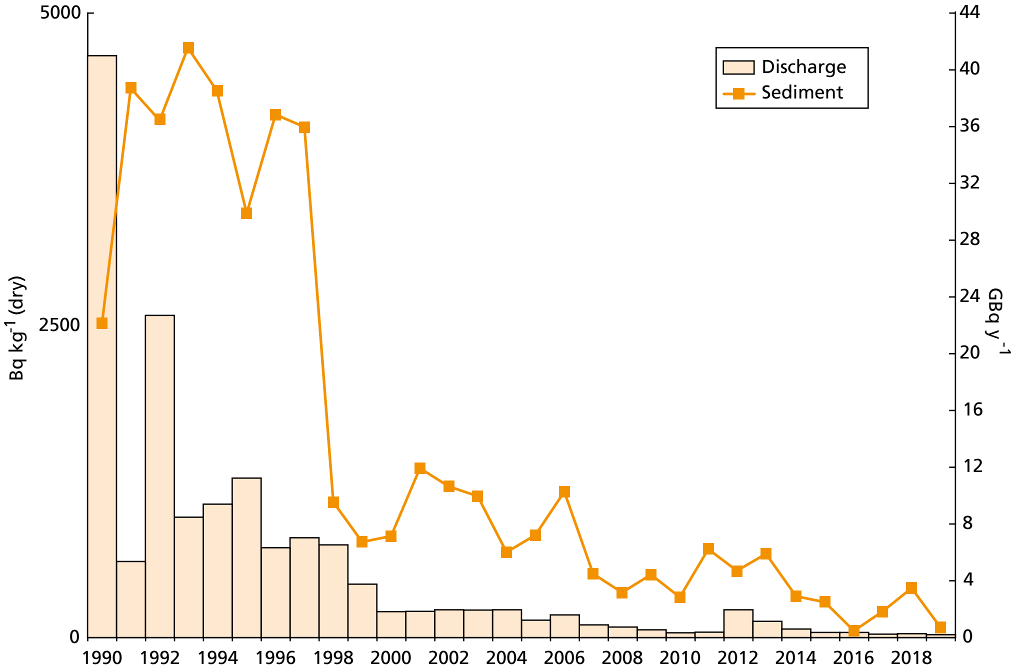
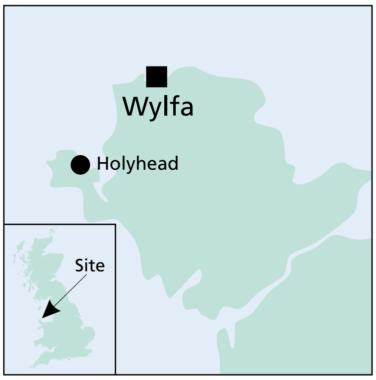


Figure 3.3. Caesium-137 liquid discharge from Trawsfynydd and concentration in sediment in Trawsfynydd lake, 1990-2019

3.2.5 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 2015. De-fuelling operations were completed in 2019 (NDA, 2020). This milestone marked the end of de-fuelling operations at all the UK's first-generation nuclear reactors.

In November 2019, NRW issued a minor variation to the permit that included removal of the discharge limits for sulphur-35 and argon-41. 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 less than 0.005 mSv in 2019 (Table 3.1), which was less than 0.5 per cent of the dose limit, and down from 0.006 mSv in 2018. In 2019, the representative person was adults spending time over sediments. The small decrease in *total dose* (from 2018) was because a lower gamma dose rate was measured over sand in 2019. The trend in *total dose* over the period 2008 – 2019 is given in Figure 3.1. *Total doses* remained broadly similar, from year to year, and were generally very low.

A source specific assessment for a high-rate consumer of locally grown foods gives an exposure that was less than the *total dose* (Table 3.1) and down from 0.006 mSv (in 2018). The small decrease was mostly attributed to a lower maximum carbon-14 concentration in milk. The dose to a high-rate consumer of fish and shellfish (including external radiation) was 0.007 mSv in 2019. The reason for the small decrease in dose from 0.008 mSv (in 2018) 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 2019 are given in Table 3.13(a). Sulphur-35 concentrations were detected at low concentrations (reported as close to, or just above, the less than value) in food (potatoes) and grass samples. The maximum carbon-14 concentration in locally produced milk decreased in 2019, in comparison to that in 2018, to a concentration just above the expected background concentration.

Liquid waste discharges and aquatic monitoring

In 2019, discharges of tritium decreased in comparison to those in 2018 as post-operational clean-out of the kegs used to store tritiated water from the gas drier system was completed in late 2018. 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 2019 are given in Tables 3.13(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 2019 were similar to those in recent years. The reported concentration of technetium-99 in seaweed in 2019 (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 3.2). Overall gamma dose rates in 2019 were generally lower than those in 2018, including the dose rate over sand at Cemaes Bay (the most significant dose contributor).

Table 3.1 Individual doses – nuclear power stations, 2019

Site	Representative person[a]	Exposure, mSv per year					
		Total	Fish and shellfish	Other local food	External radiation from intertidal areas or the shoreline[b]	Gaseous plume related pathways	Direct radiation from site
England							
Berkeley and Oldbury							
Total dose – all sources	**Prenatal children of local inhabitants (0–0.25 km)**	**<0.005**	**-**	**<0.005**	**-**	**<0.005**	**<0.005**
Source specific doses	Seafood consumers	<0.005	<0.005	-	<0.005	-	-
	Houseboat occupants	0.009	-	-	0.009	-	-
	Infant inhabitants and consumers of locally grown food	<0.005	-	<0.005	-	<0.005	-
Bradwell							
Total dose – all sources	**Adult occupants on houseboats**	**<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	<0.005	-	<0.005	-	<0.005	
Dungeness							
Total dose – all sources	**Local adult inhabitants (0.25–0.5 km)**	**0.037**	**<0.005**	**<0.005**	**<0.005**	**<0.005**	**0.037**
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	-
Hartlepool							
Total dose – all sources	**Local adult inhabitants (0–0.25 km)**	**0.013**	**<0.005**	**-**	**0.011**	**<0.005**	**<0.005**
Source specific doses	Seafood consumers[c]	0.015	<0.005	-	0.011	-	-
	Infant inhabitants and consumers of locally grown food	<0.005	-	<0.005	-	<0.005	-
Heysham							
Total dose – all sources	**Adult occupants over sediment**	**0.018**	**<0.005**	**<0.005**	**0.017**	**<0.005**	**<0.005**
Source specific doses	Seafood consumers	0.024	0.007	-	0.017	-	-
	Turf cutters	0.006	-	-	0.006	-	-
	Infant inhabitants and consumers of locally grown food	<0.005	-	<0.005	-	<0.005	-
Hinkley Point							
Total dose – all sources	**Adult occupants over sediment**	**0.021**	**<0.005**	**<0.005**	**0.021**	**-**	**-**
Source specific doses	Seafood consumers	0.014	<0.005	-	0.012	-	-
	Infant inhabitants and consumers of locally grown food	<0.005	-	<0.005	-	<0.005	-
Sizewell							
Total dose – all sources	**Local adult inhabitants (0–0.25 km)**	**0.010**	**<0.005**	**<0.005**	**<0.005**	**<0.005**	**0.009**
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 3.1 continued

Site	Representative person[a]	Exposure, mSv per year					
		Total	Fish and shellfish	Other local food	External radiation from intertidal areas or the shoreline[b]	Gaseous plume related pathways	Direct radiation from site
Scotland							
Chapelcross							
***Total dose* – all sources**	**Infant milk consumers**	**0.007**	**<0.005**	**0.007**	**<0.005**	**-**	**-**
Source specific doses	Fish, mollusc and wildfowl consumers	0.006	0.006	-	<0.005	-	-
	Crustacean consumers	<0.005	<0.005	-	-	-	-
	Infant inhabitants and consumers of locally grown food	0.006	-	0.006	-	<0.005	-
Hunterston							
***Total dose* – all sources**	**Prenatal children of local inhabitants (0.5–1 km)**	**<0.005**	**-**	**<0.005**	**<0.005**	**<0.005**	**<0.005**
Source specific doses	Seafood consumers	0.006	0.005	-	<0.005	-	-
	Infant inhabitants and consumers of locally grown food	0.007	-	0.006	-	<0.005	-
Torness							
***Total dose* – all sources**	**Prenatal children of local inhabitants (0.5–1 km)**	**<0.005**	**<0.005**	**<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	0.006	-	0.006	-	<0.005	-
Wales							
Trawsfynydd							
***Total dose* – all sources**	**Adult occupants over sediment**	**0.005**	**<0.005**	**-**	**<0.005**	**<0.005**	**-**
Source specific doses	Anglers	0.006	<0.005	-	<0.005	-	-
	Infant inhabitants and consumers of locally grown food	0.041	-	0.041	-	<0.005	-
Wylfa							
***Total dose* – all sources**	**Adult occupants over sediment**	**<0.005**	**<0.005**	**<0.005**	**<0.005**	**-**	**-**
Source specific doses	Seafood consumers	0.007	<0.005	-	<0.005	-	-
	Infant inhabitants and consumers of locally grown food	<0.005	-	<0.005	-	<0.005	-

[a] The total dose *is the dose which accounts for all sources including gaseous and liquid discharges and direct radiation. The* total dose *for the representative person with the highest dose is presented. Other dose values are presented for specific sources, either liquid discharges or gaseous discharges, and their associated pathways. They serve as a check on the validity of the* total dose *assessment. The representative person is an adult unless otherwise stated. Data are presented to 2 significant figures or 3 decimal places. Data below 0.005 mSv are reported as <0.005 mSv*

[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] *Excluding possible enhancement of naturally occurring radionuclides. See Section 3*

Table 3.2(a) Concentrations of radionuclides in food and the environment near Dungeness nuclear power stations, 2019

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		<0.04			0.11
Sole	Pipeline	1	<25	<25		<0.05			<0.05
Crabs	Pipeline	1	<25	<25		<0.04			<0.03
Scallop	Pipeline	1	<25	<25	25	<0.05	<0.027		<0.04
Sea kale	Dungeness Beach	1				<0.04			0.080
Seaweed	Folkestone Harbour	2[E]				<0.66		<1.0	<0.50
Sediment	Rye Harbour	3[E]				<0.48	<1.8		<0.38
Sediment	Camber Sands	2[E]				<0.29	<1.5		<0.23
Sediment	Pilot Sands	2[E]				<0.30	<1.6		<0.22
Seawater	Dungeness South	2[E]		<2.8		<0.28			<0.24

Material	Location	No. of sampling observ-ations	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}						
			^{238}Pu	$^{239}Pu + ^{240}Pu$	^{241}Am	^{242}Cm	$^{243}Cm + ^{244}Cm$	Gross alpha	Gross beta
Marine samples									
Whiting	Pipeline	1			<0.04				
Sole	Pipeline	1			<0.17				
Crabs	Pipeline	1			<0.11				
Scallop	Pipeline	1	0.00031	0.0015	0.00037	*	0.000022		
Sea kale	Dungeness Beach	1			<0.12				
Seaweed	Folkestone Harbour	2[E]			<0.53				
Sediment	Rye Harbour	3[E]	<0.54	<0.34	<0.68				530
Sediment	Camber Sands	2[E]			<0.45				
Sediment	Pilot Sands	2[E]			<0.39				
Seawater	Dungeness South	2[E]			<0.31			<3.6	16

Material	Location or selection[b]	No. of sampling observ-ations[c]	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}							
			^{3}H	^{14}C	^{35}S	^{60}Co	^{137}Cs	^{241}Am	Gross alpha	Gross beta
Terrestrial Samples										
Milk		2	<3.5	16	<0.22	<0.05	<0.04	<0.14		
Milk	max		<3.6	18	<0.26		<0.05	<0.16		
Potato		1	<2.1	21	<0.10	<0.05	<0.04	<0.14		
Wheat		1	<3.2	110	<0.20	<0.05	<0.04	<0.13		
Grass	Lydd	2[E]	<12	25		<1.6	<1.3			
Grass	Denge Marsh	2[E]	<11	24		<1.4	<1.1			
Freshwater	Long Pits	2[E]	<2.8		<0.16	<0.30	<0.23		<0.023	0.10
Freshwater	Pumping station Well number 1	1[E]	<3.1		<0.25	<0.42	<0.33		<0.018	0.12
Freshwater	Pumping station Well number 2	2[E]	<2.9		<0.21	<0.33	<0.27		<0.014	0.12
Freshwater	Reservoir	2[E]	<2.8		<0.18	<0.28	<0.23		<0.027	0.11

* *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 3.2(b) Monitoring of radiation dose rates near Dungeness nuclear power stations, 2019

Location	Ground type	No. of sampling observations	$\mu Gy\ h^{-1}$
Mean gamma dose rates at 1m over substrate			
Littlestone on Sea	Sand and shingle	2	0.056
Greatstone on Sea	Mud and sand	2	0.063
Pilot Sands	Sand and shingle	2	0.055
Dungeness West	Pebbles and shingle	1	0.054
Dungeness West	Sand and silt	1	0.056
Jury's Gap	Sand and silt	2	0.058
Rye Bay	Sand and silt	2	0.059

Table 3.3(a) Concentrations of radionuclides in food and the environment near Hartlepool nuclear power station, 2019

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	21	<0.04		<0.42	0.11	
Crabs	Pipeline	1	<25	<25	25	<0.05		<0.26	<0.10	
Winkles	South Gare	2	<25	<25	23	<0.05		<2.4	0.19	1.9
Seaweed	Pilot Station	2[E]				<0.73	4.5	19	<0.50	
Sediment	Old Town Basin	2[E]				<0.52			1.2	
Sediment	Seaton Carew	2[E]				<0.24			<0.20	
Sediment	Paddy's Hole	2[E]				<0.36			1.5	
Sediment	North Gare	2[E]				<0.32			<0.24	
Sediment	Greatham Creek	2[E]				<0.58			3.2	
Sediment	Redcar Sands	2[E]				<0.38			<0.28	
Sea coal	Old Town Basin	2[E]				<0.57			1.3	
Sea coal	Carr House Sands	2[E]				<0.54			1.8	
Seawater[b]	North Gare	2[E]		<2.7		<0.31			<0.25	

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				<0.13				
Crabs	Pipeline	1				<0.16				
Winkles	South Gare	2	14	0.0055	0.040	0.019	*	*		
Seaweed	Pilot Station	2[E]				<0.60				
Sediment	Old Town Basin	2[E]				<0.58				
Sediment	Seaton Carew	2[E]				<0.37				
Sediment	Paddy's Hole	2[E]				<0.76				
Sediment	North Gare	2[E]				<0.45				
Sediment	Greatham Creek	2[E]				<0.95				
Sediment	Redcar Sands	2[E]				<0.41				
Sea coal	Old Town Basin	2[E]				<0.71				
Sea coal	Carr House Sands	2[E]				<0.69				
Seawater[b]	North Gare	2[E]				<0.30			<4.6	16

Material	Location or selection[c]	No. of sampling observations[d]	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}						
			^{3}H	^{14}C	^{35}S	^{60}Co	^{137}Cs	Gross alpha	Gross beta
Terrestrial samples									
Milk		2	<3.3	17	<0.30	<0.04	<0.04		
Milk	max		<3.8	18	<0.35				
Potatoes		1	<2.0	14	<0.20	<0.05	<0.04		
Wheat		1	<3.3	110	<0.30	<0.06	<0.04		
Grass	0.8km NW of site	2[E]	<15	<16	<2.2	<1.3	<0.98		
Grass	0.6km NE of site	2[E]	<14	30	<4.5	<1.4	<1.1		
Freshwater	Boreholes, Dalton Piercy	2[E]	<2.6		<0.25	<0.28	<0.25	<0.064	0.12

* *Not detected by the method used*

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

[b] *The concentration of ^{35}S was <0.35 Bq l^{-1}*

[c] *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*

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

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

Table 3.3(b) Monitoring of radiation dose rates near Hartlepool nuclear power station, 2019

Location	Ground type	No. of sampling observations	$\mu Gy\ h^{-1}$
Mean gamma dose rates at 1m over substrate			
Fish Sands	Sand	2	0.068
Old Town Basin	Sand	2	0.073
Carr House	Sand	2	0.062
Seaton Carew	Sand	2	0.061
North Gare	Sand	2	0.062
Paddy's Hole	Pebbles and sand	1	0.18
Paddy's Hole	Pebbles and stones	1	0.18
Greatham Creek nature reserve	Mud	1	0.083
Greatham Creek nature reserve	Salt marsh	1	0.084
Redcar Sands	Sand	1	0.063

Table 3.4(a) Concentrations of radionuclides in food and the environment near Heysham nuclear power stations, 2019

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	^{238}Pu
Marine samples										
Flounder	Morecambe	2	<25	<25	47	<0.07	<0.048	0.46	2.9	0.00036
Shrimps	Morecambe	2	<25	<25	51	<0.05	<0.053	<0.21	1.7	0.0046
Winkles[b]	Middleton Sands	2	260	240	43	<0.07	0.22	9.5	2.4	0.43
Mussels[c]	Morecambe	2	110	140	63	<0.07	0.18	41	1.6	0.28
Wildfowl	Morecambe	1				<0.09			1.3	
Seaweed[d]	Half Moon Bay	2[E]				<0.57		130	1.7	
Sediment	Half Moon Bay	2[E]				<0.48			46	7.6
Sediment	Pott's Corner	2[E]				<0.46			13	
Sediment	Morecambe central beach	2[E]				<0.36			25	
Sediment	Red Nab Point	1[E]				<0.37			16	
Sediment	Shore adjacent to Northern Outfall	1[E]				<0.49			49	
Seawater[e]	Shore adjacent to Northern Outfall	2[E]		20		<0.27			<0.24	

Material	Location	No. of sampling observations	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}						
			^{239}Pu + ^{240}Pu	^{241}Pu	^{241}Am	^{242}Cm	^{243}Cm + ^{244}Cm	Gross alpha	Gross beta
Marine samples									
Flounder	Morecambe	2	0.0021		0.0039	*	*		
Shrimps	Morecambe	2	0.030		0.055	*	*		
Winkles[b]	Middleton Sands	2	2.6	11	5.2	0.0060	0.0044		120
Mussels[c]	Morecambe	2	1.7	7.4	2.7	*	*		120
Wildfowl	Morecambe	1			<0.27				
Seaweed[d]	Half Moon Bay	2[E]			1.0				
Sediment	Half Moon Bay	2[E]	43		80				
Sediment	Pott's Corner	2[E]			18				
Sediment	Morecambe central beach	2[E]			36				
Sediment	Red Nab Point	1[E]			13				
Sediment	Shore adjacent to Northern Outfall	1[E]			93				
Seawater[e]	Shore adjacent to Northern Outfall	2[E]			<0.30			<3.2	11

Table 3.4(a) continued

Material	Location or selection[f]	No. of sampling observations[g]	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}						
			^{3}H	^{14}C	^{35}S	^{60}Co	^{137}Cs	Gross alpha	Gross beta
Terrestrial samples									
Milk		2	<2.5	14	<0.30	<0.05	<0.06		
Milk	max		<2.6	15	<0.35		<0.07		
Potato		1	<2.6	17	<0.20	<0.05	<0.04		
Silage		1	<3.9	30	2.9	<0.08	<0.05		
Grass	Half Moon Bay, recreation ground	2[E]	<13	12	<22	<0.86	<0.65		
Grass	Overton	2[E]	<11	13	<18	<0.99	<0.73		
Freshwater	Damas Gill reservoir	2[E]	<2.9	<3.1	<0.21	<0.30	<0.24	0.036	0.049
Freshwater	Lower Halton Weir	2[E]	<2.9	<3.5	<0.21	<0.31	<0.27	0.024	0.065

* *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 12 Bq kg^{-1}*

[c] *The concentration of ^{210}Po was 34 Bq kg^{-1}*

[d] *The concentrations of ^{35}S and ^{129}I were 5.1 Bq kg^{-1} and <0.71 Bq kg^{-1}, respectively*

[e] *The concentrations of ^{35}S was <0.69 Bq kg^{-1}*

[f] *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*

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

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

Table 3.4(b) Monitoring of radiation dose rates near Heysham nuclear power stations, 2019

Location	Ground type	No. of sampling observations	μGy h^{-1}
Mean gamma dose rates at 1m over substrate			
Sand Gate Marsh	Salt marsh	2	0.076
Arnside 2	Salt marsh	2	0.081
Morecambe central beach	Sand	2	0.074
Half Moon Bay	Mud and sand	1	0.085
Half Moon Bay	Sand	1	0.084
Pipeline	Mud and sand	1	0.072
Red Nab Point	Sand	1	0.066
Middleton sands	Sand	2	0.081
Sunderland Point	Mud and sand	1	0.085
Sunderland Point	Sand	1	0.080
Colloway Marsh	Salt marsh	2	0.10
Lancaster	Grass	1	0.079
Aldcliffe Marsh	Salt marsh	2	0.087
Conder Green	Salt marsh	2	0.084

Table 3.5(a) Concentrations of radionuclides in food and the environment near Hinkley Point nuclear power stations, 2019

Material	Location	No. of sampling observations	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}						
			Organic ^{3}H	^{3}H	^{14}C	^{60}Co	^{90}Sr	^{99}Tc	^{137}Cs
Marine samples									
Cod	Stolford	1	<25	<25	27	<0.07			0.27
Shrimps	Stolford	1	25	36	24	<0.12			<0.11
Limpets	Stolford	1	<25	<25	19	<0.08			<0.12
European Oyster	Stolford	1	<25	<25	13	<0.06			<0.05
Seaweed	Pipeline	2[E]				<0.78		2.7	<0.56
Sediment	Pipeline	2[E]				<0.66	<0.89		10
Sediment	Stolford	2[E]				<1.1	<1.1		14
Sediment	Steart Flats	2[E]				<0.59	<1.1		8.2
Sediment	River Parrett	2[E]				<1.2	<0.83		16
Sediment	River Parrett Central 2	2[E]				<0.54	<1.4		8.3
Sediment	Weston-Super-Mare	2[E]				<0.48	<0.80		2.4
Sediment	Burnham-On-Sea	2[E]				<0.42	<0.88		0.84
Sediment	Kilve	2[E]				<0.44	<1.1		0.86
Sediment	Helwell Bay	2[E]				<0.66	<1.3		5.5
Sediment	Blue Anchor Bay	2[E]				<0.43	<0.94		1.5
Seawater	Pipeline	1[E]		24		<0.25	<0.03		<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									
Cod	Stolford	1			<0.19				
Shrimps	Stolford	1	0.00012	0.00053	0.00075	*	*		
Limpets	Stolford	1			<0.23				
European Oyster	Stolford	1			<0.24				
Seaweed	Pipeline	2[E]			<0.62				
Sediment	Pipeline	2[E]			<0.83				
Sediment	Stolford	2[E]			<1.4				
Sediment	Steart Flats	2[E]			<0.75				
Sediment	River Parrett	2[E]			<1.4				
Sediment	River Parrett Central 2	2[E]			<0.78				
Sediment	Weston-Super-Mare	2[E]			<0.55				
Sediment	Burnham-On-Sea	2[E]			<0.45				
Sediment	Kilve	2[E]			<0.56				
Sediment	Helwell Bay	2[E]			<0.77				
Sediment	Blue Anchor Bay	2[E]			<0.57				
Seawater	Pipeline	1[E]			<0.33			<4.2	11

Table 3.5(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	<2.5	15	<0.23	<0.04	<0.03	<0.14		
Milk	max		<2.6	16	<0.28	<0.05	<0.04	<0.16		
Blackberries		1	10	24	0.70	<0.05	<0.05	<0.10		
Honey		1	<3.8	69	<0.10	<0.03	<0.04	<0.76		
Wheat		1	<4.2	55	0.80	<0.05	<0.04	<0.06		
Grass	Gunter's Grove	2[E]	<10	22		<1.5	<1.0			
Grass	Wall Common	2[E]	<12	26		<1.3	<0.97			
Freshwater	Durleigh Reservoir	2[E]	<4.2		<0.15	<0.32	<0.26		<0.039	0.14
Freshwater	Ashford Reservoir	2[E]	<2.9		<0.17	<0.34	<0.28		<0.048	0.068

* *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 3.5(b) Monitoring of radiation dose rates near Hinkley Point nuclear power stations, 2019

Location	Ground type	No. of sampling observations	µGy h^{-1}
Mean gamma dose rates at 1m over substrate			
Weston-super-Mare	Mud and sand	2	0.064
Burnham-on-Sea	Sand	1	0.059
Burnham-on-Sea	Sand and silt	1	0.061
River Parrett	Mud	1	0.085
River Parrett	Mud and silt	1	0.078
River Parrett Bridgwater Central 2	Mud	2	0.077
Steart Flats	Mud	1	0.075
Steart Flats	Mud and silt	1	0.071
Stolford	Mud	1	0.084
Stolford	Mud and silt	1	0.086
Hinkley Point	Mud and rock	1	0.083
Hinkley Point	Rock and silt	1	0.087
Kilve	Mud and sand	1	0.092
Kilve	Rock and silt	1	0.092
Helwell Bay	Pebbles and sand	1	0.097
Helwell Bay	Rock and silt	1	0.094
Blue Anchor Bay	Mud and sand	1	0.073
Blue Anchor Bay	Mud and silt	1	0.079

Table 3.6(a) Concentrations of radionuclides in food and the environment near Hunterston nuclear power station, 2019

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
Marine samples								
Cod	Millport	2			<0.10	<0.10	<0.43	
Hake	Millport	2			<0.10	<0.10	<0.24	
Crabs	Millport	2			<0.10	<0.10	<0.25	0.31
Nephrops	Millport	2			<0.10	<0.10	<0.25	
Lobsters	Largs	1			<0.10	<0.10	<0.10	13
Squat lobsters	Largs	2			<0.10	<0.10	<0.16	<0.23
Winkles	Pipeline	2			<0.11	<0.10	<0.48	
Scallops	Largs	2			<0.10	<0.10	<0.27	
Oysters	Hunterston	1			<0.10	<0.10	<0.10	
Fucus vesiculosus	N of pipeline	1			<0.10	<0.10	<0.12	
Fucus ceranoides	N of pipeline	1			0.16	<0.10	<0.50	
Fucus vesiculosus	S of pipeline	2			<0.11	<0.11	<0.36	
Sediment	Largs	1			<0.10	<0.10	<0.29	
Sediment	Millport	1			<0.10	<0.10	<0.15	
Sediment	Gull's Walk	1			<0.10	0.15	<0.94	
Sediment	Ardneil Bay	1			<0.10	<0.10	<0.16	
Sediment	Fairlie	1			<0.10	<0.10	<0.22	
Sediment	Pipeline	1			<0.10	<0.10	<0.18	
Sediment	Ardrossan North Bay	1			<0.10	<0.10	<0.25	
Sediment	Ardrossan South Bay	1			<0.10	<0.10	<0.24	
Seawater	Pipeline	2	<1.0	<0.50	<0.10	<0.10	<0.10	

Material	Location	No. of sampling observations	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}					
			^{110m}Ag	^{137}Cs	^{155}Eu	^{238}Pu	^{239}Pu + ^{240}Pu	^{241}Am
Marine samples								
Cod	Millport	2	<0.12	0.31	0.17			<0.14
Hake	Millport	2	<0.10	0.52	<0.14			<0.10
Crabs	Millport	2	<0.10	<0.12	<0.20	0.004	0.015	0.014
Nephrops	Millport	2	<0.11	0.26	<0.18			<0.11
Lobsters	Largs	1	<0.10	0.23	<0.20			<0.14
Squat lobsters	Largs	2	<0.10	<0.10	<0.15	0.023	0.11	0.22
Winkles	Pipeline	2	0.44	<0.12	<0.19	0.024	0.10	0.16
Scallops	Largs	2	<0.11	0.23	<0.19	0.050	0.082	0.41
Oysters	Hunterston	1	<0.10	0.11	<0.10			<0.10
Fucus vesiculosus	N of pipeline	1	<0.10	0.39	<0.15			<0.11
Fucus ceranoides	N of pipeline	1	<0.12	0.68	<0.18			<0.16
Fucus vesiculosus	S of pipeline	2	<0.11	0.44	<0.16			<0.11
Sediment	Largs	1	<0.13	7.3	0.45			<0.24
Sediment	Millport	1	<0.10	2.7	0.57			<0.17
Sediment	Gull's Walk	1	<0.14	9.9	0.65			1.3
Sediment	Ardneil Bay	1	<0.10	1.6	<0.19			<0.20
Sediment	Fairlie	1	<0.10	4.5	<0.24			<0.24
Sediment	Pipeline	1	<0.11	3.0	<0.23			0.57
Sediment	Ardrossan North Bay	1	<0.10	2.7	<0.26			<0.27
Sediment	Ardrossan South Bay	1	<0.10	2.3	<0.24			0.75
Seawater	Pipeline	2	<0.10	<0.10	<0.14			<0.11

Table 3.6(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	<5.3	<15	<0.50	<0.10	<0.14	<0.05		<0.05		
Milk	max		<5.6									
Apples		1	<5.0	22	<0.50	<0.10	<0.18	<0.05		<0.10		
Beef		1	<5.0	32	<0.50	<0.10	<0.36	0.15		<0.11		
Beetroot		1	<5.0	<15	<0.50	<0.10	<0.34	<0.05		<0.07		
Broccoli		1	<5.0	<15	<0.50	0.12	<0.13	<0.05		<0.06		
Brussel Sprouts		1	<5.0	<15	<0.50	<0.10	<0.14	<0.05		<0.06		
Cabbage		1	<5.0	<15	<0.50	<0.10	<0.28	<0.05		<0.05		
Carrots		1	<5.0	<15	<0.50	0.15	<0.44	<0.05		<0.06		
Cauliflower		1	<5.0	<15	<0.50	<0.10	<0.10	<0.05		<0.05		
Eggs		1	<5.0	30	<0.50	<0.10	<0.42	<0.05		<0.06		
Leeks		1	<5.0	<15	<0.50	<0.10	<0.19	<0.05		<0.05		
Pork		1	5.5	46	<0.62	<0.10	<0.31	0.07		<0.10		
Potatoes		1	<5.0	<15	<0.50	<0.10	<0.46	<0.05		<0.05		
Rosehips		1	<5.0	26	<0.50	<0.10	<0.19	0.14		<0.11		
Turnips		1	<5.0	<15	<0.50	<0.10	<0.40	<0.05		<0.06		
Grass		3	<5.0	<15	1.1	<0.15	<0.10	<0.08	<0.08	<0.09	2.0	210
Grass	max			<16	1.3	<0.22	<0.12	0.10	<0.09		2.2	260
Grass[d]		3	<5.0	<15	1.1	<0.15	<0.10	<0.08	<0.08	<0.09	2.0	240
Grass	max			17	1.5	0.34	<0.16	0.10	<0.11	<0.12	3.2	280
Soil		3	<6.3	15	<2.0	0.78	<0.08	12	0.72	<0.16	170	1100
Soil	max		8.9		<2.8	0.85	<0.12	17	0.77	<0.19	180	1300
Freshwater	Knockenden Reservoir	1	<1.0				<0.01	<0.01		<0.01	<0.010	0.024
Freshwater	Loch Ascog	1	<1.0				<0.01	<0.01		<0.01	0.010	0.092
Freshwater	Munnoch Reservoir	1	<1.0				<0.02	<0.01		<0.01	<0.010	0.081
Freshwater	Camphill	1	<1.0				<0.01	<0.01		<0.01	<0.010	0.020
Freshwater	Outerwards	1	<1.0				<0.02	<0.01		<0.01	<0.010	0.024

[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 3.6(b) Monitoring of radiation dose rates near Hunterston nuclear power station, 2019

Location	Ground type	No. of sampling observations	µGy h⁻¹
Mean gamma dose rates at 1m over substrate			
Meigle Bay	Sand	1	0.054
Largs Bay	Sediment and stones	1	0.060
Largs Bay	Stones	1	0.054
Kilchatten Bay	Sand	1	0.047
Kilchatten Bay	Sediment	1	<0.047
Millport	Sand	1	<0.048
Gull's Walk	Sand	1	0.062
Gull's Walk	Sediment	1	0.054
Hunterston	Seaweed	1	0.060
Hunterston	Sediment	1	<0.047
0.5km north of pipeline	Sediment	1	0.048
0.5km north of pipeline	Sediment and stones	1	0.056
0.5km south of pipeline	Rocks	1	0.049
0.5km south of pipeline	Sediment and stones	1	0.066
Portencross	Grass	1	<0.047
Ardneil Bay	Sand	2	<0.053
Ardrossan North Bay	Sand	2	<0.047
Ardrossan South Bay	Sand	2	<0.047
Milstonford	Grass	1	<0.047
Biglies	Grass	1	<0.047
Beta dose rates			µSv h⁻¹
Millport	Sediment	2	<1.0
0.5km north of pipeline	Sediment and stones	1	<1.0
0.5km south of pipeline	Sediment	1	<1.0
0.5km south of pipeline	Sediment and stones	1	<1.0

Table 3.6(c) Radioactivity in air near Hunterston, 2019

Location	No. of sampling observations	Mean radioactivity concentration, mBq m⁻³			
		^{131}I	^{137}Cs	Gross alpha	Gross beta
Fairlie	12	<0.020	<0.010	<0.014	<0.22
West Kilbride	11	<0.020	<0.010	<0.020	<0.21
Low Ballees	2	<0.045	<0.010	0.020	<0.20

Table 3.7(a) Concentrations of radionuclides in food and the environment near Sizewell nuclear power stations, 2019

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			0.16	
Flounder	Sizewell	1	<25	<25			0.10	
Crabs	Sizewell	1	<25	<25			<0.04	
Mussels	River Alde	1	<25	<25	22		<0.04	0.00075
Sediment	Aldeburgh	2[E]				<1.6	<0.21	
Sediment	Southwold harbour	2[E]				<1.4	4.6	
Sediment	Minsmere river outfall	2[E]				<1.4	4.7	
Seawater	Sizewell beach	2[E]		<2.9	<3.1		<0.27	

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		<0.06				
Flounder	Sizewell	1		<0.12				
Crabs	Sizewell	1		<0.05				
Mussels	River Alde	1	0.0050	0.0038	0.000058	0.000057		
Sediment	Aldeburgh	2[E]		<0.33				
Sediment	Southwold harbour	2[E]		<1.4				830
Sediment	Minsmere river outfall	2[E]		<0.87				
Seawater	Sizewell beach	2[E]		<0.35			<3.0	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	<2.7	17	<0.21	<0.04		
Milk	max		<2.9	19	<0.25			
Potatoes		1	<5.3	21	<0.20	<0.04		
Barley		1	<8.4	42	1.6	<0.04		
Grass	Sizewell belts	2[E]	<13	<14		<0.93		
Grass	Sizewell common	2[E]	<14	26		<1.1		
Freshwater	Minsmere nature reserve	2[E]	<2.8		<0.16	<0.27	<0.025	0.21
Freshwater	The Meare	2[E]	<2.8		<0.17	<0.27	<0.042	0.36
Freshwater	Leisure Park	2[E]	<3.1		<0.16	<0.26	<0.050	0.40
Freshwater	Farm Reservoir	2[E]	<2.8		<0.16	<0.27	<0.032	0.16

[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 3.7(b) Monitoring of radiation dose rates near Sizewell, 2019

Location	Ground type	No. of sampling observations	$\mu Gy\ h^{-1}$
Mean gamma dose rates at 1m over substrate			
Sizewell Beach	Sand and shingle	2	0.049
Dunwich	Sand and shingle	2	0.048
Aldeburgh	Sand and shingle	2	0.056
Southwold Harbour	Mud and silt	2	0.065

Table 3.8(a) Concentrations of radionuclides in food and the environment near Torness nuclear power station, 2019

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	<0.14		<0.10	0.19
Mackerel	Pipeline	2	<0.10	<0.10	<0.14		<0.10	<0.14
Crabs	Torness	1	<0.10	<0.10	<0.11	<0.22	<0.10	<0.10
Lobsters	Torness	1	<0.10	<0.10	<0.10	2.2	<0.10	<0.10
Nephrops	Dunbar	2	<0.10	<0.10	<0.23		<0.11	<0.10
Winkles	Pipeline	2	<0.19	<0.13	<0.24		2.6	<0.10
Fucus vesiculosus	Pipeline	2	<0.27	0.39	<0.17		<0.11	<0.12
Fucus vesiculosus	Thorntonloch	2	<0.12	<0.40	<0.28	4.2	<0.21	<0.11
Fucus vesiculosus	White Sands	2	<0.10	<0.10	<0.20		<0.10	<0.16
Fucus serratus	Coldingham Bay	1	<0.10	<0.10	<0.23		<0.10	<0.10
Fucus vesiculosus	Coldingham Bay	1	<0.10	<0.10	<0.27		<0.11	<0.10
Fucus vesiculosus	Pease Bay	2	<0.10	<0.10	<0.20		<0.10	<0.10
Sediment	Dunbar	1	<0.10	<0.10	<0.31		<0.14	1.6
Sediment	Barns Ness	1	<0.10	<0.10	<0.15		<0.10	1.4
Sediment	Thorntonloch	1	<0.10	<0.10	<0.16		<0.10	0.61
Sediment	Heckies Hole	1	<0.10	<0.10	<0.10		<0.10	0.96
Sediment	Belhaven Bay	1	<0.10	<0.10	<0.22		<0.10	0.37
Sediment	Coldingham Bay	1	<0.10	<0.10	<0.10		<0.10	0.79
Sediment	Pease Bay	1	<0.10	<0.10	<0.10		<0.10	1.1
Seawater[b]	Pipeline	2	<0.10	<0.10	<0.10		<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	<0.12			<0.10		
Mackerel	Pipeline	2	<0.15			<0.16		
Crabs	Torness	1	<0.10			<0.10		
Lobsters	Torness	1	<0.10			<0.10		
Nephrops	Dunbar	2	<0.17	0.0017	0.0055	0.011		
Winkles	Pipeline	2	<0.19			<0.12	2.5	84
Fucus vesiculosus	Pipeline	2	<0.12			<0.10		
Fucus vesiculosus	Thorntonloch	2	<0.20			<0.14		
Fucus vesiculosus	White Sands	2	<0.15			<0.10		
Fucus serratus	Coldingham Bay	1	<0.23			<0.16		
Fucus vesiculosus	Coldingham Bay	1	<0.19			<0.14		
Fucus vesiculosus	Pease Bay	2	<0.14			<0.10		
Sediment	Dunbar	1	<0.32			<0.25		
Sediment	Barns Ness	1	1.1			<0.22		
Sediment	Thorntonloch	1	<0.15			<0.15		
Sediment	Heckies Hole	1	0.60			<0.19		
Sediment	Belhaven Bay	1	0.42			<0.20		
Sediment	Coldingham Bay	1	0.42			0.26		
Sediment	Pease Bay	1	0.54			<0.10		
Seawater[b]	Pipeline	2	<0.10			<0.10		

Table 3.8(a) continued

Material	Location or Selection[c]	No. of sampling observations[d]	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}					
			^{3}H	^{14}C	^{35}S	^{60}Co	^{90}Sr	^{95}Nb
Terrestrial Samples								
Milk		2	<5.0	<15	<0.50	<0.05	<0.10	<0.14
Milk	max							
Beetroot		1	<5.0	20	<0.50	<0.05	0.18	<0.33
Brussel sprouts		1	<5.0	<15	<0.50	<0.05	<0.10	<0.16
Carrots		1	<5.0	<15	<0.50	<0.05	0.17	<0.34
Eggs		1	<5.0	29	<0.50	<0.05	<0.10	<0.41
Honey		1	<5.0	140	1.2	<0.05	<0.10	<0.06
Lamb		1	<5.0	23	0.81	<0.05	<0.10	<0.27
Partridge		1	<5.0	40	<0.50	<0.05	<0.10	<0.42
Pheasant		1	<5.0	24	<0.50	<0.05	<0.10	<0.47
Pigeon		1	<5.0	24	2.2	<0.05	<0.10	<0.16
Potatoes		1	<5.0	20	<0.50	<0.05	<0.10	<0.30
Rabbit		1	<5.0	20	1.8	<0.08	<0.10	<0.34
Rosehips		1	<5.0	25	<0.50	<0.05	0.19	<0.24
Turnip		1	<5.0	<15	<0.50	<0.05	0.12	<0.30
Wild mushrooms		1	15	<15	0.50	<0.05	<0.10	<0.20
Grass		6	<5.0	27	<1.5	<0.05	<0.23	<0.41
Grass	max			33	3.6	<0.06	0.42	<0.55
Soil		3	<5.0	<15	<2.1	<0.05	0.99	<0.36
Soil	max			15	<3.6		1.8	<0.42
Freshwater	Hopes Reservoir	1	<1.0			<0.05		<0.05
Freshwater	Thorter's Reservoir	1	<1.0			<0.05		<0.05
Freshwater	Whiteadder	1	<1.0			<0.05		<0.05
Freshwater	Thornton Loch Burn	1	<1.0			<0.05		<0.05

Material	Location or Selection[c]	No. of sampling observations[d]	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					<0.06		
Beetroot		1	<0.05	0.06		<0.05		
Brussel sprouts		1	<0.06	<0.05		<0.08		
Carrots		1	<0.06	<0.05		<0.06		
Eggs		1	<0.07	<0.05		<0.08		
Honey		1	<0.05	3.6		<0.14		
Lamb		1	<0.05	<0.05		<0.11		
Partridge		1	<0.06	<0.05		<0.10		
Pheasant		1	<0.07	<0.05		<0.09		
Pigeon		1	<0.05	<0.05		<0.11		
Potatoes		1	<0.05	<0.05		<0.05		
Rabbit		1	<0.11	0.26		<0.09		
Rosehips		1	<0.05	<0.05		<0.11		
Turnip		1	<0.05	<0.05		<0.05		
Wild mushrooms		1	<0.05	0.08		<0.07		
Grass		6	<0.06	<0.05	<0.12	<0.12	4.0	350
Grass	max		<0.08	<0.06	<0.14	<0.14	8.9	450
Soil		3	<0.09	8.1	1.6	<0.21	190	1400
Soil	max		<0.10	16	1.7	<0.24	200	1500
Freshwater	Hopes Reservoir	1	<0.05	<0.05		<0.05	<0.010	0.026
Freshwater	Thorter's Reservoir	1	<0.05	<0.05		<0.05	<0.010	0.058
Freshwater	Whiteadder	1	<0.05	<0.05		<0.05	<0.010	0.038
Freshwater	Thornton Loch Burn	1	<0.05	<0.05		<0.05	0.011	0.081

[a] *Except for milk and seawater where units are Bq l^{-1} and for sediment and soil where dry concentrations apply*
[b] *The concentrations of ^{3}H and ^{35}S were <1.3 and <0.5 Bq l^{-1}, respectively*
[c] *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*
[d] *The number of farms from which milk is sampled. The number of analyses is greater than this and depends on the bulking regime*

Table 3.8(b) Monitoring of radiation dose rates near Torness nuclear power station, 2019

Location	Ground type	No. of sampling observations	µGy h⁻¹
Mean gamma dose rates at 1m over substrate			
Heckies Hole	Sediment	2	0.060
Dunbar Inner Harbour	Sediment	2	0.081
Belhaven Bay	Sediment	2	0.063
Barns Ness	Sediment	2	0.051
Skateraw	Sediment	2	<0.047
Thorntonloch	Grass	1	0.068
Thorntonloch beach	Sand	1	0.059
Thorntonloch beach	Sediment	1	0.053
Ferneylea	Grass	1	0.084
Pease Bay	Sand	1	0.053
Pease Bay	Sediment	1	0.055
St Abbs Head	Sand	1	0.092
St Abbs Head	Sediment	1	0.083
Coldingham Bay	Sand	1	0.054
Coldingham Bay	Sediment	1	<0.047
West Meikle Pinkerton	Grass	1	0.062
Mean beta dose rates on fishing gear			µSv h⁻¹
Torness	Lobster Pots	2	<1.0

Table 3.8(c) Radioactivity in air near Torness, 2019

Location	No. of sampling observations	Mean radioactivity concentration, mBq m⁻³				
		^{60}Co	^{131}I	^{137}Cs	Gross alpha	Gross beta
Innerwick	11	<0.002	<0.060	<0.010	0.020	<0.23
Cockburnspath	12	<0.003	<0.030	<0.010	<0.021	<0.22
West Barns	11	<0.003	<0.030	<0.010	0.029	<0.24

Table 3.9(a) Concentrations of radionuclides in food and the environment near Berkeley and Oldbury nuclear power stations, 2019

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								
Elvers	River Severn	1				<0.06		
Mullet	Guscar	1	<25			0.18		
Shrimps	Guscar	2	<25	24		0.26	0.00018	0.0017
Seaweed	2km south west of Berkeley	2[E]			<0.68	<0.52		
Sediment	0.5km south of Oldbury	2[E]				17		
Sediment	2km south west of Berkeley	2[E]				17		
Sediment	Sharpness	2[E]				14		
Sediment	Ledges	2[E]				13		
Seawater	2km south west of Berkeley	2[E]	<2.7			<0.21		

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							
Elvers	River Severn	1	<0.05				
Mullet	Guscar	1	<0.22				
Shrimps	Guscar	2	0.0018	*	*		
Seaweed	2km south west of Berkeley	2[E]	<0.63				
Sediment	0.5km south of Oldbury	2[E]	<1.9				
Sediment	2km south west of Berkeley	2[E]	<1.3				
Sediment	Sharpness	2[E]	<0.84				
Sediment	Ledges	2[E]	<0.81				
Seawater	2km south west of Berkeley	2[E]	<0.32			<1.9	7.0

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	<2.5	15	<0.26	<0.03		
Milk	max		<2.7	17	<0.33	<0.04		
Carrot		1	<2.1	13	0.30	<0.04		
Barley		1	<3.5	35	0.70	<0.07		
Freshwater	Gloucester and Sharpness Canal	2[E]	<2.8		<0.26	<0.21	<0.052	0.14

* *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 3.9(b) Monitoring of radiation dose rates near Berkeley and Oldbury nuclear power stations, 2019

Location	Ground type	No. of sampling observations	$\mu Gy\ h^{-1}$
Mean gamma dose rates at 1m over substrate			
0.5km south of Oldbury	Mud and salt marsh	1	0.081
0.5km south of Oldbury	Salt marsh and mud	1	0.070
2km south west of Berkeley	Mud and salt marsh	1	0.073
2km south west of Berkeley	Salt marsh and mud	1	0.076
Guscar Rocks	Mud	2	0.080
Lydney Rocks	Mud	2	0.091
Sharpness	Mud and salt marsh	1	0.076
Sharpness	Salt marsh and mud	1	0.070
Ledges	Mud and salt marsh	1	0.082
Ledges	Salt marsh and mud	1	0.069

Table 3.10(a) Concentrations of radionuclides in food and the environment near Bradwell nuclear power station, 2019

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			0.19		
Crabs	West Mersea	1			<0.04		
Native oysters	Blackwater Estuary	1			<0.11	0.00036	0.0022
Samphire	Tollesbury	1		<0.10	<0.05		
Seaweed	Waterside	2[E]		<1.4	<0.45		
Seaweed	West Mersea	1[E]		<0.47	<1.1		
Sediment	Bradwell Pipeline	2[E]			2.3		
Sediment	Waterside	2[E]			3.4		
Sediment	N side Blackwater Estuary	2[E]			4.8		
Sediment	Maldon Harbour	2[E]			9.6		
Sediment	West Mersea Beach Huts	2[E]			1.6		
Sediment	West Mersea Boatyard	2[E]			1.9		
Seawater	Bradwell Pipeline	2[E]	<2.8		<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							
Skate	Pipeline	1	<0.14				
Crabs	West Mersea	1	<0.14				
Native oysters	Blackwater Estuary	1	0.0013	0.000093	0.000018		
Samphire	Tollesbury	1	<0.15				
Seaweed	Waterside	2[E]	<0.51				
Seaweed	West Mersea	1[E]	<1.1				
Sediment	Bradwell Pipeline	2[E]	<0.60				
Sediment	Waterside	2[E]	<0.69				
Sediment	N side Blackwater Estuary	2[E]	<1.3				
Sediment	Maldon Harbour	2[E]	<1.3				
Sediment	West Mersea Beach Huts	2[E]	<0.61				
Sediment	West Mersea Boatyard	2[E]	<0.55				
Seawater	Bradwell Pipeline	2[E]	<0.33			<3.3	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			2	<3.4	16		<0.03	<0.18		
Milk		max		<4.6			<0.04	<0.25		
Cabbage			1	<2.2	12		<0.13	<0.58		
Grass			1	<2.4	18		<0.05	<0.19		
Freshwater	Coastal ditch, between power station and shore		1[E]	<3.2		<0.047	<0.34		0.97	5.7
Freshwater	Coastal ditch, east face of sector building		1[E]	<3.4			<0.21		0.38	3.6
Freshwater	Coastal ditch, east face of turbine hall		1[E]	<3.3		0.61	<0.20		<0.42	5.0
Freshwater	Coastal ditch, drain pit overflow		1[E]	<3.7			<0.21		<0.32	7.0

* *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 3.10(b) Monitoring of radiation dose rates near Bradwell, 2019

Location	Ground type	No. of sampling observations	μGy h^{-1}
Mean gamma dose rates at 1m over substrate			
Bradwell Beach	Mud and sand	1	0.061
Bradwell Beach	Sand and shells	1	0.057
Bradwell Beach opposite power station N side of estuary	Mud and salt marsh	2	0.069
Waterside	Mud and salt marsh	1	0.061
Waterside	Mud and silt	1	0.056
Maldon Harbour	Mud and salt marsh	2	0.062
West Mersea Beach Huts	Mud and silt	2	0.065
SE of West Mersea boatyard	Mud and shells	2	0.056

Table 3.11(a) Concentrations of radionuclides in food and the environment near Chapelcross nuclear power station, 2019

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	1		<15	<0.10	<0.10	<0.27	<0.19	<0.80	<0.12	<0.24
Shrimps	Inner Solway	2	<5.0		<0.10	<0.10	<0.18	<0.18	<0.46	<0.10	<0.14
Mussels	North Solway	2	<5.0		<0.10		<0.41		<0.89	<0.14	<0.26
Fucus vesiculosus	Pipeline	4			<0.10		<0.25	45	<0.60	<0.13	<0.18
Fucus vesiculosus	Browhouses	2			<0.10		<0.19	31	<0.53	<0.10	<0.17
Fucus vesiculosus	Dornoch Brow	2			<0.10		<0.24		<0.55	<0.12	<0.17
Sediment	Priestside Bank	1			<0.10		<0.24		<0.67	<0.13	<0.23
Sediment	Pipeline	4	<5.0		0.27		<0.41		<1.3	<0.17	<0.36
Sediment	Dornoch Brow	1			0.13		<0.65		<0.93	<0.17	<0.31
Sediment	Powfoot	1			<0.10		<0.26		<0.67	<0.12	<0.22
Sediment	Redkirk	1			<0.10		<0.20		<0.80	<0.14	<0.28
Sediment	Stormont	1			<0.10		<0.27		<0.74	<0.13	<0.26
Seawater	Pipeline	2	2.0		<0.10		<0.14		<0.55	<0.10	<0.16

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	1	0.21	<0.13	<0.19	0.0048	0.015	0.027	<0.48	
Shrimps	Inner Solway	2	<0.10	<0.10	<0.11	<0.0040	0.0038	0.0066	<0.32	
Mussels	North Solway	2	1.2	<0.12	<0.21	0.39	2.4	7.0		
Fucus vesiculosus	Pipeline	4	4.3	<0.11	<0.23	0.37	1.9	2.4	6.1	340
Fucus vesiculosus	Browhouses	2	7.4	<0.10	<0.35	0.58	3.8	6.9	16	420
Fucus vesiculosus	Dornoch Brow	2	6.7	<0.10	<0.18	0.50	3.0	5.2	6.0	320
Sediment	Priestside Bank	1	27	<0.16	1.2	2.5	15	31		
Sediment	Pipeline	4	110	<0.35	1.3	16	96	190		
Sediment	Dornoch Brow	1	58	<0.20	1.4	8.4	55	100		
Sediment	Powfoot	1	24	<0.20	1.0	2.5	18	24		
Sediment	Redkirk	1	39	<0.20	<0.39	3.8	21	38		
Sediment	Stormont	1	41	<0.19	<0.37	5.1	30	60		
Seawater	Pipeline	2	<0.10	<0.10	<0.13			<0.10		

Table 3.11(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	<5.2	<15	<0.50	<0.10	<0.12	<0.25	<0.05		<0.05		
Milk	max		<6.6				<0.16	<0.28					
Apples		2	<5.0	<15	<0.50	<0.10	<0.20	<0.31	<0.05		<0.06		
	max						<0.34	<0.47					
Beef		1	7.5	28	<0.50	<0.10	<0.28	<0.34	<0.05		<0.12		
Beetroot		1	<5.0	<15	<0.50	<0.10	<0.33	<0.46	<0.05		<0.07		
Broccoli		1	<5.0	15	<0.50	<0.10	<0.17	<0.32	<0.05		<0.05		
Cabbage		1	7.3	<15	<0.50	<0.10	<0.37	<0.41	<0.05		<0.05		
Carrots		1	<5.0	<15	<0.50	<0.10	<0.26	<0.37	<0.05		<0.05		
Duck		1	<5.0	<15	<0.50	<0.10	<0.19	<0.41	2.8		<0.14		
Eggs		1	<5.0	28	<0.50	<0.10	<0.44	<0.53	<0.05		<0.06		
Goose		1	<5.0	26	<0.50	<0.10	<0.22	<0.42	<0.05		<0.15		
Pork		1	<5.0	39	<0.50	<0.10	<0.36	<0.39	<0.05		<0.13		
Potatoes		1	<5.0	<15	<0.50	<0.10	<0.32	<0.40	<0.05		<0.05		
Rosehips		1	6.7	23	<0.50	0.39	<0.28	<0.34	<0.05		<0.11		
Turnip		1	<5.0	<15	<0.50	0.11	<0.33	<0.37	<0.05		<0.05		
Grass		4	<6.7	<16	<0.84	0.24	<0.13	<0.33	<0.11	<0.12	<0.13	2.4	320
Grass	max		12	20	1.2	0.32	<0.15	<0.39	0.23	<0.17	<0.19	4.5	570
Soil		4	<5.1	<15	<2.2	1.1	<0.23	<0.42	7.9	1.6	<0.41	200	1500
Soil	max		<5.2	15	<3.7	1.4	<0.27	<0.44	9.9	1.7	<0.78	240	1800
Freshwater	Purdomstone	1	<1.0				<0.05	<0.06	<0.05		<0.05	<0.010	0.056
Freshwater	Winterhope	1	<1.0				<0.05	<0.06	<0.05		<0.05	<0.010	0.033
Freshwater	Black Esk	1	<1.0				<0.01	<0.04	<0.01		<0.01	0.011	0.017
Freshwater	Gullielands Burn	1	8.2				<0.05	<0.05	<0.05		<0.05	<0.010	0.088

[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 3.11(b) Monitoring of radiation dose rates near Chapelcross, 2019

Location	Material or ground type	No. of sampling observations	μGy h^{-1}
Mean gamma dose rates at 1m over substrate			
Glencaple Harbour	Sediment	2	0.064
Priestside Bank	Sediment	2	0.063
Powfoot Merse	Sediment	2	0.061
Gullielands	Grass	1	0.059
Seafield	Sediment	2	0.061
Woodhead	Grass	1	0.064
East Bretton	Grass	1	0.054
Pipeline	Salt marsh	2	0.065
Pipeline	Sediment	2	0.079
Dumbretton	Grass	1	0.055
Battlehill	Sediment	2	0.062
Dornoch Brow	Sand	1	0.070
Dornoch Brow	Sediment	1	0.071
Dornoch Brow Merse	Salt marsh	1	0.072
Dornoch Brow Merse	Sediment	1	0.063
Browhouses	Sand	1	0.069
Browhouses	Sediment	1	0.065
Redkirk	Salt marsh	1	0.064
Redkirk	Sediment	1	0.060
Stormont	Sediment	2	0.064
Mean beta dose rates			μSv h^{-1}
Pipeline	Fishing nets	3	<1.0
500m East of pipeline	Sediment	1	<1.0
500m West of pipeline	Sediment	1	<1.0

Table 3.11(c) Radioactivity in air near Chapelcross, 2019

Location	No. of sampling observations	Mean radioactivity concentration, mBq m^{-3}			
		^{131}I	^{137}Cs	Gross alpha	Gross beta
Eastriggs	12	<0.018	<0.010	<0.016	<0.21
Kirtlebridge	11	<0.022	<0.010	<0.017	<0.20
Brydekirk	8	<0.033	<0.010	0.017	<0.20

Table 3.12(a) Concentrations of radionuclides in food and the environment near Trawsfynydd nuclear power station, 2019

Material	Location	No. of sampling observations	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}						
			^{3}H	^{14}C	^{60}Co	^{90}Sr	^{137}Cs	^{154}Eu	^{238}Pu
Freshwater samples									
Rainbow trout	Trawsfynydd Lake	2		32	<0.06	0.16	0.57	<0.19	<0.000015
Sediment	Lake shore near café	1[E]			<0.61	<1.5	130		<0.48
Sediment	SE of footbridge	1[E]			<0.65	<2.1	58		<0.46
Sediment	Cae Adda	2[E]			<0.59	<1.4	51		<0.45
Freshwater	Pipeline	2[E]	<2.6		<0.25		<0.20		
Freshwater	Gwylan Stream	2[E]	<2.7		<0.24		<0.20		
Freshwater	Afon Prysor	2[E]	<2.6		<0.25		<0.20		
Freshwater	1.5km SE of power station	2[E]	<2.6		<0.12		<0.11		
Freshwater	Afon Tafarn-helyg	2[E]	<2.5		<0.20		<0.17		

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
Freshwater samples								
Rainbow trout	Trawsfynydd Lake	2	0.000012	0.000054	*	0.000020		
Sediment	Lake shore near café	1[E]	0.46	<0.73				
Sediment	SE of footbridge	1[E]	<0.33	<0.70				
Sediment	Cae Adda	2[E]	<0.69	<0.59				
Freshwater	Pipeline	2[E]					<0.026	0.028
Freshwater	Gwylan Stream	2[E]					<0.026	0.059
Freshwater	Afon Prysor	2[E]					<0.026	0.034
Freshwater	1.5km SE of power station	2[E]					<0.028	<0.031
Freshwater	Afon Tafarn-helyg	2[E]					<0.026	0.031

Material	Selection[b]	No. of sampling observations[c]	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	<2.6	17	0.042	<0.08	<0.075			<0.30
Milk	max		<3.0	18	0.066	0.10	0.10			<0.31
Potatoes		1	<2.8	18		<0.05		0.000060	0.00043	0.00019
Grass		1	<4.1	27		2.5		0.00086	0.034	0.0040

* *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 3.12(b) Monitoring of radiation dose rates near Trawsfynydd nuclear power station, 2019

Location	Ground type	No. of sampling observations	μGy h^{-1}
Mean gamma dose rates at 1m over substrate			
Lake shore (pipeline)	Moss and stones	1	0.092
Lake shore (SE of footbridge)	Grass	1	0.083
Lake shore (SE of footbridge)	Grass and stones	1	0.091
Lake shore (1.5km SE)	Grass	1	0.085
Lake shore (1.5km SE)	Grass and herbage	1	0.084
Cae Adda	Grass	1	0.077
Cae Adda	Pebbles and stones	1	0.081
Lake shore	Concrete	2	0.088

Table 3.13(a) Concentrations of radionuclides in food and the environment near Wylfa nuclear power station, 2019

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									
Dab	Pipeline	1	<25	<25	29		0.89		
Crabs	Pipeline	1	<25	<25	33		0.13		
Lobsters	Pipeline	1	<25	<25	48	23	0.39	0.0051	0.030
Winkles	Cemaes Bay	1	<25	<25	25	14	0.23	0.018	0.11
Seaweed	Cemaes Bay	2^{E}				24	<0.52		
Sediment	Cemaes Bay	2^{E}					3.1		
Sediment	Cemlyn Bay West	2^{E}					2.0		
Seawater	Cemaes Bay	2^{E}		<2.6			<0.18		

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								
Dab	Pipeline	1		<0.11				
Crabs	Pipeline	1		<0.06				
Lobsters	Pipeline	1	0.40	0.11	*	*		130
Winkles	Cemaes Bay	1	0.50	0.15	*	*		130
Seaweed	Cemaes Bay	2^{E}		<0.57				
Sediment	Cemaes Bay	2^{E}		1.2				
Sediment	Cemlyn Bay West	2^{E}		<0.43				
Seawater	Cemaes Bay	2^{E}		<0.27			<1.6	8.3

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	<3.5	17	<0.44	<0.03	<0.11
Milk	max		<3.6	18	<0.48	<0.04	<0.14
Potatoes		1	<2.4	25	<0.20	<0.06	<0.16
Grass		1	<2.8	65	2.4	<0.07	<0.18
Grass	Foel Fawr	2^{E}	<11	14		<1.0	
Grass	Wylfa Head Nature Reserve	2^{E}	<14	26		<0.82	

* *Not detected by the method used*

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

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

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

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

Table 3.13(b) Monitoring of radiation dose rates near Wylfa nuclear power station, 2019

Location	Ground type	No. of sampling observations	μGy h^{-1}
Mean gamma dose rates at 1m over substrate			
Cemaes Bay	Pebbles and sand	1	0.066
Cemaes Bay	Sand	1	0.066
Cemlyn Bay West	Sand and shingle	1	0.065
Cemlyn Bay West	Shingle	1	0.065
Porth Yr Ogof	Sand and shingle	1	0.074
Porth Yr Ogof	Shingle	1	0.066

4. Research and radiochemical production establishments

This section considers the results of monitoring near research establishments (Dounreay, Harwell, Winfrith and two minor research sites) and two sites associated with the radiopharmaceutical industry (Grove Centre and Maynard Centre). The two minor research sites considered in this section are the Imperial College Reactor Centre and the site at Culham which is not a nuclear licensed site.

The NDA owns the licensed nuclear sites at Harwell and Winfrith in England, and Dounreay in Scotland. Dounreay Site Restoration Limited (DSRL) is the site licensed company for Dounreay, responsible for the decommissioning and clean-up of the Dounreay site and is a wholly-owned subsidiary of the Cavendish Dounreay Partnership. The Harwell and Winfrith sites, previously operated by RSRL, were re-licensed in 2015 into a single site licensed company and merged to be part of Magnox Limited.

All the nuclear research 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.

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 NRW to the Amersham and Cardiff sites, respectively, allowing the discharge of radioactive wastes in 2019.

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. Independent monitoring of the environment around the sites is conducted by the Environment Agency, FSA and SEPA. The Environment Agency has an agreement with NRW to carry out monitoring on its behalf in Wales.

In 2019, gaseous and liquid discharges were below regulated limits for each of the establishments (see Appendix 2, Tables A2.1 and A2.2). Solid waste transfers in 2019 from nuclear establishments in Scotland (Dounreay) are also given in Appendix 2 (Table A2.4).

Key points

- *Total doses* (Research) for the representative person were less than 3 per cent of the annual dose limit in 2019 (for sites that were assessed)
- *Total doses* (Radiochemical production) for the representative person were less than 14 per cent of the annual dose limit in 2019

Dounreay, Highland

- *Total dose* for the representative person was 0.010 mSv and decreased in 2019

GE Healthcare Limited, Grove Centre, Amersham, Buckinghamshire

- *Total dose* for the representative person was 0.14 mSv and unchanged in 2019
- Gaseous discharges of radon-222 decreased in 2019

Harwell, Oxfordshire

- *Total dose* for the representative person was 0.010 mSv and decreased in 2019

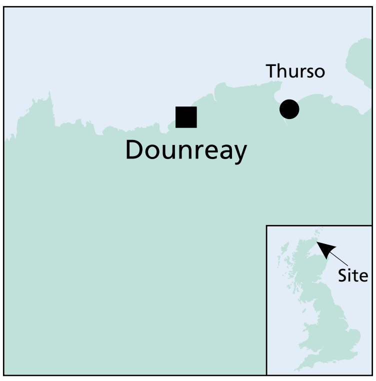
Maynard Centre, Cardiff

- *Total dose* for the representative person was less than 0.005 mSv and unchanged in 2019
- Gaseous discharges of tritium and carbon-14 decreased in 2019

Winfrith, Dorset

- *Total dose* for the representative person was 0.027 mSv and unchanged in 2019

4.1 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 the site will achieve an interim end state, being the point at which decommissioning is complete, by 2033 (NDA, 2020).

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 Parent Body Organisation (PBO) for Dounreay. However, DSRL remains the responsible body for the purpose of the nuclear site licence and the environmental permits.

SEPA granted an authorisation in 2013 to DSRL for the Low Level Radioactive Waste disposal facility that is located adjacent to the main Dounreay site. The first phase of the disposal site comprised the construction and operation of two concrete vaults that began accepting low level radioactive waste and demolition low level waste from the Dounreay site in 2015. The safety case and planning permission allow for two additional construction phases, each comprising two vaults, with phase two construction currently planned to commence in 2022.

There are no authorised routes for liquid or gaseous discharges from the Dounreay LLWF. The facility is designed to contain the radioactive waste over a long time, allowing radioactive decay to occur while the waste remains isolated from the environment.

In February 2019, a contamination incident occurred within a facility in the Fuel Cycle Area (FCA). The cause of the incident was a valve operational failure during the testing of a ventilation system. This resulted in disturbance of radioactively contaminated dust within the ventilation system and subsequent discharge into the facility and through a gaseous discharge stack to atmosphere. The increased discharge of radioactivity to the environment as a result of the contamination incident was calculated to be less than one per cent of the relevant authorised gaseous discharge limit and there was no breach of discharge limits. Although the environmental impact of the discharge is considered to be very low, SEPA's investigation into the incident concluded that DSRL contravened multiple conditions of its authorisation under EASR 18. SEPA issued a Regulatory Notice to DSRL that outlines the steps DSRL is required to take to address the identified contraventions.

In September 2019, SEPA undertook a compliance inspection of DSRL's implementation of standards and codes of practice, which form part of the site's management system. The inspection identified a number of of shortcomings in the implementation of site standards relating to the inspection, maintenance and use of equipment which are relied upon for environmental compliance. The inspection also identified that DSRL contravened multiple conditions of its authorisation under EASR 18. SEPA issued a Regulatory Notice to DSRL that outlines the steps DSRL is required to take to address the identified contraventions.

In 2019, radioactive waste discharges from Dounreay were made by DSRL under an EASR radioactive substances authorisation granted by SEPA. The quantities of both gaseous and liquid discharges were generally similar to those releases in 2018 (Appendix 2, Tables A2.1 and A2.2). Solid waste transfers from Dounreay in 2019 are also given in Appendix 2 (Table A2.4).

The most recent habits survey was conducted in 2018 (SEPA, *in press*/c). This habits survey did not identify Geo occupants, who visit Oigin's Geo, as an external exposure pathway.

Doses to the public

The *total dose* from all pathways and sources of radiation was 0.010 mSv in 2019 (Table 4.1), or 1 per cent of the dose limit, and down from 0.035 mSv in 2018. In 2019, the representative person was adults consuming wild mushrooms at high-rates, and a change from that in 2018 (adults consuming game meat). The decrease in *total dose* was mostly due to a lower concentration of caesium-137 concentration in game (venison) in 2019, in comparison to that in 2018. This activity is most likely from historical releases.

The trend in the annual *total dose* over the period 2008 – 2019 is given in Figure 4.1. 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 and 2018 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).

A source specific assessment for external pathways for fishermen give exposures that were less than the *total dose* in 2019 (Table 4.1). The annual dose to a consumer of terrestrial foodstuffs was 0.020 mSv in 2019, or 2 per cent of the dose limit for members of the public of 1 mSv, and similar to that in 2018 (0.019 mSv). As in previous years, adults were identified as the most exposed age group. The annual dose to a consumer of fish and shellfish, including external exposure from occupancy over local beaches, was 0.006 mSv. The dose (external pathways only) to members of the public visiting Oigin's Geo, based on previously

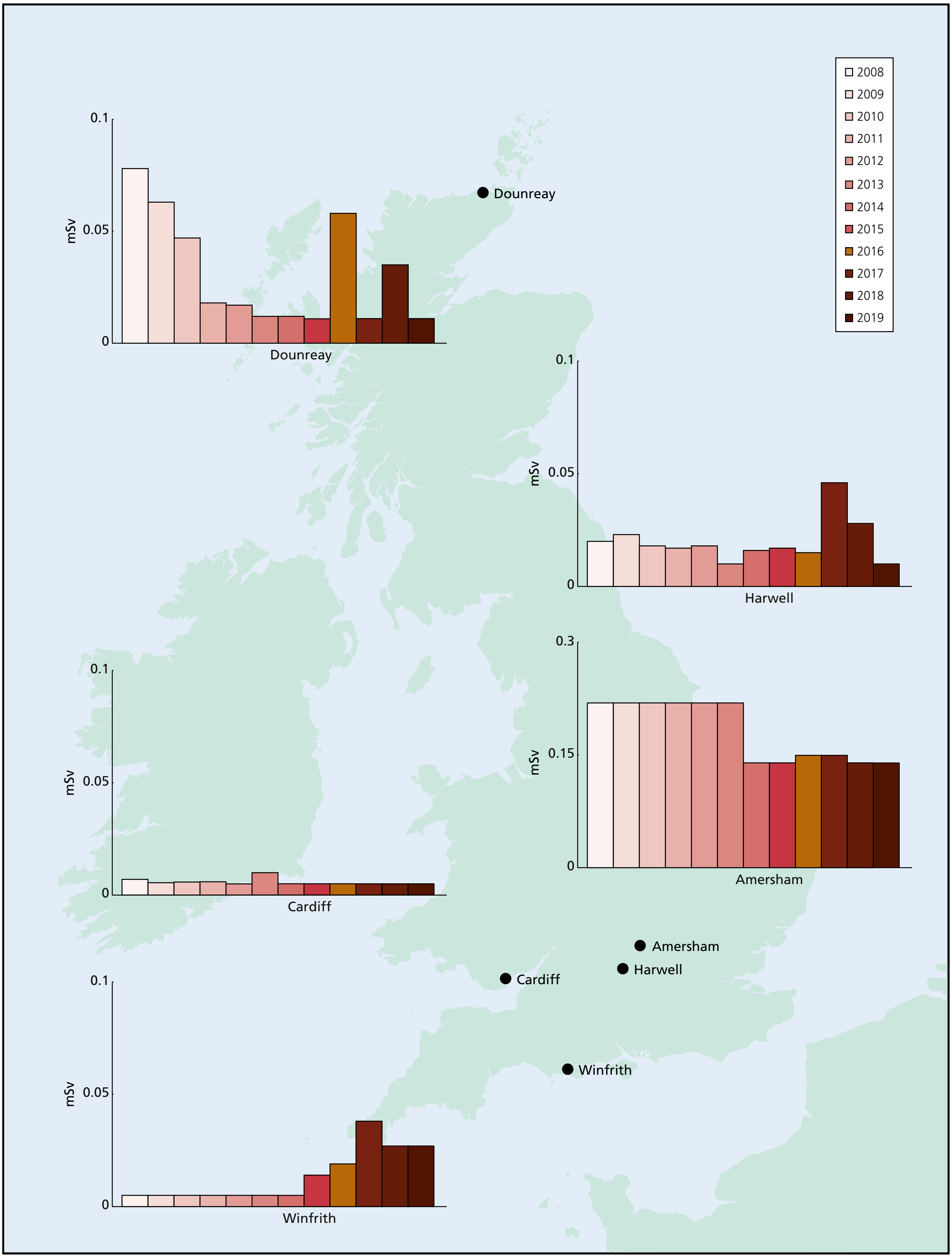


Figure 4.1. *Total dose* at research and radiochemical production establishments, 2008–2019
(Small doses less than or equal to 0.005 mSv are recorded as being 0.005 mSv). Note different scale for Amersham

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. Monitoring conducted in 2019 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 2019.

The sampling locations for the terrestrial (and marine) monitoring programmes are shown in Figure 4.2 (Dounreay) and Figure 4.3 (north of Scotland). Figure 4.3 also provides time trends of radionuclide discharges (gaseous and liquid). The results for terrestrial samples and radioactivity in air are given in Tables 4.2(a) and (c). Table 4.2(a) also contains results of additional freshwater sampling undertaken in response to increased concentrations in Loch Baligill in 2018 (discussed in Section 7.7).

The concentrations of radionuclides at Dounreay were generally low and similar to those in previous years. In 2019, low concentrations of strontium-90, caesium-137, plutonium-239+240 and americium-241 are reported in a few food samples (close to the less than values). The concentration of plutonium-239+240 in a leek sample was slightly higher in 2019, in comparison to that in recent years. Tritium and antimony-125 and iodine-129 concentrations are all reported as less than values in 2019. Activity concentrations in air samples at locations near to the site (Table 4.2(c)) are reported as less than values (or close to the less than value).

Monitoring for caesium-137 in a venison sample was continued in 2019 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 7.8 Bq kg^{-1} and less elevated than those enhanced concentrations measured in other game in previous years (venison: 42 Bq kg–1, 160 Bq kg^{-1} and 69 Bq kg^{-1} in 2018, 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. The caesium-137 concentration in a honey sample (23 Bq kg^{-1}) was also positively detected again in 2019 (sample not collected in 2018), but lower than the maximum concentration in 2016 (38 Bq kg^{-1}). Earlier RIFE reports have provided results and interpretation of honey monitoring (e.g. Environment Agency, FSA, FSS, NIEA, NRW and SEPA, 2018).

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).

Routine marine monitoring included sampling of seafood and 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 the FSS (then FSA in Scotland).

Crabs were collected together with mussels and winkles from areas along the Caithness 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 4.2(a) and (b). Activity concentrations were generally low in 2019 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 4.3 also gives time trend information for technetium-99 concentrations (from Sellafield) in seaweed at Sandside Bay (location shown in Figure 4.2), Kinlochbervie and Burwick. Data indicate a general decline in concentrations over the period at all three locations. Overall, gamma dose rates were similar in 2019, in comparison to those in 2018. Beta dose rate measurements are reported as less than values (Table 4.2(b)) in 2019.

During 2019, DSRL continued vehicle-based monitoring of local public beaches for radioactive fragments in compliance with the requirements of the authorisation granted by SEPA. In 2019, six fragments were recovered from Sandside Bay and four from the Dounreay foreshore. The caesium-137 activity measured in the fragments recovered from Sandside Bay ranged between 7.8 kBq and 48 kBq (similar to ranges observed in recent years).

In December 2016, one fragment was detected and recovered from the Dounreay foreshore due to the

* *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 collection of seafoods within a 2 km radius of the discharge pipeline.*

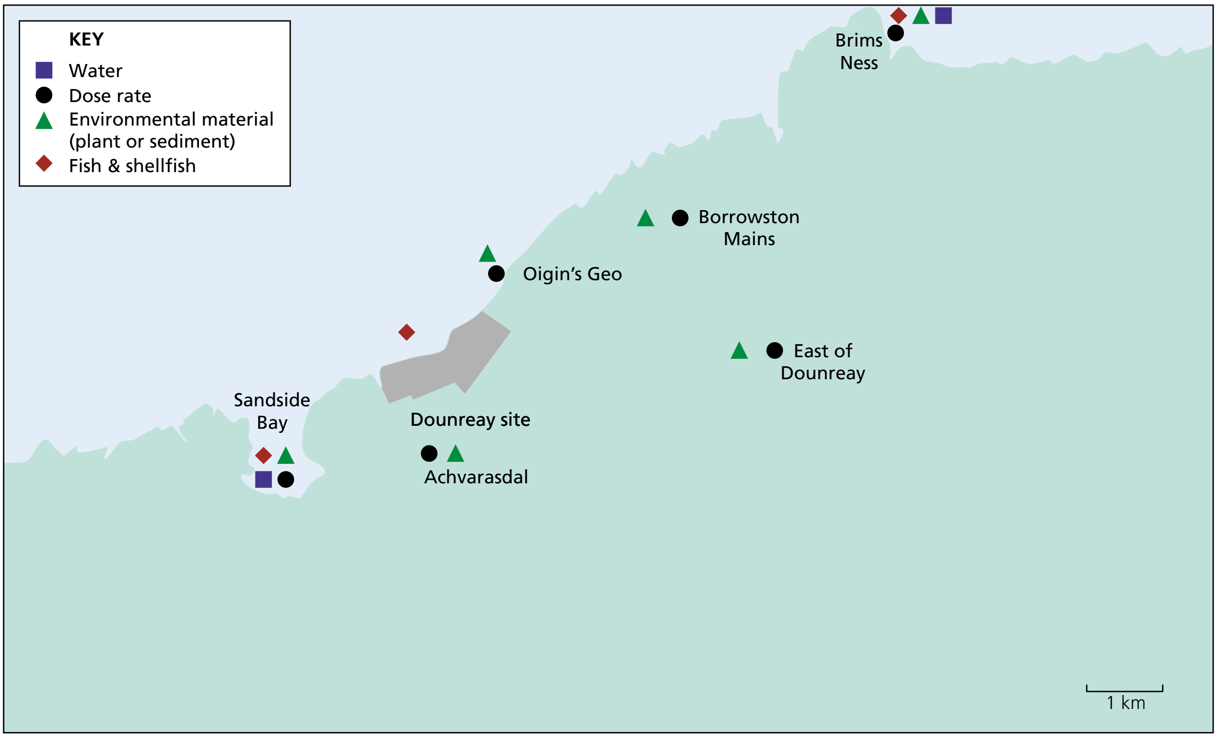


Figure 4.2. Monitoring locations at Dounreay, 2019 (not including farms or air sampling locations)

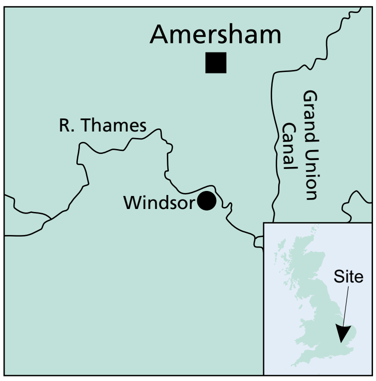
measurement of americium-241. Unlike fragments normally detected and removed, the presence of caesium-137 contamination was not detected in this fragment by gamma-ray spectrometry. Simulated digestion analysis was undertaken on the fragment. The results indicated that low quantities of americium-241 were released and as a result the fragment would not represent a risk to public health. Further examination and analysis has been carried out to establish the radiological and non-radiological composition. Work is being undertaken to identify 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.

* *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.*

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.

4.2 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.

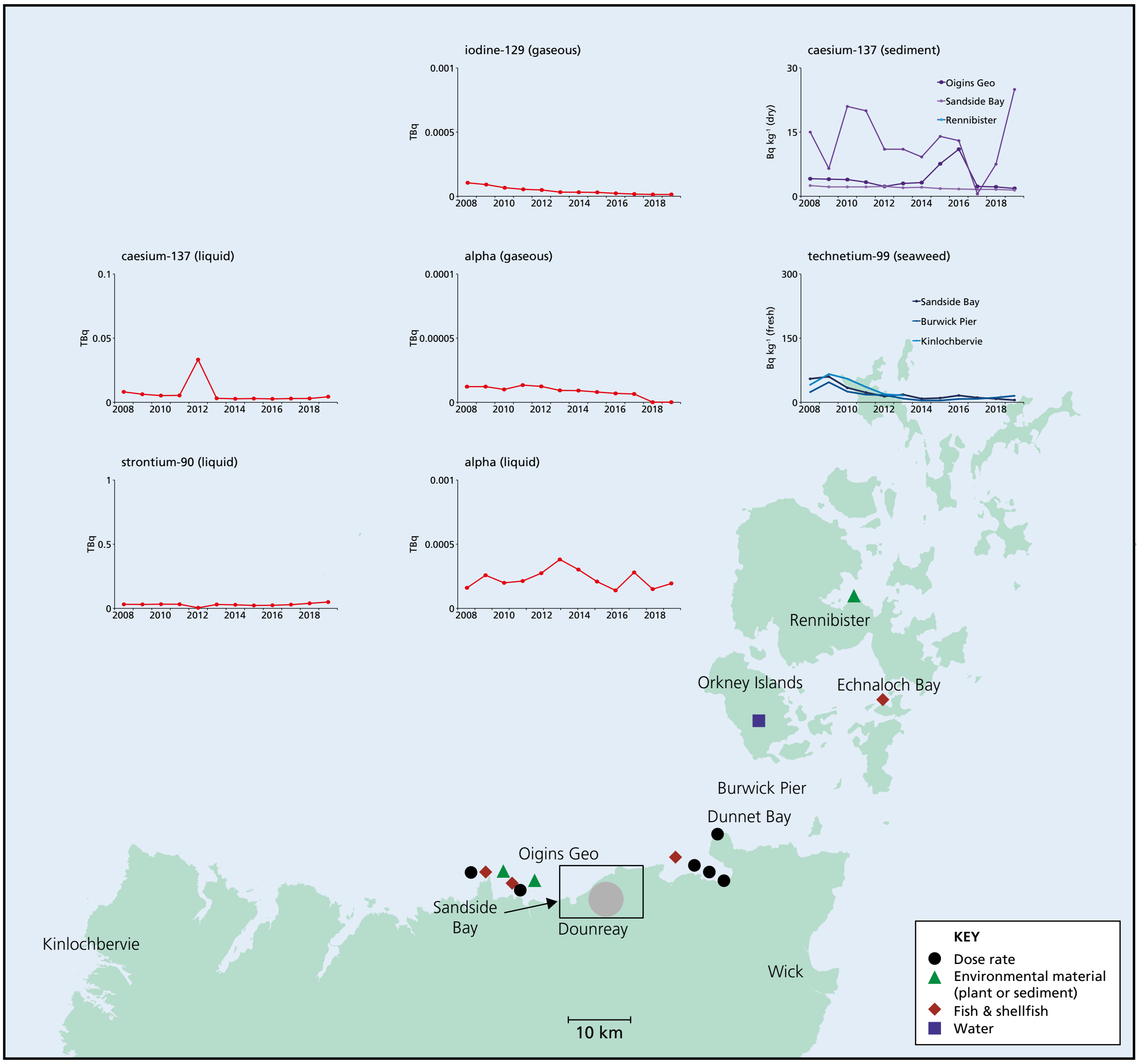


Figure 4.3. Monitoring locations, discharges of gaseous and liquid radioactive wastes and monitoring of the environment in the north of Scotland, 2019 (not including farms or air sampling locations). The rectangle around the Dounreay site is the area presented in Figure 4.2.

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

Doses to the public

The *total dose* from all pathways and sources of radiation was 0.14 mSv in 2019 (Table 4.1) or 14 per cent of the dose limit, and unchanged from 2018. 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 2019. 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 2008 – 2019 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 Sewage Treatment Works (STW), which serves the sewers to which permitted discharges are made, give exposures that were less than the *total dose* in 2019 (Table 4.1). The dose for a high-rate consumer of locally grown foods (which included a contribution from the gaseous plume related pathways) was 0.007 mSv, or approximately 1 per cent of the dose limit to members of the public of 1 mSv, and lower than the dose in 2018 (0.008 mSv). As in previous years, gaseous discharges of

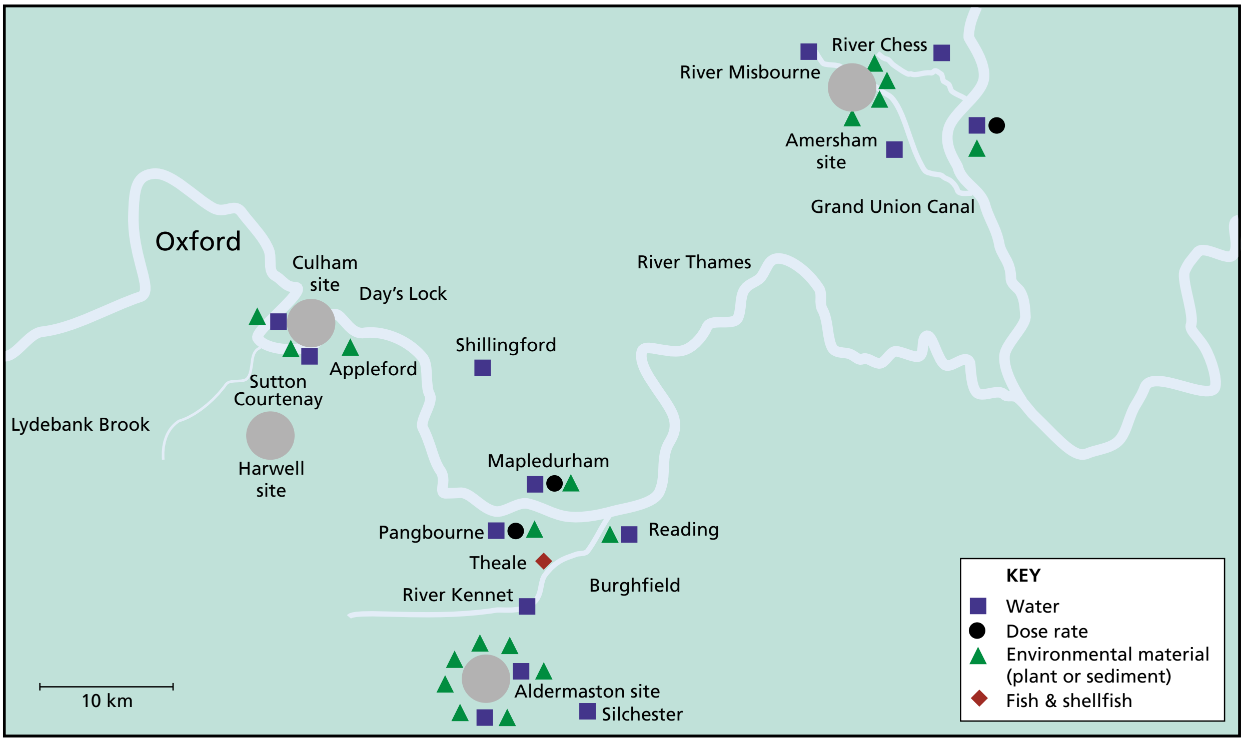


Figure 4.4. Monitoring locations at Thames sites, 2019 (not including farms)

radon-222 remain the dominant contributor in 2019 and the reason for the small decrease in dose was mostly due to a lower modelled dose contribution of radon-222 in air from the gaseous discharges in 2019 (in comparison to that in 2018). 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 2019.

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, inadvertent ingestion and inhalation of re-suspended radionuclides was less than 0.005 mSv in 2019.

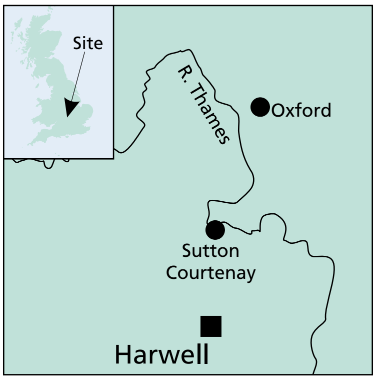
Gaseous discharges and terrestrial monitoring

The Amersham facility is permitted to discharge gaseous radioactive wastes via stacks on the site. Discharges of radon-222 decreased (by a small amount) in 2019, in comparison to those releases in 2018. The results for the terrestrial monitoring for 2019 are given in Tables 4.3(a) and (b). As in 2018, sulphur-35 was positively detected at a very low concentration in one food sample (wheat) in 2019. Tritium was also positively detected (unlike in recent years), just above the less than value in wheat. 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 2019 are given in Table 4.3(a). Activity concentrations in freshwater, and effluent and sludge from Maple Lodge STW, are mostly reported as less than values in 2019. 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 2019 (Table 4.3(b)) and were similar to those measured in recent years.

4.3 Harwell, Oxfordshire



The Harwell site 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. The most recent habits survey was conducted in 2015 (Clyne *et al.*, 2016b).

Doses to the public

The *total dose* from all pathways and sources of radiation was 0.010 mSv in 2019 (Table 4.1), which was approximately 1 per cent of the dose limit, and down from 0.028 mSv in 2018. 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 2019 (Table 1.1). The trend in annual *total dose* over the period 2008 – 2019 is given in Figure 4.1. The *total doses* remained broadly similar, from year to year (up to 2016), and were low. The increase in *total dose* in 2017 (from 2016), and then decrease in 2018, was attributed to changes in the estimate of direct radiation from the site.

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 2019 (Table 4.1).

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 2019. The monitoring programme sampled milk, fruit and cereal. Sampling locations at Harwell and in other parts of the Thames catchment are shown in Figure 4.4. The results of the terrestrial monitoring programme in 2019 are shown in Table 4.4. In 2019, tritium and caesium-137 concentrations in terrestrial samples are all reported as less than values.

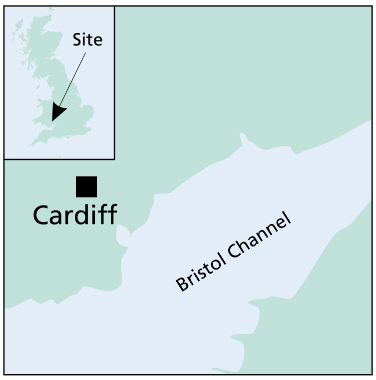
Liquid waste discharges and aquatic monitoring

Regulated discharges from Harwell are discharged to sewers serving the Didcot STW; treated effluent subsequently enters the River Thames at Long Wittenham. Discharges to the River Thames at Sutton Courtenay ceased in 2013, thereafter the decommissioning of the treated waste effluent discharge point was completed by RSRL. Magnox Limited has removed the pipeline (as it is no longer required) at Sutton Courtenay. Further information is available via: **https://www.gov.uk/government/publications/decommissioning-of-the-harwell-site-discharge-pipeline**

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 from Lydebank Brook were the lowest releases in recent years. Figure 4.5 shows trends of discharges over time (2008 – 2019) 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 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 2019, 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 recent years). The concentrations of all radionuclides in flounder from the lower reaches of the Thames are reported as less than values.

4.4 Maynard Centre, Cardiff



GE Healthcare Limited operated a second establishment on the Forest Farm industrial estate near Whitchurch, Cardiff. Until 2010, the Maynard Centre manufactured radio-chemicals, products containing tritium and

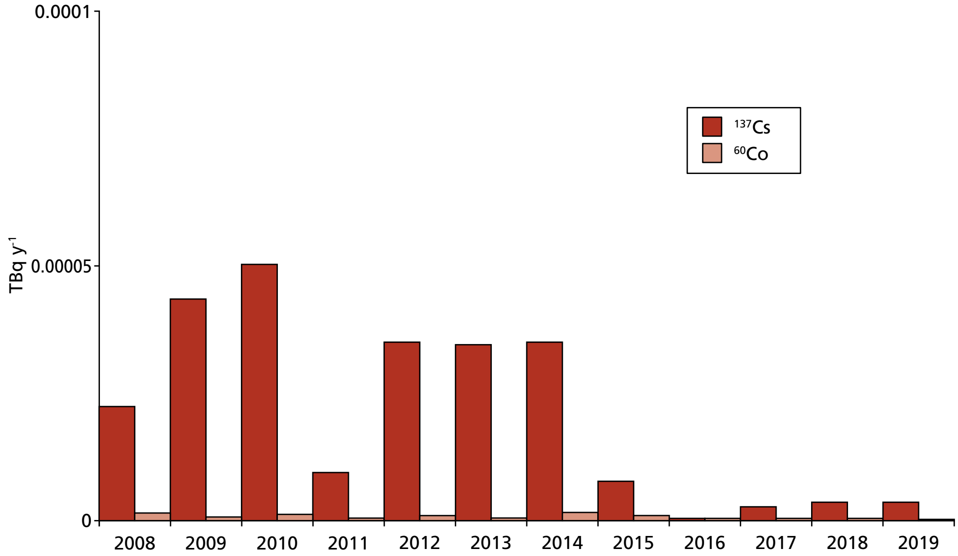


Figure 4.5. Trends in liquid discharges of caesium-137 and cobalt-60 from Harwell, Oxfordshire 2008-2019

carbon-14, for the healthcare and life sciences research markets. GE Healthcare Limited partially surrendered its environmental permit for the Maynard Centre site in 2015 and around 90 per cent of the site was de-licensed. The rest of the site was re-licensed as a stand-alone nuclear site (covered by a new nuclear site licence and EPR permit), known as the Cardiff Nuclear Licensed Site (CNLS) which continued to be operated by GE Healthcare Limited. The reduced licensed site at CNLS related to the storage and repackaging of legacy Intermediate Level Waste for off-site disposal and located entirely within the confines of the previously licensed site (and its security boundary). On 10 December 2019, ONR de-licensed the remainder of the nuclear site, following many years of nuclear site decommissioning.

In 2019 (prior to the full surrender of the environmental permit on the 17th December 2019), gaseous discharges from the Maynard Centre resulted from tritium and carbon-14 out-gassing from stored wastes, with only small amounts originating from decommissioning. Radioactive liquid wastes that were previously discharged from the site ceased in 2015.

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 discharges are much lower than releases from the Maynard Centre in the past. 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*., 2004).

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 4.1) in 2019, or less than 0.5 per cent of the dose limit, and unchanged from 2018. This dose estimate takes into account the higher dose coefficient 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 (as in 2018). Trends in *total doses* over time (2008 – 2019) are shown in Figure 4.1. 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.

Source specific assessments for a for a high-rate consumer of locally grown foods, a high-rate consumer of seafood and a recreational user of the River Taff were also less than 0.005 mSv in 2019 (Table 4.1). The reason for the decrease in dose to a high-rate consumer of seafood (from 0.008 mSv in 2018) was because gamma dose rates were measured over different ground types from one year to next.

The dose coefficients for OBT differ from those for tritiated water (see Appendix 1, Annex 3.4) and the estimates of dose to members of the public account for this. For ingestion of seafood caught near Cardiff, an area taken to be equivalent to the Bristol Channel and 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 higher 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 4.6.

Gaseous discharges and terrestrial monitoring

The Maynard Centre discharged radioactivity to the atmosphere via stacks on the site during 2019. As a result of the cessation of discharges, releases of tritium and carbon-14 decreased in 2019 in comparison to those in 2018.

The focus of the terrestrial sampling was for the analyses of tritium, carbon-14 and sulphur-35 in milk, crops, freshwater and grass. The results of monitoring for 2019 are given in Table 4.5(a) and were generally similar in comparison to those reported in previous years. Tritium concentrations in all terrestrial food samples are reported as less than values in 2019. Carbon-14 was detected in locally produced milk at concentrations just above the expected background concentration in 2019. Carbon-14 concentrations in both milk and potato samples decreased by small amounts, in comparison to those in 2018. A low concentration of sulphur-35 (which is not discharged by the site) was detected in one food sample (potatoes) just above the less than value, but concentrations were generally similar to those in recent years. Iodine-125 concentrations in food samples, and tritium concentrations in sediments (marine and terrestrial), are all reported as less than values in 2019.

In 2019, 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 2019 (as in recent years), 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 – 2019) are shown in Figure 4.7. The 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 2019.

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 (2008 – 2019) are given in Figures 4.8 and 4.9 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 2019 are given in Tables 4.5(a) and (b). Tritium and OBT concentrations in all fish and mollusc samples are reported as less than values in 2019 (activity concentrations in limpets were reported as positively detected just above the less than value in 2018). This suggests that the effects of historical discharges of tritium (and the mechanism of association of tritium with organic matter) is no longer persistent, unlike previous observations in 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 4.8 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 2019. The trend of carbon-14 concentrations and the relationship to discharges is shown in Figure 4.9 (overall, concentrations declining in both foods). Concentrations of caesium-137 in marine samples remain low and can largely be explained by other

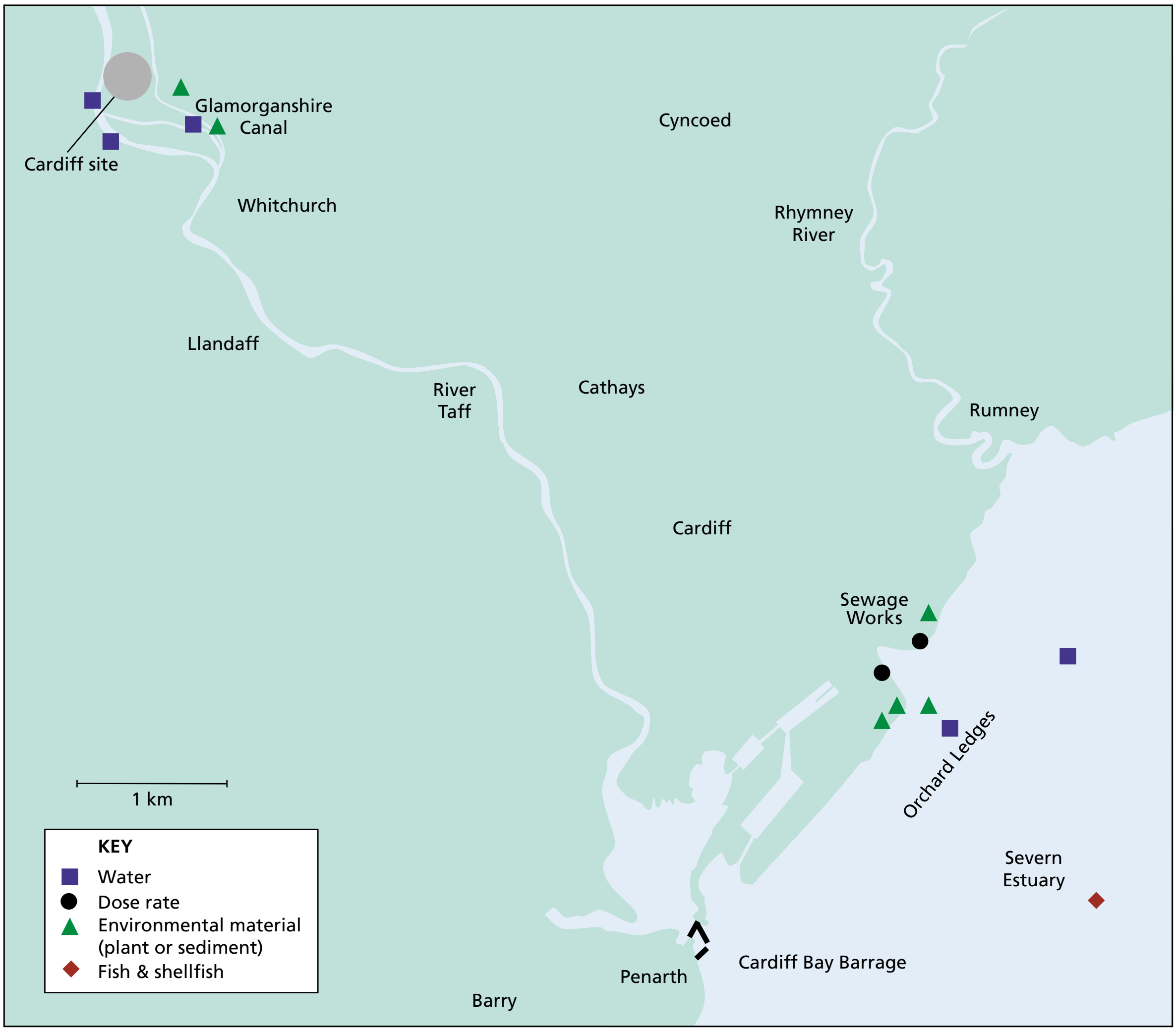
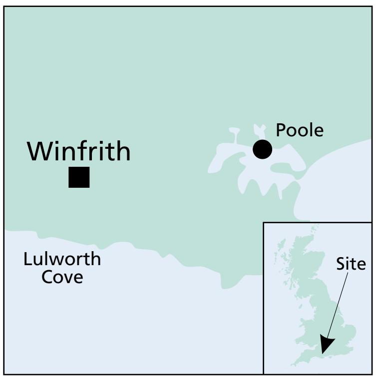


Figure 4.6. Monitoring locations at Cardiff, 2019 (not including farms)

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 4.5(b)) in 2019 were generally similar to those in 2018. It is unlikely these rates are attributable to discharges from the Maynard Centre or Pharmaron.

4.5 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.

In February 2019, the ONR and Environment Agency granted a new nuclear site licence and environmental permit transfer (respectively) to Inutec Limited (who trade as Tradebe Inutec), for their operations on part of the 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.

In August 2019, a habits survey was conducted to determine the consumption and occupancy rates by members of the public (Moore *et al*., 2020b). A large decrease in the fish consumption rates has been observed, together small increases in mollusc and crustacean rates, in comparison with those of the previous survey in 2003. The occupancy rate was over sand and stones in 2019 (previously mud and sand). Revised figures for consumption

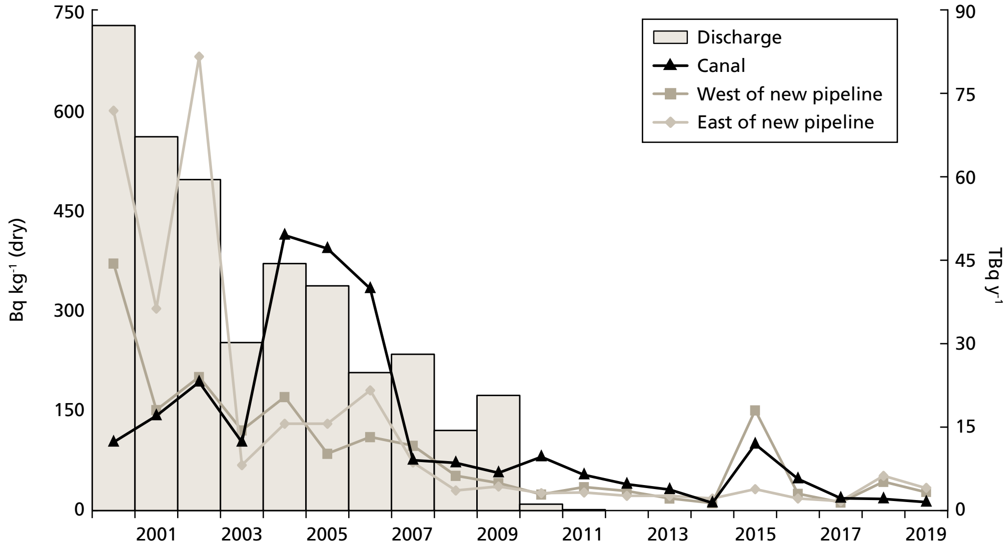


Figure 4.7. Tritium liquid discharge from Cardiff and mean concentrations in sediment near Cardiff, 2000-2019

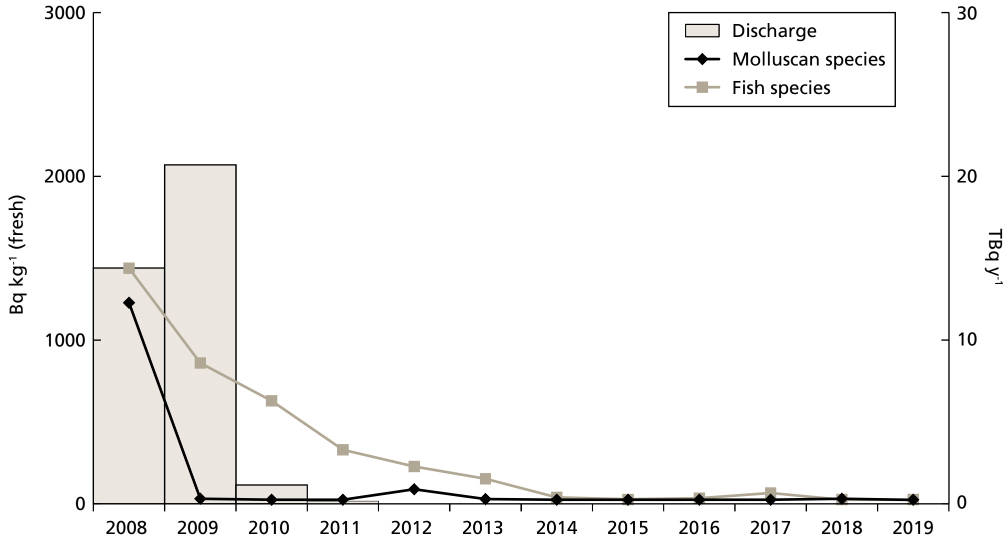


Figure 4.8. Tritium liquid discharge from Cardiff and mean concentrations in fish and molluscs near Cardiff, 2008-2019 (species include all those reported in RIFE for the given year)

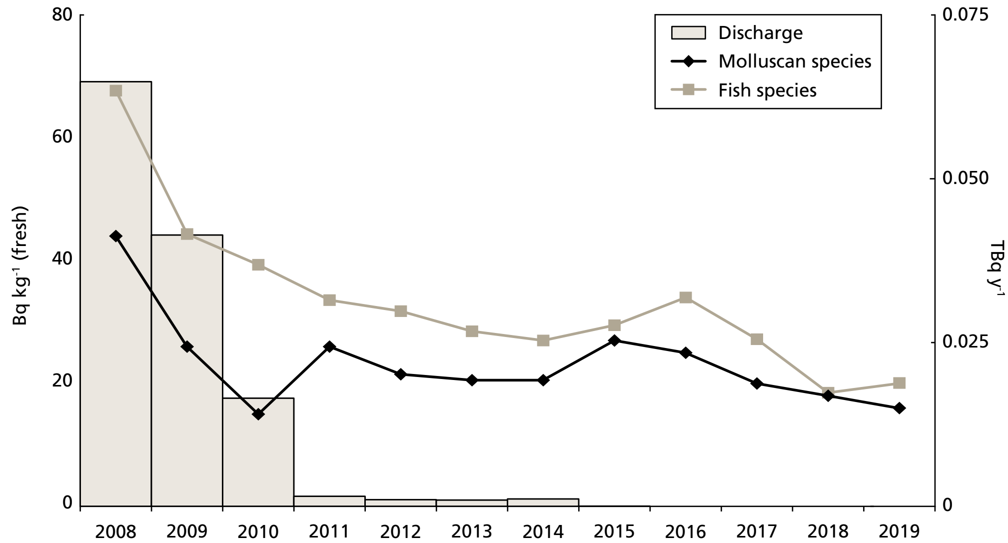


Figure 4.9. Carbon-14 liquid discharge from Cardiff and mean concentrations in fish and molluscs near Cardiff, 2008-2019 (species include all those reported in RIFE for the given year)

rates of fish, together with occupancy rates, are provided in Appendix 1 (Table X2.2).

Doses to the public

In 2019, the *total dose* from all pathways and sources of radiation was 0.027 mSv (Table 4.1), or less than 3 per cent of the dose limit, and unchanged from 2018. The representative person was adults living near the site. This dose was almost entirely due to direct radiation from the Winfrith site. Trends in annual *total doses* over time are shown in Figure 4.1. 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 2019 (Table 4.1).

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 2019. The focus of the terrestrial sampling was 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 4.10. Data for 2019 are given in Table 4.6(a). Results from terrestrial samples provide little indication of an effect due to gaseous discharges. Carbon-14 concentrations in locally produced milk were similar to those values used to represent background concentrations. 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 2019 (reported as < 1 per cent of the annual limit or nil). Liquid waste from Tradebe Inutec is transferred off site to the Tradebe Incinerator at Fawley. It is then discharged with the incinerator liquid waste into Southampton Water under a non-nuclear permit.

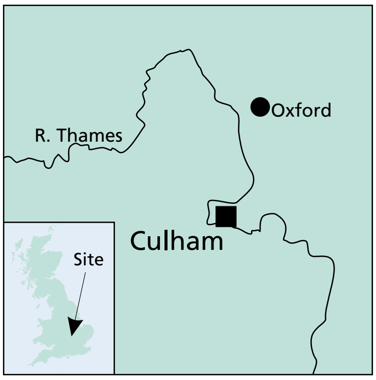
Figure 4.11 shows trends of liquid discharges over time (2008 – 2019) for tritium and alpha-emitting radionuclides. In recent years, alpha-emitting radionuclide discharges have decreased since the peak in 2013. In comparison, tritium discharges have varied more between years, with periodic peaks in releases, due to operations at Tradebe Inutec, but have also generally declined since 2015.

Analyses of seafood and marine indicator materials and measurements of external radiation over muddy intertidal areas were conducted. Data for 2019 are given in Tables 4.6(a) and (b). Concentrations of radionuclides in the marine environment were low and similar to those in previous years. Caesium-137 and americium-241 concentrations were all reported as below the less than value. In 2019, technetium-99 was positively detected (just above the less than value) in a seaweed sample (unlike in 2018). Gamma dose rates were difficult to distinguish from natural background.

4.6 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 2019 due to operation of these sites.

4.6.1 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 2019, was estimated to be much less than 0.005 mSv in 2019 (Table 4.1).

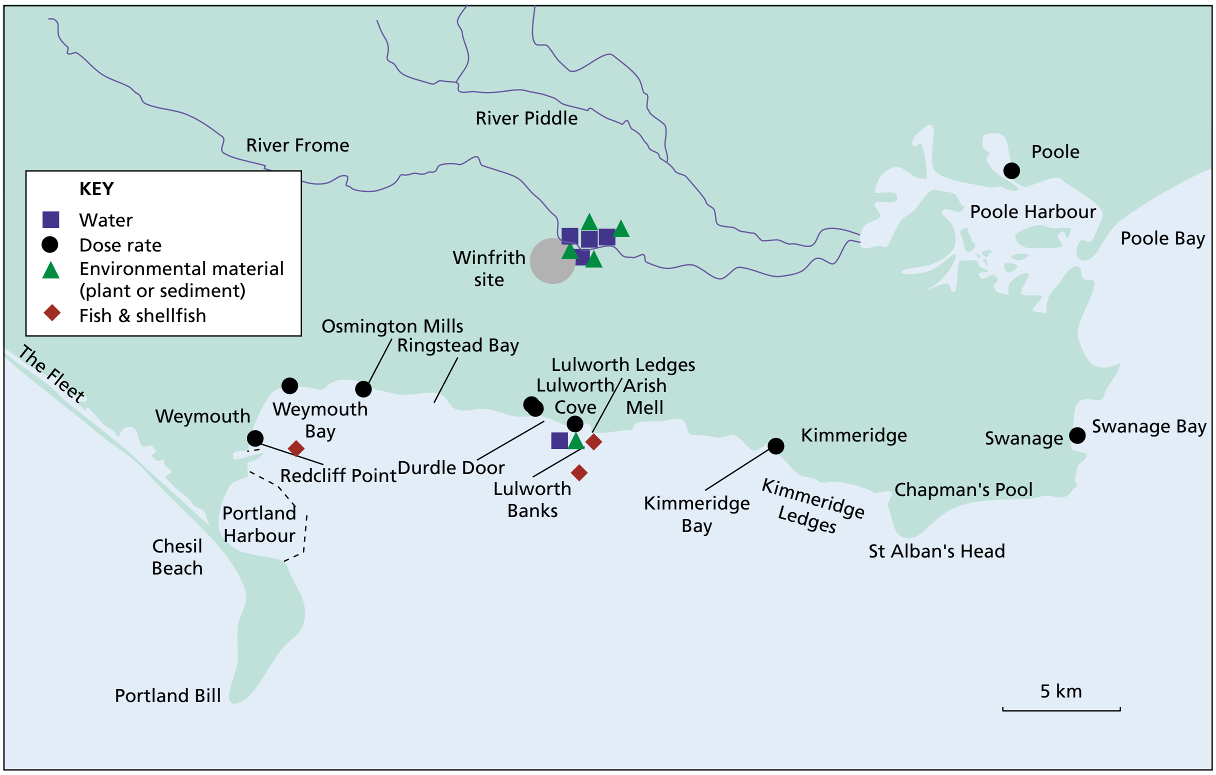


Figure 4.10. Monitoring locations at Winfrith, 2019 (not including farms)

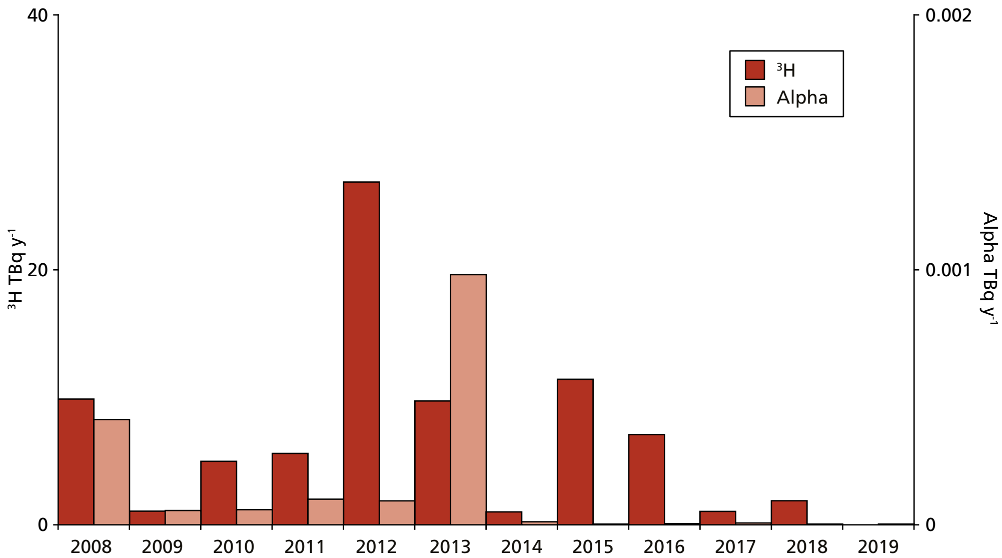


Figure 4.11. Trends in liquid discharges of tritium and alpha emitting radionuclides from Winfrith, Dorset 2008-2019

Monitoring of soil and grass around Culham and of sediment and water from the River Thames was undertaken in 2019. Locations and data are shown in Figure 4.4 and Table 4.7, 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 (48 Bq kg^{-1}) was higher in 2019, in comparison to that in 2018 (28 Bq kg^{-1}), but similar to those in previous years. 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.

4.6.2 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. Decommissioning plans are in an advanced state, with eventual de-licensing of the site by the end of 2021.

As in previous years, gaseous and liquid discharges were very low (gaseous reported as nil) in 2019 (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 are reported as less than values.

Table 4.1 Individual doses – Research and radiochemical production sites, 2019

Site	Representative person[a]	Exposure, mSv per year						
		Total	Fish and shellfish	Other local food	External radiation from intertidal areas or river banks[b]	Intakes of sediment or water[c]	Gaseous plume related pathways	Direct radiation from site
Amersham								
***Total dose* – all sources**	**Local adult inhabitants (0–0.25 km)**	**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	0.007[d]	-	<0.005	-	-	0.006	-
	Workers at Maple Lodge STW	<0.005	-	-	<0.005[e]	<0.005[f]	-	-
Cardiff								
***Total dose* – all sources**	**Prenatal children of occupants over sediment**	**<0.005**	**<0.005**	**-**	**<0.005**	**-**	**-**	**-**
Source specific doses	Prenatal children of seafood consumers	<0.005	<0.005	-	<0.005	-	-	-
	Prenatal children of recreational users of River Taff	<0.005	-	-	<0.005	<0.005	-	-
	Infant inhabitants and consumers of locally grown food	<0.005	-	<0.005	-	-	<0.005	-
Culham								
Source specific dose	Drinkers of river water	<0.005	-	-	-	<0.005	-	-
Dounreay								
***Total dose* – all sources**	**Adult mushroom consumers**	**0.010**	**<0.005**	**0.010**	**-**	**-**	**-**	**-**
Source specific doses	Seafood consumers	0.006	<0.005	-	0.005	-	-	-
	Inhabitants and consumers of locally grown food	0.020	-	0.020			<0.005	
Harwell								
***Total dose* – all sources**	**Local adult inhabitants (0–0.25 km)**	**0.010[d]**	**-**	**-**	**-**	**-**	**<0.005**	**0.010**
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 (0.5–1 km)**	**0.027**	**<0.005**	**<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. Data are presented to 2 significant figures or 3 decimal places. Data below 0.005 mSv are reported as <0.005 mSv*

[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*

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

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

Table 4.2(a) Concentrations of radionuclides in food and the environment near Dounreay, 2019

Material	Location	No. of sampling observations	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			<0.49		<0.23	<0.19	<0.12
Crabs	Pipeline	2		<0.10	<0.30	0.74	<0.17	<0.10	<0.11
Crabs	Strathy	2			<0.48		<0.18	<0.10	<0.11
Crabs	Melvich Bay	2			<0.68	<0.41	<0.20	<0.10	<0.11
Winkles	Brims Ness	4		<0.10	<0.62		<0.22	<0.10	<0.11
Winkles	Sandside Bay	4		<0.10	<0.89	0.22	<0.32	<0.12	<0.17
Mussels	Echnaloch Bay	4			<0.44	0.83	<0.20	<0.10	<0.10
Fucus vesiculosus	Brims Ness	4			<0.36		<0.17	<0.10	<0.11
Fucus vesiculosus	Sandside Bay	4			<0.38	4.7	<0.20	<0.11	<0.11
Fucus vesiculosus	Burwick Pier	4			<0.37	18	<0.23	<0.10	<0.13
Sediment	Oigin's Geo	4			<0.20		<0.20	1.7	<0.18
Sediment	Brims Ness	1			<0.10		<0.15	1.3	<0.14
Sediment	Sandside Bay	1			<0.10		<0.16	1.4	<0.10
Sediment	Melvich Bay	1			<0.16		<0.16	1.2	<0.13
Sediment	Strathy	1			<0.16		<0.16	0.79	<0.14
Sediment	Rennibister	1			<0.42		<0.23	24	<0.15
Seawater	Brims Ness	2	<1.0		<0.16		<0.12	<0.10	<0.10
Seawater	Sandside Bay	2	<1.0		<0.19		<0.20	<0.10	<0.11

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	Scrabster	2	<0.19	0.00063	0.0014	0.0020		
Crabs	Pipeline	2	<0.15	0.0081	0.042	0.059	1.5	140
Crabs	Strathy	2	<0.14	0.0019	0.0091	0.033		
Crabs	Melvich Bay	2	<0.15	0.0024	0.011	0.015		
Winkles	Brims Ness	4	<0.15	<0.014	<0.014	0.23		
Winkles	Sandside Bay	4	<0.26	0.011	0.052	0.039		
Mussels	Echnaloch Bay	4	<0.16	0.0065	0.040	0.048		
Fucus vesiculosus	Brims Ness	4	<0.16			<0.12	9.5	830
Fucus vesiculosus	Sandside Bay	4	<0.18			<0.27	4.6	400
Fucus vesiculosus	Burwick Pier	4	<0.21			<0.15		
Sediment	Oigin's Geo	4	<0.71	1.2	5.4	4.0		
Sediment	Brims Ness	1	<0.26	2.2	12	13		
Sediment	Sandside Bay	1	<0.22	3.1	14	15		
Sediment	Melvich Bay	1	<0.23	0.10	1.1	0.98		
Sediment	Strathy	1	<0.27	0.097	0.77	1.3		
Sediment	Rennibister	1	<0.21	0.19	0.94	1.7		
Seawater	Brims Ness	2	<0.10			<0.10		
Seawater	Sandside Bay	2	<0.17			<0.11		

Table 4.2(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	^{234}U
Terrestrial samples - Annual										
Beef muscle		1	<5.0	<0.10	<0.11	<0.09	<0.06	0.09	<0.11	<0.050
Beef offal		1	<5.0	<0.10	<0.19	<0.11	<0.062	<0.05	<0.08	<0.050
Carrots		1	<5.0	<0.10	<0.14		<0.43	<0.05	<0.10	
Cauliflower		1	<5.0	<0.10	<0.15	<0.12	<0.050	<0.05	<0.09	
Eggs		1	<5.0	<0.10	<0.76		<0.54	<0.06	<0.16	
Honey		1	<5.0	<0.10	<0.15	<0.16	<0.057	23	<0.14	
Lamb muscle		1	<5.0	<0.10	<0.14	<0.11	<0.073	1.2	<0.12	<0.050
Leeks		1	<5.0	0.13	<0.12		<0.41	<0.05	<0.06	
Pheasant		1	<5.0	<0.10	<0.24	<0.12	<0.050	1.1	<0.11	
Potatoes		1	<5.0	<0.10	<0.38		<0.19	<0.05	<0.09	
Rosehips		1	<5.0	0.48	<0.37	<0.14	<0.050	0.41	<0.12	
Turnips		1	<5.0	0.22	<0.36		<0.25	<0.05	<0.10	
Venison		1	<5.0	<0.10	<0.17	<0.12	<0.060	7.8	<0.13	
Grass		6	<5.0	0.23	<0.09		<0.18	<0.06	<0.10	<0.14
	max		<5.1	0.30	<0.12		<0.19	<0.08	<0.12	<0.22
Soil		6	<5.0	0.92	<0.18		<0.40	15	1.9	31
Soil	max			1.1	<0.24		<0.64	18	2.1	39
Freshwater	Loch Calder	1	<1.0		<0.01			<0.01		
Freshwater	Loch Shurrery	1	<1.0		<0.01			0.01		
Freshwater	Loch Baligill[c]	4	<1.0		<0.01			0.02		
Freshwater	Heldale Water	1	<1.0		<0.02			<0.01		
Freshwater	Allt na Cleitte (Achridigill) Portskerra[c]	1			<0.01			0.02		
Freshwater	Achridigill, Melvich[c]	1			<0.01			0.02		
Freshwater	Allt na Ceardaich, Strathy[c]	1			<0.01			<0.01		
Freshwater	Allt na Tuchcaid, Strathy[c]	1			<0.01			0.01		
Freshwater	Alltan Domhaich, Portskerra[c]	1			<0.01			0.02		
Freshwater	Baligill Burn[c]	1			<0.01			0.02		
Freshwater	Loch Beag, Melvich[c]	1	<1.0		<0.01			<0.01		
Freshwater	Loch Dhu House, Bailigill[c]	1	<1.0		<0.01			<0.01		
Freshwater	Loch Eracha[c]	1	<1.0		<0.01			<0.01		

Table 4.2(a) continued

Material	Location or selection[b]	No. of sampling observ-ations	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}						
			^{235}U	^{238}U	^{238}Pu	^{239}Pu + ^{240}Pu	^{241}Am	Gross alpha	Gross beta
Terrestrial samples - Annual									
Beef muscle		1	<0.050	<0.050	<0.050	<0.050	<0.050		
Beef offal		1	<0.050	<0.050	<0.050	<0.050	0.050		
Carrots		1			<0.050	<0.050	<0.050		
Cauliflower		1			<0.050	<0.050	<0.050		
Eggs		1			<0.050	<0.050	0.050		
Honey		1			<0.050	<0.050	0.050		
Lamb muscle		1	<0.050	<0.050	<0.050	<0.050	<0.050		
Leeks		1			0.060	0.32	0.066		
Pheasant		1			<0.050	<0.050	<0.050		
Potatoes		1			<0.050	<0.050	<0.050		
Rosehips		1			<0.050	<0.050	0.050		
Turnips		1			<0.050	0.054	<0.050		
Venison		1			<0.050	<0.050	0.050		
Grass		6	<0.050	<0.11	<0.050	<0.050	<0.050		
	max			<0.24					
Soil		6	1.6	30	<0.057	<0.37	0.23		
Soil	max		2.2	37	<0.066	<0.43	0.29		
Freshwater	Loch Calder	1					<0.01	<0.010	0.060
Freshwater	Loch Shurrery	1					<0.01	<0.010	0.048
Freshwater	Loch Baligill[c]	4					<0.01	0.028	0.10
Freshwater	Heldale Water	1					<0.01	<0.010	0.056
Freshwater	Allt na Cleitte (Achridigill) Portskerra[c]	1					<0.01	0.011	0.059
Freshwater	Achridigill, Melvich[c]	1					<0.01	0.029	0.069
Freshwater	Allt na Ceardaich, Strathy[c]	1					<0.01	0.017	0.063
Freshwater	Allt na Tuchcaid, Strathy[c]	1					<0.01	0.015	0.069
Freshwater	Alltan Domhaich, Portskerra[c]	1					<0.01	0.015	0.063
Freshwater	Baligill Burn[c]	1					<0.01	0.022	0.057
Freshwater	Loch Beag, Melvich[c]	1					<0.01	0.026	0.069
Freshwater	Loch Dhu House, Bailigill[c]	1					<0.01	0.015	0.094
Freshwater	Loch Eracha[c]	1					<0.01	0.015	0.087

[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*
[c] *Additional freshwater sampling has been undertaken in response to increased concentrations in Loch Baligill in 2018*

Table 4.2(b) Monitoring of radiation dose rates near Dounreay, 2019

Location	Material or ground type	No. of sampling observations	μGy h⁻¹
Mean gamma dose rates at 1m over substrate			
Sandside Bay	Sand	2	<0.047
Sandside Bay	Winkle Bed	2	0.10
Oigin's Geo	Rocks and sediment	1	0.16
Oigin's Geo	Stones	1	0.14
Brims Ness	Stones	1	0.092
Melvich	Salt marsh	1	0.055
Melvich Sands	Sand	2	0.050
Strathy Sands	Sand	2	0.050
Thurso riverbank	Rocks	1	0.087
Thurso riverbank	Sediment and stones	1	0.079
Achvarasdal	Grass	2	0.075
Thurso Park	Grass	2	0.081
Borrowston Mains	Grass	2	0.078
Castletown Harbour	Sand	2	0.066
Dunnet Bay	Sand	2	0.058
Hallam	Grass	2	0.083
Mean beta dose rates			μSv h⁻¹
Sandside Bay	Sediment	2	<1.0
Oigin's Geo	Stones	2	<1.0
Thurso riverbank	Sediment and rocks	1	<1.0
Thurso riverbank	Sediment and stones	1	<1.0
Castletown Harbour	Sand	1	<1.0
Castletown Harbour	Fishing gear	1	<1.0

Table 4.2(c) Radioactivity in air near Dounreay, 2019

Location	No. of sampling observations	Mean radioactivity concentration, mBq m⁻³			
		^{131}I	^{137}Cs	Gross alpha	Gross beta
Shebster	12	<0.019	<0.010	<0.017	<0.21
Reay	11	<0.024	<0.010	0.013	<0.20
Balmore	11	<0.026	<0.011	<0.019	<0.21

Table 4.3(a) Concentrations of radionuclides in food and the environment near Amersham, 2019

Material	Location	No. of sampling observations	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}				
			^{3}H	^{131}I	^{137}Cs	Gross alpha	Gross beta
Freshwater samples							
Flounder	Woolwich Reach	1	<25	<0.75	<0.04		
Sediment	Upstream of outfall (Grand Union Canal)	2[E]		<0.31	1.0	120	190
Sediment	Downstream of outfall (Grand Union Canal)	2[E]		<0.47	0.72	160	240
Freshwater	Downstream of outfall (Grand Union Canal)	1[E]	<3.1	<0.25	<0.28	<0.061	0.64
Freshwater	River Chess	1[E]	<2.6	<0.27	<0.26	<0.033	0.062
Freshwater	River Misbourne – downstream	1[E]	<2.7	<0.30	<0.33	<0.027	0.064
Crude effluent[b]	Maple Lodge Sewage Treatment Works	2[E]	<8.9		<0.30	<0.089	0.53
Digested sludge[c]	Maple Lodge Sewage Treatment Works	2[E]	<15	2.1	<0.17	<1.6	5.2
Final effluent[d]	Maple Lodge Sewage Treatment Works	2[E]	<8.4		<0.27	<0.054	0.70

Material	Location or selection[e]	No. of sampling observations[f]	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}					
			^{3}H	^{35}S	^{125}I	^{137}Cs	Gross alpha	Gross beta
Terrestrial samples								
Milk		1	<4.4	<0.28	<0.0028	<0.04		
Courgette		1	<2.5	<0.20		<0.03		
Wheat		1	6.9	0.70		<0.06		
Grass	Orchard next to site	1[E]			<0.86	<0.97	<1.5	160
Grass	Water Meadows (River Chess)	1[E]			<0.75	<0.92	<1.9	180
Soil	Orchard next to site	1[E]			<0.39	4.0	150	400
Soil	Water Meadows (River Chess)	1[E]			<0.50	11	270	440

* *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] *The concentration of ^{3}H as tritiated water was <4.9 Bq l^{-1}*

[c] *The concentration of ^{3}H as tritiated water was <4.8 Bq l^{-1}*

[d] *The concentration of ^{3}H as tritiated water was <4.8 Bq l^{-1}*

[e] *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*

[f] *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 Amersham, 2019

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	0.059
Downstream of outfall (Grand Union Canal)	Grass	2	0.059
Upstream of outfall (Grand Union Canal)	Grass	2	0.060
Water Meadows (River Chess)	Grass	1	0.052
Orchard next to site	Grass	1	0.080

Table 4.4 Concentrations of radionuclides in food and the environment near Harwell, 2019

Material	Location	No. of sampling observ-ations	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}						
			^{3}H	^{60}Co	^{131}I	^{137}Cs	^{241}Am	Gross alpha	Gross beta
Freshwater samples									
Flounder	Woolwich Reach	1	<25	<0.04	<0.75	<0.04	<0.27		
Freshwater	River Thames (Long Wittenham)	4[E]	<3.2	<0.31		<0.28		<0.044	0.31
Freshwater	River Thames (Shillingford)	2[E]	<3.4	<0.30		<0.24		<0.057	0.28

Material	Location or selection[b]	No. of sampling observations[c]	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}		
			Organic ^{3}H	^{3}H	^{137}Cs
Terrestrial samples					
Milk		2	<2.5	<2.5	<0.04
Milk	max		<2.7	<2.7	
Strawberries		1	<5.6	<5.6	<0.04
Barley		1	<3.4	<3.4	<0.03

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

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

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

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

Table 4.5(a) Concentrations of radionuclides in food and the environment near Cardiff, 2019

Material	Location	No. of sampling observations	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}				
			Organic ^{3}H[d]	^{3}H	^{3}H[e]	^{14}C	^{137}Cs
Marine samples							
Flounder	East of new pipeline	2	<25	<25		22	0.15
Lesser spotted dogfish	Off Orchard Ledges	1	<25	<25		18	0.37
Limpets	Lavernock Point	1	<25	<25		16	0.15
Seaweed	Orchard Ledges	2[E]		<10		22	
Sediment	East of sewage outfall	2[E]		<34		<9.8	
Sediment	West of sewage outfall	2[E]		<28		<7.7	
Seawater	West of sewage outfall	1[E]		<9.7	<2.6	<4.0	

Material	Location or selection[b]	No. of sampling observations[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		1	<3.5	<3.5		18	<0.23		<0.05
Potato		1	<4.0	<4.0		25	0.50	<0.059	<0.04
Barley		1	<7.8	<7.8		22	<0.20	<0.067	<0.07
Grass	0.5km north east of site	1[E]		<9.5		7.7			
Grass	0.5km north west of site	1[E]		<9.1		<2.8			
Sediment	Glamorgan canal	2[E]		<44		<36			
Freshwater	River Taff upstream	1[E]		<10		7.5			
Freshwater	River Taff downstream	1[E]		<11	<2.8	<4.4			
Freshwater	Glamorgan canal	1[E]		<11	<2.7	<5.3			

[a] *Except for milk, water and effluent where units are Bq l^{-1} and for sediment where dry concentrations apply*
[b] *Data are arithmetic means unless stated as 'max' in this column. 'Max' data are selected to be maxima. If no 'max' value is given the mean value is the most appropriate for dose assessments*
[c] *The number of farms from which milk is sampled. The number of analyses is greater than this and depends on the bulking regime*
[d] *The organic fraction may be higher than the total tritium value for some analyses due to uncertainties in the analytical methods for tritium. For dose assessments in this report, the higher of the two values has been used*
[e] *As tritiated water*
[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 Cardiff, 2019

Location	Ground type	No. of sampling observations	μGy h^{-1}
Mean gamma dose rates at 1m over substrate			
East of Pipeline	Mud	2	0.080
West of Pipeline	Mud and silt	1	0.093
West of Pipeline	Rock and stones	1	0.095
Peterstone Wentlooge	Mud	2	0.079

Table 4.6(a) Concentrations of radionuclides in food and the environment near Winfrith, 2019

Material	Location or selection[b]	No. of sampling observ-ations[c]	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}					
			^{14}C	^{99}Tc	^{137}Cs	^{241}Am	Gross alpha	Gross beta
Marine samples								
Plaice	Weymouth Bay	1			<0.14	<0.45		
Crabs	Lulworth Banks	1	30		<0.06	<0.06		
Seaweed	Lulworth Cove	1[E]		0.95	<0.43	<0.50		
Seaweed	Bognor Rock	2[E]		<2.4	<0.45	<0.54		
Seawater	Lulworth Cove	1[E]			<0.26	<0.31	<4.5	13

Material	Location or selection[b]	No. of sampling observ-ations[c]	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}					
			Organic ^{3}H	^{3}H	^{14}C	^{137}Cs	Gross alpha	Gross beta
Terrestrial samples								
Milk		2	<3.1	<3.1	15	<0.04		
Milk	max		<3.6	<3.6	16	<0.05		
Beetroot		1	<2.2	<2.2	13	<0.03		
Barley		1	<3.5	<3.5	75	<0.05		
Grass	Near Newburgh Farm Cottages	2[E]		<16	20	<0.97	<1.7	190
Grass	Adjacent to railway	2[E]		<14	23	<0.99	3.8	190
Sediment	North of site	1[E]				2.6	140	<99
Sediment	R Frome (upstream)	1[E]				0.75	65	<91
Sediment	R Frome (downstream)	1[E]				6.3	260	340
Sediment	R Win, East of site	1[E]				0.55	110	<90
Freshwater	North of site	2[E]		6.6		<0.27	0.051	0.099
Freshwater	R Frome (upstream)	2[E]		<2.9		<0.27	<0.035	0.092
Freshwater	R Frome (downstream)	2[E]		<2.8		<0.30	<0.036	0.090
Freshwater	R Win, East of site	2[E]		<2.9		<0.30	<0.054	0.17

[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 4.6(b) Monitoring of radiation dose rates near Winfrith, 2019

Location	Ground type	No. of sampling observations	µGy h^{-1}
Mean gamma dose rates at 1m over substrate			
Weymouth Bay	Sand and shingle	1	0.052
Osmington Mills	Pebbles and rock	1	0.060
Durdle Door	Shingle	1	0.050
Lulworth Cove	Sand and shingle	1	0.056
Kimmeridge Bay	Pebbles and sand	1	0.067
Swanage Bay	Sand	1	0.051
Poole Harbour	Sand	1	0.050

Table 4.7 Concentrations of radionuclides in the environment near Culham, 2019

Material	Location	No. of sampling observations	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}					
			^{3}H	^{14}C	^{131}I	^{137}Cs	Gross alpha	Gross beta
Freshwater	River Thames (upstream)	2	<3.1			<0.26	<0.035	0.33
Freshwater	River Thames (downstream)	2	<3.2			<0.29	<0.036	0.22
Grass	0.6 km East of site perimeter	2	<12	26		<0.99		170
Sediment	River Thames (upstream)	1			4.6	6.3		
Sediment	River Thames (downstream)	2				48		
Soil	1 km East of site perimeter	1	<7.7	16		3.7		380

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

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 2019, 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 2019 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 6 per cent of the dose limit for all sites assessed

Aldermaston, Berkshire

- *Total dose* for the representative person was less than 0.005 mSv and decreased in 2019

Barrow, Cumbria

- *Total dose* for the representative person was 0.057 mSv and increased in 2019

Derby, Derbyshire

- *Total dose* for the representative person was less than 0.005 mSv and unchanged in 2019

Devonport, Devon

- *Total dose* for the representative person was less than 0.005 mSv and unchanged in 2019
- Gaseous discharges of tritium increased and liquid discharges of tritium, cobalt-60 and "other radionuclides" decreased, in 2019

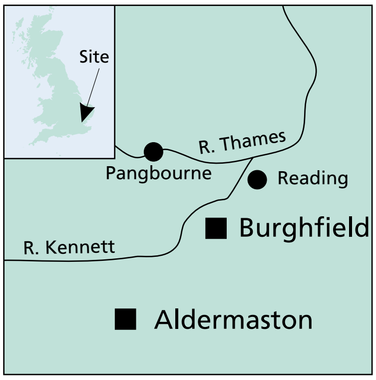
Faslane and Coulport, Argyll and Bute

- *Total dose* for the representative person was 0.007 mSv and decreased in 2019

Rosyth, Fife

- *Total dose* for the representative person was less than 0.005 mSv and decreased in 2019
- Gaseous discharges increased in 2019 (but remained low)

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.

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 2019, the *total dose* from all pathways and sources of radiation was less than 0.005 mSv (Table 5.1), or less than 0.5 per cent of the dose limit, and down from 0.010 mSv in 2018. The representative person was infants (1-year-old) consuming milk at high-rates, and a change from that in 2018 (adults living near to the site). The decrease in *total dose,* and change in the representative person (from 2018), was mostly due to a lower estimate of direct radiation from the site in 2019.

Source specific assessments for high-rate consumers of locally grown foods, for sewage workers and for anglers, give exposures that were also less than 0.005 mSv in 2019 (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. Samples of milk, terrestrial foodstuffs, grass and soil were taken from locations close to the site (Figure 4.4) and the results of the terrestrial monitoring in 2019 are given in Table 5.2(a). In 2019, tritium concentrations and other radionuclides in foodstuffs (including milk) were very low or reported as less than values. Caesium-137 concentrations were positively detected in soil samples and were generally similar in 2019, in comparison to those in 2018 (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 2019. Concentrations of uranium isotopes in 2019 were generally similar to those values in 2018. 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 4.4), and to the Aldermaston Stream. A time-series trend of generally decreasing tritium discharges from Aldermaston (2008– 2019) 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 2019 (as in recent years). The concentrations of artificial radioactivity detected in the Thames catchment were very low in 2019 and generally similar to those in 2018. In 2019, tritium concentrations in freshwater and terrestrial samples were all reported as less than values. Iodine-131 was not positively detected in food samples in 2019. Activity concentrations of artificial radionuclides in shellfish were very low in 2018 and similar to those reported in recent years. Analyses of caesium-137 and uranium activity concentrations in River Kennet sediments were broadly consistent with those in recent years. In 2019, 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 of tritium, carbon-14 and cobalt-60 were all very low (< 1 per cent of the annual limit) in 2019. The most recent habits survey was undertaken in 2012 (Garrod *et al*., 2013).

The *total dose* from all pathways and sources of radiation was 0.057 mSv (Table 5.1) in 2019, or less than 6 per cent of the dose limit, and up from 0.046 mSv in 2018. The representative person was adults living on a local houseboat. The increase in *total dose* was mostly due to higher gamma dose rates over mud and sand (Askam Pier and Roa Island) in 2019, in comparison to those 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 houseboat give exposures that were less than the *total dose* in 2019 (Table 5.1). No assessment of seafood consumption was undertaken in 2019 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).

The FSA's terrestrial monitoring is limited to vegetable and grass (or silage) sampling. The Environment Agency monitors dose rates and analysis of sediment samples from local intertidal areas and is directed primarily at the far-field effects of Sellafield discharges. The results are given in Table 5.3(a). No effects of discharges from Barrow were apparent in the concentrations of radioactivity in

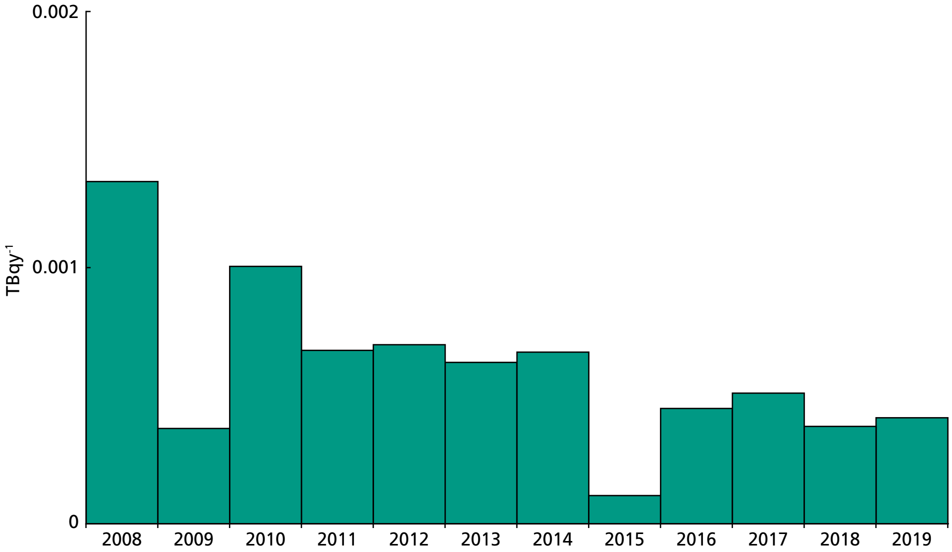


Figure 5.1. Trends in liquid discharges of tritium from Aldermaston, Berkshire 2008-2019
(including discharges to Silchester sewer and Aldermaston Stream)

vegetables and silage, most reported as less than values. In 2019, the reported gross beta concentration in sediment (in the vicinity of the discharge point) was lower in 2019, in comparison to that in 2018. Dose rates in intertidal areas near Barrow in 2019 are given in Tables 5.3(b) and Table 2.9. As in previous years, dose rates were enhanced above those expected due to natural background, and higher in comparison to those in 2018. Any enhancement above natural background is most likely due to the far-field effects of historical discharges from Sellafield.

5.3 Derby, Derbyshire

Rolls-Royce Submarines Limited (RRSL) (formerly Rolls-Royce Marine Power Operations Limited), 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. 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 the 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).

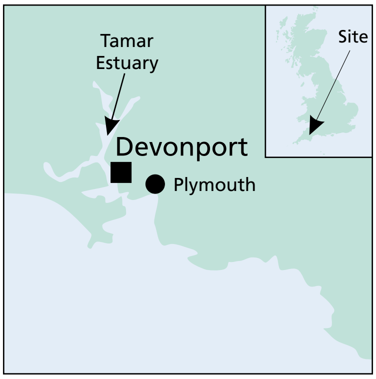
Doses to the public

The *total dose* from all pathways and sources of radiation was less than 0.005 mSv in 2019 (Table 5.1), which is less than 0.5 per cent of the dose limit, and unchanged from 2018. The representative person was adults consuming locally sourced water. 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 2019 (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 2019 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 2019 were broadly similar to those reported elsewhere in Derbyshire (Table 7.7).

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.*, 2018). The routine monitoring programme in 2019 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 2019 (Table 5.1), which was less than 0.5 per cent of the dose limit, and unchanged from 2018. The representative person was adults consuming locally collected marine plants at high-rates, who also consumed fish (which largely determined the exposure) and spent time in intertidal areas. The trend in annual *total doses* at Devonport remains less than 0.005 mSv (Figure 6.1, Environment Agency, FSA, FSS, NIEA, NRW and SEPA, 2019).

Source specific assessments for a high-rate consumer of locally grown food (including doses from external and inhalation from gaseous discharges), for fish and shellfish, and for an occupant of a houseboat, give exposures that were also less than 0.005 mSv in 2019 (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

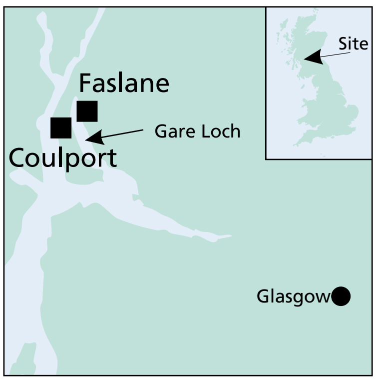
Discharges of tritium increased in 2019 in comparison to those releases in 2018. Crop and vegetable samples were analysed for a number of radionuclides. Activity concentrations in terrestrial samples are reported as less than values in 2019.

Liquid waste discharges and aquatic monitoring

Discharges of tritium, cobalt-60 and "other radionuclides" to the Hamoaze (estuary) decreased in 2019, in comparison to those releases in 2018. The trends of tritium and cobalt-60 discharges with time (2008 – 2019) 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 in 2019. 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 2019. Gamma dose rates in the vicinity of Devonport in 2019, were similar to those in recent years, and reflect the local effects of enhanced background radiation from natural sources.

5.5 Faslane and Coulport, Argyll and Bute



The HMNB Clyde establishment consists of the naval base at Faslane and the armaments depot at Coulport. Babcock Marine, a subsidiary of Babcock International Group plc, operates HMNB Clyde, Faslane in partnership with the MoD. However, the MoD remains in control of the undertaking, through the Naval Base Commander, Clyde (NBC Clyde) in relation to radioactive waste disposal. MoD through NBC Clyde also remains in control of the undertaking at Coulport although many of the activities

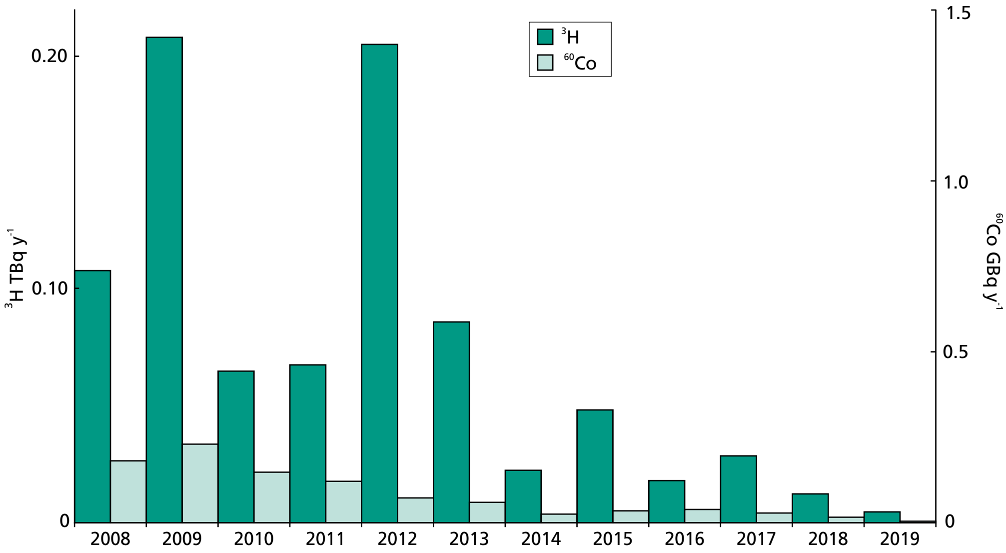


Figure 5.2. Trends in liquid discharges of tritium and cobalt-60 from Devonport, Devon 2008-2019

undertaken at Coulport have been outsourced to an industrial alliance comprising of AWE plc, Babcock and Lockheed Martin UK (known as ABL).

Discharges of liquid radioactive waste, into 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 Letters of Agreement (LoA) between SEPA and the MoD. During 2018, SEPA received an application to amend the LoA for liquid discharges from Faslane to include the disposal of general effluents containing very low levels of tritium. This amendment was made in 2019.

The construction of a new radioactive waste treatment facility at Faslane continued in 2019 and is expected to be completed in 2021. An application for a revised LoA that includes discharges from the facility was submitted to SEPA in 2019. SEPA launched a consultation on the application between January and March 2020. More information describing the consultation can be found at: **https://consultation.sepa.org.uk/radioactive-substances-unit/hmnb-clyde-application-consultation/consult_view/**.

In 2019, gaseous tritium discharges (from Coulport) were similar, in comparison to those releases in 2018. Liquid discharges (from Faslane), including tritium, were less than 1 per cent of the annual limit in 2019 (see 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. Solid waste transfers in 2019 are given in Appendix 2 (Table A2.4).

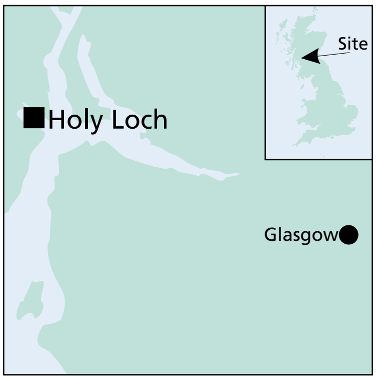
The most recent habits survey to determine the consumption and occupancy rates by members of the public was undertaken in 2016 (Dale *et al.*, 2019b).

The *total dose* from all pathways and sources of radiation was 0.007 mSv in 2019 (Table 5.1), which is less than 1 per cent of the dose limit, and down from 0.008 mSv in 2018. The representative person was adults consuming fish at high-rates. Activity concentrations in fish (not collected in 2019) were estimated using reported environmental fish data in 2019, sampled outside the aquatic habits survey area of this site (but within the Firth of Clyde). The small change in *total dose* in 2019 was mostly due to a lower less than value of americium-241 in fish, in comparison to that in 2018. The assessment of this *total dose* is conservative (due to the assumption of fish data). In 2019, 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 0.008 mSv and less than 0.005 mSv, respectively. The reason for the change in dose (from 0.010 mSv in 2018) to the consumer of fish and shellfish is the same as that contributing to the maximum *total dose*.

The routine marine monitoring programme consisted of the analysis of shellfish, seawater, seaweed and sediment samples, and gamma dose rate measurements. Terrestrial monitoring included beef, honey, water, grass and soil sampling. The results in 2019 are given in Tables 5.3(a) and (b) and were generally similar to those in 2018. Caesium-137 was positively detected at a low concentration in honey (as in recent years). Radionuclide concentrations were generally reported as less than values in 2019. 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 (Tables 5.3b). Tritium, gross alpha and gross beta concentrations in freshwater were much lower than the investigation levels in the European Directive 2013/51.

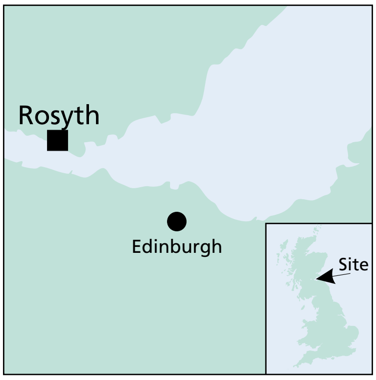
5.6 Holy Loch, Argyll and Bute



A small programme of monitoring at Holy Loch continued during 2019 in order to determine the effects of past discharges from the US submarine support facilities which closed in 1992. Radionuclide concentrations were low (Table 5.3(a)). Gamma dose rate measurements over intertidal areas (Table 5.3(b)) were generally lower to those values reported in 2018. 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 0.005 mSv in 2019, which was 0.5 per cent of the dose limit for members of the public of 1 mSv (Table 5.1), and down from 0.009 mSv in 2018. The decrease in dose was mostly due to lower gamma dose rates measured over sediment (Mid-Loch and North Sandbank) in 2019.

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 maintains an overview of procedures 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. The authorisation was transitioned to a permit under the Environmental Authorisations (Scotland) Regulations 2018 (EASR 18) with a new permit being issued in March 2019. 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.

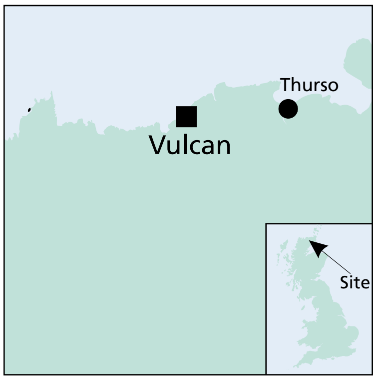
The most recent habits survey was undertaken in 2015 (Tyler *et al*., 2016) and the results of the survey are incorporated in estimating the doses at Rosyth.

The *total dose* from all pathways and sources of radiation was less than 0.005 mSv in 2019 (Table 5.1), which was less than 0.5 per cent of the dose limit, and down from 0.010 mSv in 2018. In 2019, the representative person was adults living near the site, and was a change from that in 2018 (adults spending time over sediments). The decrease in *total dose* from 2018 was mostly due to lower gamma dose rates over sediment observed in 2019. The source specific assessment for marine pathways (fishermen and beach users) was estimated to be 0.006 mSv in 2019 (from 0.013 mSv in 2018). The reason for the decrease in dose is the same as that contributing to the maximum *total dose*.

The gaseous and liquid discharges from Rosyth in 2019 are given in Appendix 2 (Tables A2.1 and A2.2, respectively), and solid waste transfers in Table A2.4. Gaseous discharges increased in 2019 (but remained low), in comparison to those releases in 2018 (reported as nil). The apparent increases are due to introducing standardised monitoring and gaseous discharge results (by the operator), that include estimates based on the analytical limits of detection. Liquid wastes are discharged via a dedicated pipeline to the Firth of Forth. Liquid discharges of cobalt-60 decreased (in comparison to 2018) due to lower limits of detection being achieved in 2019. In all cases the activities in the liquid discharged were well below the 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 in 2019, and similar to those in recent years, and in most part due to the combined effects of Sellafield, weapon testing and Chernobyl. Gamma dose rates were generally similar (in comparison to those in 2018) and difficult to distinguish from natural background, although the dose rates were lower in sediment at Port Edgar in 2019. The gross alpha concentration in a surface water sample from the Holl Reservoir in 2019 was detected just above the investigation level for drinking water (Table 5.3a). A further sample was taken in 2020 from the reservoir indicating that the alpha concentration has returned to normal. This gross alpha result will be reported in RIFE 26.

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 4). 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 2019 are given in Appendix 2 (Table A2.1 and Table A2.4, respectively).

Table 5.1 Individual doses – defence sites, 2019

Site	Representative person[a]	Exposure mSv, per year						
		Total	Fish and shellfish	Other local food	External radiation from intertidal areas or river banks[b]	Intakes of sediment or water[c]	Gaseous plume related pathways	Direct radiation from site
Aldermaston and Burghfield								
Total dose – all sources	**Infant milk consumers**	**<0.005[d]**	**-**	**<0.005**	**-**	**-**	**-**	**-**
Source specific doses	Anglers	<0.005[d]	<0.005	-	<0.005	-	-	-
	Infant inhabitants and consumers of locally grown food	<0.005[d]	-	<0.005	-	-	<0.005	-
	Workers at Silchester STW	<0.005	-	-	<0.005[e]	<0.005[f]	-	-
Barrow								
Total dose – all sources	**Adult occupants on houseboats[g]**	**0.057**	**-**	**-**	**0.057**	**-**	**-**	**-**
Source specific doses	Houseboat occupants	0.055	-	-	0.055	-	-	-
	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	<0.005	<0.005	-	<0.005	-	-	-
	Children Inhabitants and consumers of locally grown food	<0.005[c]	-	<0.005	-	-	<0.005	-
Devonport								
Total dose – all sources	**Adult consumers of marine plants and algae**	**<0.005**	**<0.005**	**-**	**<0.005**	**-**	**-**	**-**
Source specific doses	Seafood consumers	<0.005	<0.005	-	<0.005	-	-	-
	Houseboat occupants	<0.005	-	-	<0.005	-	-	-
	Inhabitants and consumers of locally grown food	<0.005	-	<0.005	-	-	<0.005	-
Faslane								
Total dose – all sources	**Adult fish consumers**	**0.007**	**0.006**	**-**	**<0.005**	**-**	**-**	**-**
Source specific doses	Seafood consumers	0.008	0.006	-	<0.005	-	-	-
	Consumers of locally grown food	<0.005	-	<0.005	-	-	-	-
Holy Loch								
Source specific doses	Anglers	0.005	-	-	0.005	-	-	-
Rosyth								
Total dose – all sources	**Local adult inhabitants (0.5–1km)**	**<0.005**	**-**	**-**	**<0.005**	**-**	**-**	**<0.005**
Source specific doses	Fishermen and beach users	0.006	<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 specified. Data are presented to 2 significant figures or 3 decimal places. Data below 0.005 mSv are reported as <0.005 mSv*

[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*

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

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

[g] *Exposures at Barrow are largely due to discharges from the Sellafield site*

Table 5.2(a) Concentrations of radionuclides in food and the environment near Aldermaston, 2019

Material	Location	No. of sampling observ-ations	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}						
			Organic ^{3}H	^{3}H	^{131}I	^{137}Cs	^{234}U	^{235}U	^{238}U
Freshwater samples									
Flounder	Woolwich Reach	1		<25	<0.75	<0.04			
Signal crayfish	Ufton Bridge - Theale	1	<25	<25	<0.93	<0.04	0.038	0.0011	0.025
Sediment	Pangbourne	2[E]				<0.61	15	<1.4	18
Sediment	Mapledurham	2[E]				53	13	<1.1	13
Sediment	Aldermaston	3[E]				3.0	22	<1.1	19
Sediment	Spring Lane	4[E]				<1.2	11	<0.91	12
Sediment	Stream draining south	4[E]				<0.55	31	<1.6	32
Sediment	Near Chamber 39 of PPL	3[E]				2.7	12	<1.2	11
Sediment	Oval pond near Chamber 14	4[E]				<1.4	14	<1.2	14
Sediment	River Kennet	4[E]				2.2	13	<1.0	14
Sediment	Hosehill Lake	3[E]				<1.4	18	<1.1	17
Gully Pot sediment	Falcon Gate	1[E]		<21		<0.94	28	1.4	26
Gully Pot sediment	Tadley Entrance	1[E]		<33		5.0	19	<0.99	20
Gully Pot sediment	Burghfield Gate	1[E]		<36		<1.1	14	1.3	19
Freshwater	Pangbourne	2[E]		<3.1		<0.30	0.0074	<0.0011	0.0059
Freshwater	Mapledurham	2[E]		<3.1		<0.38	0.0069	<0.0016	0.0052
Freshwater	Aldermaston	4[E]		<3.0		<0.27	0.0070	<0.0015	0.0042
Freshwater	Spring Lane	4[E]		<3.0		<0.28	<0.0023	<0.0011	<0.0020
Freshwater	Stream draining south	4[E]		<3.0		<0.27	<0.0046	<0.0022	<0.0039
Freshwater	Near Chamber 39 of PPL	3[E]		<2.9		<0.28	0.0078	<0.0016	0.0053
Freshwater	Oval pond near Chamber 14	4[E]		<2.9		<0.23	<0.0017	<0.0011	<0.0014
Freshwater	River Kennet	4[E]		<2.9		<0.31	0.0064	<0.0017	<0.0043
Freshwater	Hosehill Lake	4[E]		<3.2		<0.23	0.0062	<0.0015	<0.0044
Crude liquid effluent	Silchester treatment works	2[E]		<4.9		<0.25	<0.0063	<0.0034	<0.0037
Final liquid effluent	Silchester treatment works	2[E]		<5.0		<0.25	<0.0019	<0.0012	<0.0015
Sewage sludge	Silchester treatment works	2[E]		<10	14	<0.15	0.14	0.0057	0.13

Table 5.2(a) continued

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			<0.27				
Signal crayfish	Ufton Bridge - Theale	1	0.000083	0.00035	0.00061	*	*		
Sediment	Pangbourne	2[E]	<0.38	<0.35	<1.0			270	450
Sediment	Mapledurham	2[E]	<0.36	0.68	<1.1			250	430
Sediment	Aldermaston	3[E]	<0.39	2.2	<0.85			230	460
Sediment	Spring Lane	4[E]	<0.36	0.38	<0.75			170	420
Sediment	Stream draining south	4[E]	<0.48	<0.36	<0.82			330	980
Sediment	Near Chamber 39 of PPL	3[E]	<0.39	<0.36	<0.69			130	240
Sediment	Oval pond near Chamber 14	4[E]	<0.39	<0.28	<0.77			210	370
Sediment	River Kennet	4[E]	<0.51	<0.39	<0.76			180	250
Sediment	Hosehill Lake	3[E]	<0.34	<0.25	<0.95			170	440
Gully Pot sediment	Falcon Gate	1[E]	<0.46	<0.39	<1.4			270	510
Gully Pot sediment	Tadley Entrance	1[E]	<0.22	0.16	<1.4			610	880
Gully Pot sediment	Burghfield Gate	1[E]	<0.31	<0.33	<1.8			240	560
Freshwater	Pangbourne	2[E]	<0.0021	<0.0017	<0.0047			<0.035	0.21
Freshwater	Mapledurham	2[E]	<0.0025	<0.0033	<0.0048			<0.041	0.19
Freshwater	Aldermaston	4[E]	<0.0034	<0.0023	<0.0044			<0.036	0.20
Freshwater	Spring Lane	4[E]	<0.0034	<0.0025	<0.0045			<0.025	0.15
Freshwater	Stream draining south	4[E]	<0.0041	<0.0030	<0.0053			<0.027	0.19
Freshwater	Near Chamber 39 of PPL	3[E]	<0.0053	<0.0039	<0.0044			<0.033	0.12
Freshwater	Oval pond near Chamber 14	4[E]	<0.0031	<0.0021	<0.0042			<0.022	0.076
Freshwater	River Kennet	4[E]	<0.0055	<0.0028	<0.0048			<0.032	0.11
Freshwater	Hosehill Lake	4[E]	<0.0048	<0.0030	<0.0035			<0.028	0.41
Crude liquid effluent	Silchester treatment works	2[E]	0.0063	<0.0019	<0.36			<0.068	0.59
Final liquid effluent	Silchester treatment works	2[E]	<0.0029	<0.0014	<0.36			<0.045	0.43
Sewage sludge	Silchester treatment works	2[E]	<0.0059	<0.0036	<0.18			<1.6	5.2

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	<3.8	<0.04	0.0054	<0.00046	<0.0038
Milk	max		<4.0		0.0079	<0.00052	0.0072
Carrots		1	<2.1	<0.05	0.0051	0.00051	0.0056
Wheat		1	<3.1	<0.03	<0.00059	<0.00042	<0.00059
Grass and herbage	0.25km east of Main gate	1[E]	<14	<0.67	0.12	<0.035	0.11
Grass and herbage	Opposite Gate 36	1[E]	<17	<1.4	0.11	<0.052	<0.087
Grass and herbage	Opposite Gate 26A	1[E]	<8.6	<1.1	0.15	<0.035	0.17
Grass and herbage	Tadley, Perimeter fence	1[E]	<8.3	<0.99	<0.060	<0.037	<0.060
Soil	0.25km east of Main gate	1[E]	<15	6.0	18	1.3	20
Soil	Opposite Gate 36	1[E]	<13	14	15	<1.1	15
Soil	Opposite Gate 26A	1[E]	<14	6.2	8.4	<0.81	9.6
Soil	Tadley, Perimeter fence	1[E]	<12	7.5	25	<1.8	26

Material	Location or selection[b]	No. of sampling observations[c]	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}				
			^{238}Pu	^{239}Pu + ^{240}Pu	^{241}Am	Gross alpha	Gross beta
Terrestrial samples							
Milk		2	0.000026	0.000020	0.000031		
Milk	max		0.000027	0.000022	0.000042		
Carrots		1	0.000013	0.000032	0.00013		
Wheat		1	0.000033	0.00013	0.00035		
Grass and herbage	0.25km east of Main gate	1[E]	<0.026	0.028		1.5	140
Grass and herbage	Opposite Gate 36	1[E]	0.095	0.013		<1.7	190
Grass and herbage	Opposite Gate 26A	1[E]	<0.016	<0.0066		2.6	150
Grass and herbage	Tadley, Perimeter fence	1[E]	<0.019	<0.010		1.8	150
Soil	0.25km east of Main gate	1[E]	<0.94	1.1		270	450
Soil	Opposite Gate 36	1[E]	<0.28	0.82		180	350
Soil	Opposite Gate 26A	1[E]	<0.20	0.47		110	250
Soil	Tadley, Perimeter fence	1[E]	<0.25	0.74		300	480

* *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, 2019

Location	Ground type	No. of sampling observations	µGy h^{-1}
Mean gamma dose rates at 1m over substrate			
Pangbourne, riverbank	Grass	1	0.066
Pangbourne, riverbank	Grass and mud	1	0.067
Mapledurham, riverbank	Grass and mud	2	0.065

Table 5.3(a) Concentrations of radionuclides in food and the environment near defence establishments, 2019

Material	Location or selection[a]	No. of sampling observ-ations	Mean radioactivity concentration (fresh)[b], Bq kg^{-1}							
			Organic ^{3}H	^{3}H	^{14}C	^{60}Co	^{95}Nb	^{125}Sb	^{131}I	^{137}Cs
Barrow										
Potatoes	Barrow	1[F]		<2.3		<0.07	<0.06	<0.12	<0.09	<0.06
Silage	Barrow	1[F]		<2.5		<0.17	<5.0	<0.37	*	2.4
Sediment	Walney Channel - N of discharge point	2				<0.57	<0.42	<1.9		91
Derby										
Potatoes	Derby	1[F]				<0.03	<0.04	<0.06	<0.07	<0.03
Wheat	Derby	1[F]				<0.08	<0.07	<0.15	<0.12	<0.06
Sediment	River Derwent, upstream	1				<0.37				1.8
Sediment	Fritchley Brook	1				<1.3				
Sediment	River Derwent, downstream	4				<1.5				4.5
Water	River Derwent, upstream	1				<0.36				
Water[c]	Fritchley Brook	1		<2.7		<0.43				<0.35
Water	River Derwent, downstream	4				<0.24				
Devonport										
Ballan wrasse	Plymouth Sound	1[F]	<25	<25	29	<0.07	<0.13	<0.17	<1.7	<0.07
Crabs	Plymouth Sound	1[F]			18	<0.15	<0.32	<0.28	<22	<0.10
Shrimp	River Lynher	1[F]			22	<0.04	<0.34	<0.13	*	<0.04
Mussels	River Lynher	1[F]	<25	<25	15	<0.10	<0.15	<0.21	<1.2	<0.09
Seaweed[d]	Kinterbury	2				<0.87				
Sediment[e]	Kinterbury	2		<23		<0.59				1.5
Sediment	Torpoint South	2		<8.1		<0.57				
Sediment	Lopwell	2		<70		<1.4				5.2
Seawater	Torpoint South	1		<3.0	<2.6	<0.35				
Seawater	Millbrook Lake	1		<3.0	<2.6	<0.33				
Sludge	Camel's Head Sewage Treatment Works	1		<21		<0.40			31	0.54
Barley		1[F]		<6.0		<0.04	<0.04	<0.10	<0.07	<0.05
Onion		1[F]		<2.3		<0.05	<0.08	<0.10	<0.13	<0.04
Faslane										
Mussels	Rhu	1				<0.10	<0.43	<0.25		0.18
Winkles	Rhu	1				<0.10	<0.92	<0.26		0.19
Fucus vesiculosus	Garelochhead	1				<0.10	<0.30	<0.21		0.39
Fucus vesiculosus	Carnban	1				<0.10	<0.28	<0.20		0.27
Fucus vesiculosus	Rhu	1				<0.10	<0.67	<0.19		1.0
Fucus vesiculosus	Cairndhu Point	1				<0.10	<0.91	<0.22		0.27
Fucus vesiculosus	Helensburgh	1				<0.10	<0.85	<0.22		0.43
Sediment	Garelochhead	1				<0.10	<0.19	<0.17		3.2
Sediment	Carnban	1				<0.10	<0.17	<0.15		1.4
Sediment	Rhu	1				<0.10	<0.10	<0.10		2.3
Seawater	Carnban	2		<1.0		<0.10	<0.11	<0.14		<0.10
Beef muscle	Faslane	1				<0.04	<0.12			<0.03
Honey	Faslane	1				<0.05	<0.05			0.15
Grass	Auchengaich Reservoir	1		<5.0		<0.05	<0.38			0.36
Grass	Lochan Ghlas Laoigh	1		<5.0		<0.05	<0.11			0.07
Soil	Auchengaich	1		<5.0		<0.05	<0.47			20
Soil	Lochan Ghlas Laoigh	1		<5.0		<0.15	<0.91			25
Freshwater	Helensburgh Reservoir	1		<1.0		<0.01	<0.03			<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

Table 5.3(a) continued

Material	Location or selection[a]	No. of sampling observ-ations	Mean radioactivity concentration (fresh)[b], Bq kg^{-1}							
			Organic ^{3}H	^{3}H	^{14}C	^{60}Co	^{95}Nb	^{125}Sb	^{131}I	^{137}Cs
Freshwater	Lochan Ghlas Laoigh	1		<1.0		<0.01	<0.02			<0.01
Freshwater	Loch Eck	1		<1.0		<0.01	<0.01			<0.01
Freshwater	Loch Lomond	1		<1.0		<0.01	<0.01			<0.01
Holy Loch										
Sediment	Mid-Loch	1				<0.10	<0.12	<0.21		3.0
Rosyth										
Mackerel	Rosyth	1				<0.10	<0.80	<0.17		0.19
Winkles	St David's Bay	1				<0.10	<0.61	<0.27		0.14
Fucus vesiculosus	East of dockyard	1				<0.10	<0.16	<0.20		<0.10
Sediment	East of dockyard	1				<0.10	<0.17	<0.13		2.0
Sediment	Port Edgar	1				<0.10	<0.17	<0.16		11
Sediment	West of dockyard	1				<0.10	<0.13	<0.10		0.66
Sediment	East Ness Pier	1				<0.10	<0.16	<0.13		3.2
Sediment	Blackness Castle	1				<0.10	<0.11	<0.10		1.4
Sediment	Charlestown Pier	1				<0.10	<0.21	<0.15		0.55
Seawater	East of dockyard	2		<1.0		<0.10	<0.16	<0.10		<0.10
Freshwater	Castlehill Reservoir	1		<1.0		<0.01	<0.01			<0.01
Freshwater	Holl Reservoir	1		<1.0		<0.01	<0.01			<0.01
Freshwater	Gartmorn Dam	1		<1.0		<0.01	<0.01			<0.01
Freshwater	Morton No. 2 Reservoir	1		<1.0		<0.01	<0.01			<0.01

Material	Location or selection[a]	No. of sampling observ-ations	Mean radioactivity concentration (fresh)[b], Bq kg^{-1}							
			^{154}Eu	^{155}Eu	^{234}U	^{235}U	^{238}U	^{241}Am	Gross alpha	Gross beta
Barrow										
Potatoes	Barrow	1[F]	<0.21	<0.29				<0.16		
Silage	Barrow	1[F]	<0.54	<0.69				<0.36		
Sediment	Walney Channel - N of discharge point	2	<1.6	<0.91				240	590	850
Derby										
Potatoes	Derby	1[F]	<0.09	<0.13	0.0062	0.00043	0.0070	<0.59		
Wheat	Derby	1[F]	<0.24	<0.18	<0.00038	<0.00038	<0.00038	<0.18		
Sediment	River Derwent, upstream	1			21	0.94	19		270	420
Sediment	Fritchley Brook	1			24	0.73	25		370	610
Sediment	River Derwent, downstream	4			37	1.7	35		430	660
Water	River Derwent, upstream	1							0.081	0.14
Water[c]	Fritchley Brook	1			0.0065	<0.0012	0.0058		0.031	0.20
Water	River Derwent, downstream	4							<0.043	0.13
Devonport										
Ballan wrasse	Plymouth Sound	1[F]	<0.28	<0.16				<0.20		
Crabs	Plymouth Sound	1[F]	<0.36	<0.21				<0.24		
Shrimp	River Lynher	1[F]	<0.14	<0.13				<0.13		
Mussels	River Lynher	1[F]	<0.27	<0.17				<0.18		
Sediment[e]	Kinterbury	2						<0.56		
Sludge	Camel's Head Sewage Treatment Works	1						0.78		
Barley		1[F]	<0.13	<0.19				<0.51		
Onion		1[F]	<0.14	<0.09				<0.11		

Table 5.3(a) continued

Material	Location or selection[a]	No. of sampling observ-ations	Mean radioactivity concentration (fresh)[b], Bq kg^{-1}							
			^{154}Eu	^{155}Eu	^{234}U	^{235}U	^{238}U	^{241}Am	Gross alpha	Gross beta
Faslane										
Mussels	Rhu	1	<0.11	<0.17				<0.10		
Winkles	Rhu	1	<0.11	<0.19				<0.11		
Fucus vesiculosus	Garelochhead	1	<0.12	<0.20				<0.13		
Fucus vesiculosus	Carnban	1	<0.10	<0.18				<0.12		
Fucus vesiculosus	Rhu	1	<0.11	<0.20				<0.14		
Fucus vesiculosus	Cairndhu Point	1	<0.12	<0.21				<0.13		
Fucus vesiculosus	Helensburgh	1	<0.12	<0.21				<0.14		
Sediment	Garelochhead	1	<0.15	0.51				<0.31		
Sediment	Carnban	1	<0.12	<0.25				<0.27		
Sediment	Rhu	1	<0.10	0.66				0.46		
Seawater	Carnban	2	<0.10	<0.12				<0.10		
Beef muscle	Faslane	1						<0.12		
Honey	Faslane	1						<0.06		
Grass	Auchengaich Reservoir	1		<0.15				<0.15		
Grass	Lochan Ghlas Laoigh	1		<0.07				<0.07		
Soil	Auchengaich	1		1.3				<0.26		
Soil	Lochan Ghlas Laoigh	1		1.4				<0.38		
Freshwater	Helensburgh Reservoir	1						<0.01	<0.010	0.014
Freshwater	Loch Finlas	1						<0.01	<0.010	0.023
Freshwater	Auchengaich Reservoir	1						<0.01	<0.010	0.013
Freshwater	Lochan Ghlas Laoigh	1						<0.01	<0.010	0.031
Freshwater	Loch Eck	1						<0.01	<0.010	0.021
Freshwater	Loch Lomond	1						<0.01	<0.010	0.019
Holy Loch										
Sediment	Mid-Loch	1	<0.20	0.76				<0.39		
Rosyth										
Mackerel	Rosyth	1	<0.10	<0.13				<0.10		
Winkles	St David's Bay	1	<0.14	<0.21				<0.12		
Fucus vesiculosus	East of dockyard	1	<0.10	<0.18				<0.12		
Sediment	East of dockyard	1	<0.13	<0.28				<0.28		
Sediment	Port Edgar	1	<0.11	1.5				1.7		
Sediment	West of dockyard	1	<0.10	0.31				<0.11		
Sediment	East Ness Pier	1	<0.12	<0.27				<0.27		
Sediment	Blackness Castle	1	<0.10	0.55				0.28		
Sediment	Charlestown Pier	1	<0.12	0.63				<0.21		
Seawater	East of dockyard	2	<0.10	<0.10				<0.10		
Freshwater	Castlehill Reservoir	1						<0.01	<0.010	0.033
Freshwater	Holl Reservoir	1						<0.01	0.11	0.17
Freshwater	Gartmorn Dam	1						<0.01	0.010	0.15
Freshwater	Morton No. 2 Reservoir	1						<0.01	<0.010	0.033

* *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 0.0060, 0.0058 and <0.0049 Bq l^{-1}, respectively*

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

[e] *The concentrations of ^{238}Pu and $^{239+240}Pu$ were <0.98 and 1.6 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, 2019

Establishment	Location	Ground type	No. of sampling observations	$\mu Gy\ h^{-1}$
Mean gamma dose rates at 1m over substrate				
Barrow	Askam Pier	Mud and sand	3	0.076
Barrow	Askam Pier	Sand and mud	1	0.088
Barrow	Walney Channel, N of discharge point	Mud and sand	3	0.077
Barrow	Walney Channel, N of discharge point	Sand	1	0.093
Barrow	Roa Island	Mud	1	0.085
Barrow	Roa Island	Sand	1	0.083
Devonport	Torpoint South	Mud and shingle	2	0.099
Devonport	Kinterbury Access Gate	Mud	1	0.078
Devonport	Kinterbury Access Gate	Mud and shingle	1	0.076
Devonport	Lopwell	Mud	1	0.085
Devonport	Lopwell	Mud and shingle	1	0.090
Faslane	Garelochhead	Sand	1	<0.047
Faslane	Garelochhead	Sediment	1	0.054
Faslane	Gulley Bridge Pier	Sediment	1	0.057
Faslane	Gulley Bridge Pier	Sediment and stones	1	0.050
Faslane	Rhu	Sand	1	<0.047
Faslane	Rhu	Sediment	1	0.047
Faslane	Helensburgh	Sand	1	<0.047
Faslane	Helensburgh	Sediment	1	0.055
Faslane	Carnban	Rocks and sediment	1	0.057
Faslane	Carnban	Sediment and stones	1	0.050
Faslane	Rahane	Rocks and sediment	1	0.065
Faslane	Rahane	Sediment and stones	1	0.055
Faslane	Rosneath Bay	Sediment	1	0.054
Faslane	Rosneath Bay	Sediment and stones	1	0.055
Faslane	Auchengaich	Grass	1	<0.047
Faslane	Lochan Ghlas	Grass	1	0.064
Holy Loch	Kilmun Pier	Rocks	1	0.061
Holy Loch	Mid-Loch	Sediment	1	0.059
Holy Loch	North Sandbank	Sediment	1	0.055
Rosyth	Blackness Castle	Rocks and sediment	1	<0.047
Rosyth	Blackness Castle	Sand	1	0.061
Rosyth	Charlestown Pier	Sand	1	0.053
Rosyth	Charlestown Pier	Sediment	1	0.052
Rosyth	East Ness Pier	Sand	1	0.053
Rosyth	East Ness Pier	Sediment	1	<0.047
Rosyth	East of Dockyard	Sand	1	0.049
Rosyth	East of Dockyard	Sediment	1	<0.047
Rosyth	Port Edgar	Sediment	2	0.054
Rosyth	West of Dockyard	Sand	1	<0.047
Rosyth	West of Dockyard	Sediment	1	<0.047

6. Industrial, landfill, legacy and other non-nuclear sites

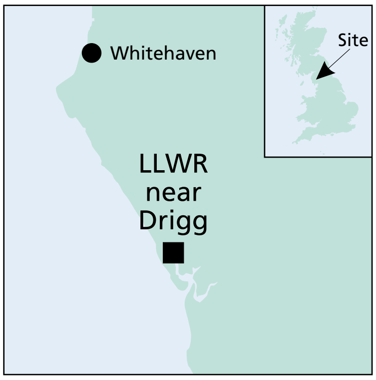
This section considers the results of monitoring by the Environment Agency, FSA and SEPA for industrial, landfill, legacy and other non-nuclear sites that may have introduced radioactivity into the environment:

(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 in England, near Whitehaven (Cumbria), which used to manufacture phosphoric acid from imported phosphate ore,
(iii) two legacy sites in Scotland, at Dalgety Bay (Fife) and Kinloss (Moray),
(iv) other non-nuclear sites.

Key points

- Doses (dominated by the effects of legacy discharges from other sources) decreased at the LLWR in 2019
- Doses at landfill sites (excluding the LLWR) were less than 0.5 per cent of the dose limit in 2019
- Doses (dominated by the effects of naturally occurring radionuclides from legacy discharges) decreased at Whitehaven in 2019

6.1 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 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 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). LLWR's Plutonium Contaminated Materials (PCM) Decommissioning Programme was completed in 2019 (almost 4 years ahead of schedule). Five decommissioned concrete bunkers which housed legacy PCM, will be demolished and material re-used as in-fill for the final engineered cap over vaults and trenches.

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 2019, be distinguished from those due to Sellafield.

The current permit 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). In 2019, Revised Joint Waste Management Plans (JWMP) were published (in conjunction with LLW Repository Limited) for three radioactive waste-producing site licence companies (LLWR Limited, Magnox Limited and Sellafield Limited), covering the next five financial years (2019/20 – 2023/24). More information can be found at the UK.Gov website: **https://www.gov.uk/government/collections/joint-waste-management-plans-jwmp**.

As emplacement of waste in its final disposal location, it is intended in future 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 2019/20) 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 693 m^3 of waste was received by the site with the intention of disposal in financial year 2019/2020, 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 has continued for samples of water and sediment. The results are given in Table 6.2. 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. Concentrations of some radionuclides (plutonium-238 and plutonium-239+240) in sediment from the Drigg stream were higher in 2019, in comparison to those in 2018, but similar to those in previous years. 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 2019 show that the activity concentrations have continued to be very low in the railway drain and have reduced significantly since the construction of the "cut-off wall". 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 2019 are given in Table 6.2 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 2.3). A new habits survey for Sellafield was published in 2020 and the results have been included in the dose assessments for the site (Moore *et al*., 2020a).

The *total dose* from all pathways and sources of radiation was 0.24 mSv in 2019, or 24 per cent of the dose limit for members of the public of 1 mSv (Tables 1.2 and 6.1) 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* from gaseous releases and direct radiation was 0.029 mSv in 2019 (Table 1.2). The representative person was adults living near the site. The decrease in *total dose* (from 0.053 mSv in 2018) was due to a lower estimate of direct radiation from the site in 2019. A source specific assessment of exposure for consumers of locally grown terrestrial food (animals fed on oats), using 2019 modelled activity concentrations in animal products, gives an exposure that was 0.005 mSv in 2019, and similar to that in recent years.

6.2 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 permit for the MRF site 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 2019 (Appendix 2, Tables A2.1 and A2.2). The permit includes conditions requiring Cyclife UK Limited to monitor discharges and undertake environmental monitoring. In 2019, direct radiation from the site was less than 0.001 mSv (Table 1.1) and the radiological impact was very low.

6.3 Other landfill sites

Some organisations are granted authorisations by SEPA (in Scotland) or permits by the Environment Agency (in England and Wales*) 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 2019 are shown

* *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.*

in Figure 6.1 and the results are presented in Tables 6.3 and 6.4.

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 Summerston landfill (City of Glasgow) site (with the highest observed concentration of tritium) would result in a dose of less than 0.005 mSv in 2019 (Table 6.1), 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 2019.

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.
- 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 2019, 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 6.5. 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 6.5, the dose in 2019 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 6.1). The assessment excludes potassium-40 because its presence is homeostatically controlled in the body.

The Environment Agency has received an application from FCC Recycling (UK) Limited to vary Lillyhall landfill site's environmental permit. Currently, Lillyhall landfill site is permitted to accept radioactive waste at very low levels (a maximum average activity of 4 Bq g^{-1}, or 40 Bq g^{-1} for tritium). The permit was granted in 2011 and to date the landfill has not accepted any radioactive waste. The operator is proposing to increase the activity limits to a maximum average activity of 200 Bq/g, as the current limits are very restrictive. Subsequently, the Environment Agency launched a consultation on the application between March and May 2019. The Environment Agency expect a decision to be made on the application in 2020 (**https://consult.environment-agency.gov.uk/cumbria-and-lancashire/lillyhall-landfill-site-rsa-permit-variation/**).

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.

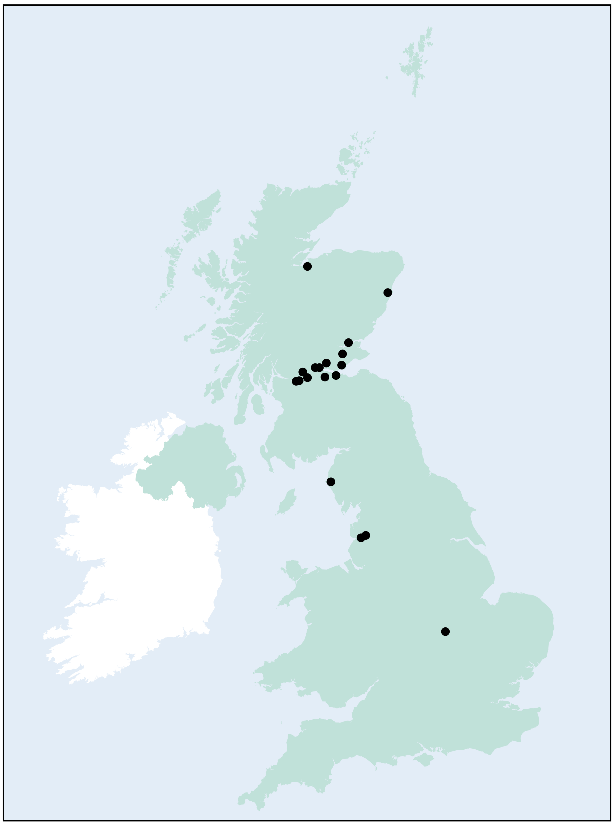


Figure 6.1. Landfill sites monitored in 2019

6.4 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 is regarded as Technologically Enhanced Naturally Occurring Radioactive Material (TENORM) i.e. elevated levels of naturally occurring radioactive material resulting from industrial activity. Historical discharges continue to have an impact (close to the former discharge point), through the production of the radioactive products. The impact is due to the decay of 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. The plant was subsequently decommissioned and 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 2019 are shown in Table 6.6. 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 6.2 and 6.3 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 2019 (where comparisons can be made), in comparison with those in 2018. Polonium-210 concentrations were generally lower in both crab and lobster samples in 2019, and as in recent years, these concentrations continued to be within or close to the expected range due to natural sources. For crustacean 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 6.2 and 6.3 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 whilst there remains an indication that concentrations are higher than natural background. Further analysis has confirmed that this approach is unlikely to underestimate doses (Dewar *et al.,* 2014).

In 2018, the Environment Agency, with the support of FSA, NIEA and SEPA, performed additional polonium-210 analyses in shellfish samples to obtain baseline data, providing naturally sourced polonium-210 concentrations that are unlikely to be influenced by TENORM in the Irish Sea. Further details are presented in RIFE 24 (Environment Agency, FSA, FSS, NIEA, NRW and SEPA, 2019).

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 Cumbrian coastal community consumer who, centred on the Sellafield site to the south of Whitehaven, obtained their sources of seafood

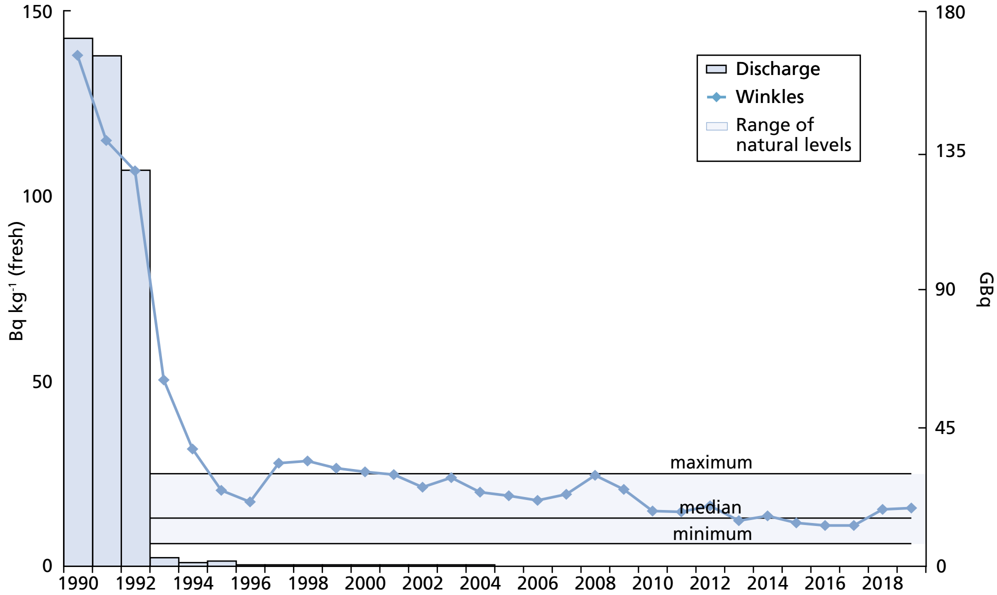


Figure 6.2. Polonium-210 discharge from Whitehaven and concentration in winkles at Parton, 1990-2019

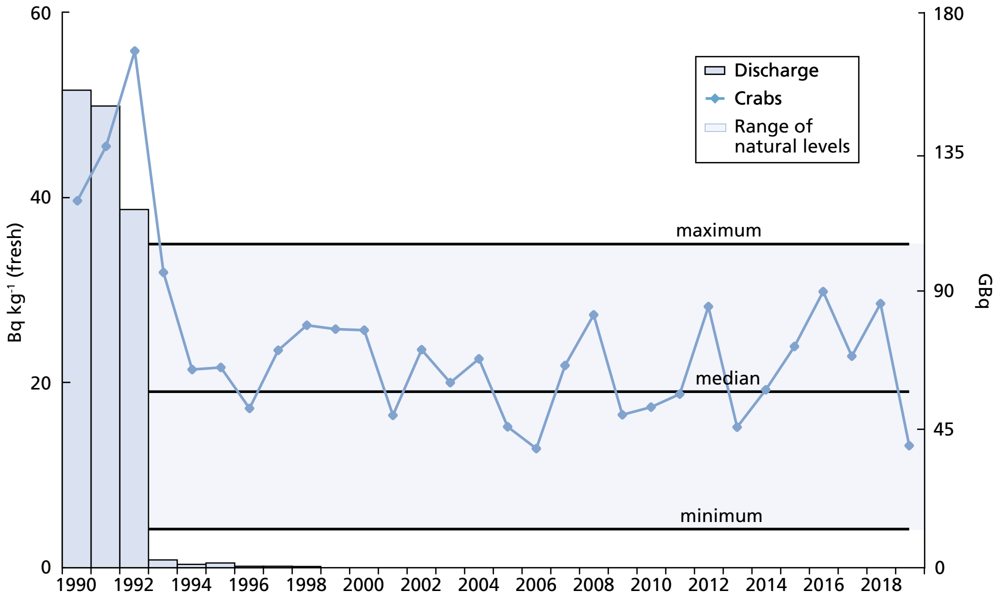


Figure 6.3. Polonium-210 discharge from Whitehaven and concentration in crabs at Parton, 1990-2019

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 6.1). 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 2019 (Moore *et al.*, 2020a). 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 0.24 mSv in 2019 (Table 6.1), or 24 per cent of the dose limit to members of the public, and down from 0.37 mSv in 2018. 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 0.19 mSv, and was lower in 2019, in comparison to that in 2018 (0.33 mSv). The decrease in *total dose* in 2019 was mostly attributed to lower concentrations of polonium-210 in locally caught crustacean shellfish (crabs), in comparison to those in 2018. The largest contribution to dose to a Cumbrian coastal community seafood consumer near Whitehaven and Sellafield continues to be from the legacy of historical discharges near Whitehaven. A source specific dose assessment targeted directly at local consumers of seafood (at high-rates), gives an exposure of 0.27 mSv in 2019 (Table 6.1).

The longer-term trend in annual *total dose* over the period 2008 – 2019 is shown in Figure 6.4. 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 crustaceans. Over a longer period, the trend is of generally declining dose (Figure 7.4, Environment Agency, FSA, FSS, NIEA, NRW and SEPA, 2018).

6.5 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, 2017).

Additional public protection measures were established following the increased number of particle finds and the discovery of the high activity particles in 2011. These were maintained during 2019 and into 2020. 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 Person 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. Work continues towards the implementation of the preferred management option, working collaboratively with stakeholders. 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**.

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

The remediation contract was awarded by MoD in February 2020 with the intention of the remediation works taking place over summer 2020, 2021 and possibly into summer 2022. However, SEPA have had confirmation from MoD that their contractor will not be on site at Dalgety Bay in 2020 and that remediation works will progress in 2021. MoD have confirmed that they have submitted an amendment to the Fife Council Planning Department which will extend the existing planning permission for the remediation works by three years. SEPA is continuing

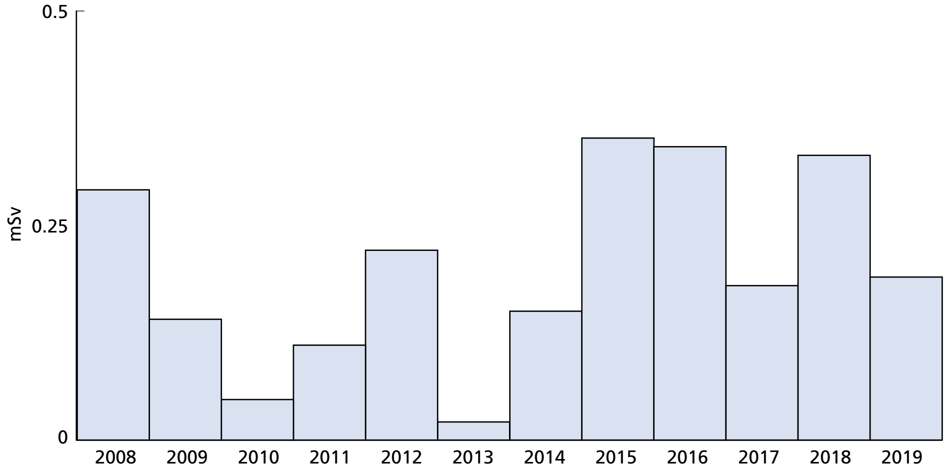


Figure 6.4. Trend in *total dose* to seafood consumers from naturally-occurring radionuclides near Whitehaven, 2008-2019

to work with the MoD and their contractors with regard to the remediation methodology for the site and the associated regulatory permits.

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/**.

6.6 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 (Natural Scotland and 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**.

6.7 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 the atmosphere 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 2019 is given in Tables 6.7 and 6.8. Data for Scotland are presented in Tables 6.9 and 6.10 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 2019, 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 sewage treatment works (at Daldowie). The results are given in Table 6.11.

The results in 2019 were generally similar to those in 2018. 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 estimated to be 0.013 mSv in 2019, or approximately 1 per cent of the dose limit for members of the public, and up from less than 0.005 mSv in 2018. The apparent increase in dose was due to an increase in the less than value for iodine-131 in a mussel sample (< 29 Bq kg^{-1}) in 2019 (in comparison to < 0.33 Bq kg^{-1} in 2018).

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 and made discharges to sea. Monitoring of seaweed (*Fucus vesiculosus*) from Aberdeen Harbour was not carried out in 2019 (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 2019, the dose rate on sediment was 0.080 μGy h^{-1} and similar to background.

Table 6.1 Individual doses – industrial and landfill sites, 2019

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[c]	Intakes of sediment and water[d]
***Total dose* – all sources**							
Whitehaven and LLWR near Drigg	**Adult molluscs consumers**	**0.24[e]**	**0.035**	**0.19**	**-**	**0.018**	**-**
Source specific doses							
LLWR near Drigg	Infant consumers of locally grown food	0.005	-	-	0.005	-	-
	Consumers of water from Drigg stream	<0.005[f]	-	-	-	-	<0.005
Landfill sites for low-level radioactive wastes	Inadvertent leachate consumers (infants)	<0.005	-	-	-	-	<0.005
Whitehaven (habits averaged 2015-19)	Seafood consumers	0.27[d]	0.035	0.21	-	0.027	-

[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. Data are presented to 2 significant figures or 3 decimal places. Data below 0.005 mSv are reported as <0.005 mSv*

[b] *None of the people represented in this table were considered to receive direct radiation from the sites listed*

[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)*

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

[e] *Includes the effects of discharges from the adjacent Sellafield site*

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

Table 6.2 Concentrations of radionuclides in terrestrial food and the environment near Drigg, 2019

Material	Location or selection	No. of sampling observ-ations[a]	Mean radioactivity concentration (fresh)[b], Bq kg^{-1}								
			^{3}H	^{14}C	^{60}Co	^{90}Sr	^{95}Zr	^{95}Nb	^{99}Tc	^{106}Ru	^{125}Sb
Milk		1	<6.4	17	<0.03	0.031	<0.07	<0.05	<0.012	<0.29	<0.08
Deer muscle		1	<2.9	41	<0.04	<0.041	<0.06	<0.04	<0.080	<0.27	<0.09
Eggs		1	<6.6	29	<0.04	<0.044	<0.05	<0.07		<0.27	<0.08
Potatoes		1	<2.3	26	<0.05	0.051	<0.12	<0.04	<0.17	<0.51	<0.09
Sheep muscle		1	<3.3	29	<0.04	<0.042	<0.05	<0.07	<0.065	<0.28	<0.09
Sheep offal		1	<4.2	27	<0.05	0.013	<0.08	<0.09	<0.12	<0.38	<0.11
Oats		1	<4.0	44	<0.08	0.35	<0.07	<0.05	<0.16	<0.42	<0.13
Sediment	Drigg Stream	4[E]			<0.40	<1.2	<0.57	<0.32		<2.6	<1.4
Freshwater	Drigg Stream	4[E]	<3.1		<0.34	<0.029					
Freshwater	Railway drain	1[E]	<3.6		<0.30						

Material	Location or selection	No. of sampling observ-ations[a]	Mean radioactivity concentration (fresh)[b], Bq kg^{-1}								
			^{129}I	^{134}Cs	^{137}Cs	Total Cs	^{144}Ce	^{210}Po	^{228}Th	^{230}Th	^{232}Th
Milk		1	<0.0030	<0.04	<0.14		<0.26				
Deer muscle		1	<0.015	<0.03	2.0	2.0	<0.18				
Eggs		1	<0.022	<0.03	<0.05	<0.047	<0.17				
Potatoes		1	<0.024	<0.04	0.18	0.18	<0.18				
Sheep muscle		1	<0.014	<0.03	0.55	0.55	<0.18				
Sheep offal		1	<0.019	<0.05	0.27	0.27	<0.26				
Oats		1	<0.024	<0.05	0.20	0.20	<0.26				
Sediment	Drigg Stream	4[E]		<0.38	56		<1.5	16	16	21	16
Freshwater	Drigg Stream	4[E]		<0.35	<0.27			<0.0063	<0.0043	<0.0016	<0.00090
Freshwater	Railway drain	1[E]		<0.30	<0.24			<0.0080	<0.0043	<0.0012	<0.00095

Material	Location or selection	No. of sampling observ-ations[a]	Mean radioactivity concentration (fresh)[b], Bq kg^{-1}								
			^{234}U	^{235}U	^{238}U	^{238}Pu	^{239}Pu + ^{240}Pu	^{241}Pu	^{241}Am	Gross alpha	Gross beta
Milk		1				<0.000067	<0.000077	<0.21	<0.000023		
Deer muscle		1				0.00016	0.00010	<0.43	0.00014		
Eggs		1				<0.000091	0.00021	<0.25	0.00029		
Potatoes		1				0.000044	0.00067	<0.28	0.00088		
Sheep muscle		1				0.000066	0.00046	<0.25	0.0012		
Sheep offal		1				0.0016	0.0098	<0.41	0.012		
Oats		1				0.00093	0.0068	<0.32	0.015		
Sediment	Drigg Stream	4[E]	20	<1.8	19	4.6	33	75	35	190	450
Freshwater	Drigg Stream	4[E]	<0.0096	<0.0018	<0.0075	<0.0028	<0.0020	<0.30	<0.0052	<0.037	0.37
Freshwater	Railway drain	1[E]	0.005	<0.00089	0.0038	<0.0035	<0.0017	<0.098	<0.0031	0.036	0.41

[a] *The number of farms from which milk is sampled. The number of analyses is greater than this and depends on the bulking regime*
[b] *Except for milk and freshwater where units are Bq l^{-1}, and for sediment where dry concentrations apply*
[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 6.3 Concentrations of radionuclides in surface water leachate from landfill sites in Scotland, 2019

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	160	<15	<0.05	<0.05
City of Glasgow	Cathkin	1	97	<15	<0.05	<0.05
Clackmannanshire	Black Devon	1	20	<15	<0.05	<0.05
Dumbartonshire	Birdston	1	<5.0	<15	<0.05	<0.05
Dundee City	Riverside	1	<5.0	<15	<0.05	<0.05
Edinburgh	Braehead	1	<5.0	<15	<0.05	<0.05
Fife	Balbarton	1	20	<15	<0.05	<0.05
Fife	Melville Wood	1	87	<15	<0.05	<0.05
Highland	Longman landfill	1	<5.0	<15	<0.05	<0.05
North Lanarkshire	Dalmacoulter	1	110	<15	<0.05	<0.05
North Lanarkshire	Kilgarth	1	<5.0	<15	<0.05	<0.05
Stirling	Lower Polmaise	1	120	<15	0.06	<0.05

Table 6.4 Concentrations of radionuclides in water from landfill sites in England and Wales, 2019

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	<2.8	<5.3	<0.34	<0.27	<0.0045	<0.0014
Clifton Marsh	Borehole 19	2	<3.9	<6.7	<0.38	<0.31	<0.0053	<0.0015
Clifton Marsh	Borehole 40	2	<2.9	<4.0	<0.28	<0.22	<0.0048	<0.0038
Clifton Marsh	Borehole 59	2	13	<4.3	<0.30	<0.24	<0.0055	<0.0015

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	<0.0010	0.15	0.0094	0.14	0.34	0.97
Clifton Marsh	Borehole 19	2	<0.0035	0.062	<0.0029	0.052	<0.99	5.1
Clifton Marsh	Borehole 40	2	<0.0031	0.0055	<0.0010	0.0042	<0.11	1.1
Clifton Marsh	Borehole 59	2	<0.0014	0.014	<0.0014	0.011	<0.16	1.4

Table 6.5 Concentrations of radionuclides in water near the East Northants Resource Management Facility landfill site, 2019

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	<2.8	<8.1	<0.33	0.016	<0.0042	<0.00092	<0.00062	0.030	<0.0024	0.029	0.11	0.28
K15A Groundwater borehole	<2.9	<8.2	<0.35	0.034	<0.0033	<0.0011	<0.00079	0.015	<0.0018	0.015	0.13	0.12
K17 Northern perimeter Groundwater borehole	<2.8	<6.1	<0.28	0.034	<0.0033	<0.00092	<0.00039	0.035	<0.0020	0.032	<0.15	0.78
Horse Water spring		<6.2	<0.28								<0.046	0.43
Willow brook		<4.8	<0.22								<0.054	0.39

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

Table 6.6 Concentrations of naturally occurring radionuclides in the environment, 2019[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	16	1.1						
Winkles	Nethertown	4	11	1.5	0.75	0.58	0.52	0.82	0.034	0.74
Winkles	Ravenglass	2	16	1.4						
Mussels	Whitehaven	2	37	1.4						
Prawns	Seascale	1	3.4	0.0028						
Crabs	Parton	2	13	0.21						
Crabs	Sellafield coastal area	2	12	<0.026	0.093	0.015	0.010	0.074	0.0024	0.070
Lobsters	Parton	2	22	0.013						
Lobsters	Sellafield coastal area	2	9.3	<0.011						
Nephrops	Whitehaven	2	2.5	0.16	0.022	0.019	0.012	0.033	0.0011	0.030
Cod	Parton	1	0.70	0.011						
Cod	Whitehaven	1	0.63	0.0095						
Plaice	Whitehaven	2	2.0	0.22	0.035	0.00072	<0.00011	0.024	0.0011	0.020
Plaice	Drigg	2	1.5	0.25	0.051	0.00060	0.0017	0.031	0.0011	0.025
Annual samples (further afield)										
Winkles	South Gare (Hartlepool)	2	14	1.9						
Winkles	Middleton Sands	2	12							
Mussels	Morecambe	2	34							
Mussels	Ribble Estuary	1			0.17	0.078	0.036			
Limpets	Kirkcudbright	1[S]	3.4							
Crabs	Kirkcudbright	2[S]	3.0							
Lobsters	Kirkcudbright	2[S]	2.2							
Shrimps	Ribble Estuary	1			0.015	0.0027	0.011			
Wildfowl	Ribble Estuary	1				0.0065	0.00091			
Sediment	Kirkcudbright	2[S]						12	0.43	11
Sediment	Rascarrel Bay	1[S]						5.3	0.32	4.2

[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*
[S] *Measurements are made on behalf of the Scottish Environment Protection Agency, all other measurements are made on behalf of the Food Standards Agency*

Table 6.7 Discharges of gaseous radioactive wastes from non-nuclear establishments in England, Northern Ireland and Wales, 2019[a]

	Discharges during 2019, 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					2.3E+12	
^{14}C	3.0E+08				4.4E+13	1.0E+09
^{18}F	1.7E+11		1.1E+08		5.7E+11	
^{35}S			1.5E+08		1.3E+08	
^{99m}Tc			1.3E+08		1.0E+06	
^{106}Ru					1.0E+06	
^{125}I	5.0E+04		3.2E+07		1.7E+08	
^{129}I					3.5E+06	
^{131}I			1.4E+08		3.2E+08	
^{131m}			1.2E+08			
^{137}Xe					1.2E+09	
Uranium Alpha					1.0E+00	
Plutonium Alpha					2.2E+02	
^{241}Am					4.1E+02	
Other Alpha particulate			1.8E+07		4.7E+10	
Other Beta/Gamma				2.4E+11		
Other Beta/Gamma Particulate	8.0E+11		9.7E+07		1.6E+13	

[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 2018*

Table 6.8 Discharges of liquid radioactive waste from non-nuclear establishments in England, Northern Ireland and Wales, 2019[a]

	Discharges during 2019, 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	6.1E+09		1.8E+08	7.9E+07	1.3E+13		
^{14}C	4.1E+08		1.2E+06		4.3E+11		
^{18}F	7.0E+11		4.0E+12	1.7E+11	3.6E+12		
^{32}P	3.6E+09		4.4E+09		1.1E+08		
^{33}P	1.2E+08		9.1E+07		3.0E+07		
^{35}S	5.2E+09		7.1E+08		1.7E+09		
^{51}Cr	3.5E+08		4.0E+10	9.8E+07	1.7E+09		
^{57}Co			6.7E+07		2.6E+03		
^{60}Co					2.3E+06		
^{67}Ga	5.3E+07		4.2E+09				
^{75}Se	6.9E+07		4.3E+10	1.4E+08	8.5E+07		
^{89}Sr			7.1E+08				
^{90}Sr	1.8E+07				4.0E+01		
^{90}Y			5.0E+11	1.4E+09			
^{99}Tc	1.0E+07		1.2E+11		5.0E+02		
^{99m}Tc	1.8E+11		4.7E+13	1.4E+12	6.5E+11		
^{111}In	9.6E+08		1.8E+11	2.3E+09	2.0E+08		
^{123}I	3.3E+11		9.2E+11	3.1E+10	1.5E+10		
^{125}I	2.4E+09	7.0E+07	2.4E+09		1.1E+10		
^{129}I					1.0E+00		
^{131}I			8.3E+12	2.6E+11	2.5E+11		
^{134}Cs					2.7E+07		
^{137}Cs	3.7E+07				5.6E+09		
^{153}Sm			1.4E+09	1.2E+09			
^{201}Tl			1.8E+10				
^{230}Th					2.3E+08		
^{232}Th	1.5E+06				4.3E+08		
Uranium Alpha	2.1E+07				4.9E+08		
^{237}Np					1.0E+00		
^{241}Pu					8.2E+03		
Plutonium Alpha					2.0E+03		
^{241}Am	1.2E+06		4.4E+02		8.9E+03		
^{242}Cm					5.0E+00		
Total Alpha	2.4E+07		2.4E+11	4.0E+05	4.0E+10		3.1E+09
Total Beta/Gamma (excl Tritium)	1.2E+12		6.0E+13		4.4E+12		2.6E+09
Other Alpha particulate	3.4E+03		8.7E+09		6.4E+07		
Other Beta/Gamma[b]	6.8E+10		3.6E+12		1.3E+11		
Other Beta/Gamma particulate					4.6E+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 2018*

[b] *Excluding specific radionuclides*

Table 6.9 Discharges of gaseous radioactive wastes from non-nuclear establishments in Scotland by OSPAR region, 2019[a]

	Discharges during 2019, Bq					
	OSPAR Region II – Greater North Sea			OSPAR Region III – Celtic Seas		
	Education (Universities and Colleges)	Hospitals	Other (Research, manufacturing and public sector)	Education (Universities and Colleges)	Hospitals	Other (Research, manufacturing and public sector)
^{3}H	Nil	Nil	Nil	Nil	Nil	Nil
^{14}C	Nil	Nil	3.7E+02	Nil	7.1E+07	Nil
^{18}F	Nil	Nil	Nil	Nil	5.9E+09	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	6.2E+09	Nil	Nil	7.2E+05
Other Alpha	Nil	Nil	Nil	Nil	Nil	4.0E+00
Other Beta/Gamma	2.9E+11	Nil	Nil	8.0E+04	Nil	2.3E+02
Other Radionuclides Not Listed	1.8E+10	Nil	Nil	Nil	1.4E+10	Nil

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

Table 6.10 Discharges of liquid radioactive waste from non-nuclear establishments in Scotland by OSPAR region, 2019[a]

	Discharges during 2019, 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	2.4E+08	Nil	3.6E+09	Nil	2.8E+08	7.0E+06	3.8E+07
^{14}C	5.6E+06	Nil	1.9E+10	Nil	3.6E+06	1.3E+08	6.7E+04
^{18}F	Nil	1.2E+11	2.0E+07	Nil	Nil	3.2E+11	Nil
^{22}Na	3.0E+06	Nil	Nil	Nil	Nil	Nil	Nil
^{32}P	3.4E+08	1.2E+08	4.6E+08	Nil	2.0E+08	1.9E+08	Nil
^{33}P	2.9E+09	Nil	Nil	Nil	Nil	Nil	Nil
^{35}S	8.1E+08	Nil	1.2E+08	Nil	2.1E+09	Nil	Nil
^{51}Cr	Nil	1.5E+08	Nil	Nil	Nil	1.0E+08	Nil
^{57}Co	Nil	Nil	Nil	Nil	Nil	Nil	Nil
^{60}Co	Nil	Nil	Nil	Nil	Nil	Nil	Nil
^{67}Ga	Nil	Nil	Nil	Nil	Nil	Nil	Nil
^{75}Se	Nil	8.9E+07	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	5.2E+08	Nil	Nil	Nil	1.2E+08	Nil
^{99m}Tc	Nil	3.0E+12	Nil	Nil	Nil	2.6E+12	Nil
^{111}In	Nil	4.6E+09	Nil	Nil	Nil	4.8E+08	Nil
^{123}I	3.1E+10	4.6E+10	Nil	Nil	Nil	2.5E+10	Nil
^{125}I	1.1E+06	6.7E+06	Nil	Nil	Nil	8.2E+06	2.1E+06
^{131}I	4.9E+09	3.2E+11	Nil	Nil	Nil	3.3E+11	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	5.3E+05	7.6E+08	Nil	Nil	Nil
^{210}Po	Nil	Nil	5.3E+05	7.6E+08	Nil	Nil	Nil
^{226}Ra	Nil	Nil	2.3E+05	2.2E+09	Nil	Nil	Nil
^{228}Ra	Nil	Nil	7.0E+04	2.4E+09	Nil	Nil	Nil
^{232}Th	Nil	Nil	1.6E+05	Nil	Nil	Nil	8.2E+05
Uranium Alpha	Nil	Nil	2.3E+05	Nil	Nil	Nil	Nil
^{237}Np	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Plutonium Alpha	Nil	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	3.3E+06
Other Alpha	Nil	1.7E+08	Nil	Nil	Nil	Nil	6.1E+04
Other Beta/Gamma[b]	1.6E+11	1.9E+09	4.9E+01	Nil	Nil	5.8E+10	1.0E+06
Other Radionuclide Not Listed	Nil	3.8E+08	6.5E+07	Nil	Nil	6.9E+11	Nil

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

Table 6.11 Monitoring in the Firth of Forth, River Clyde and near Glasgow, 2019[a]

Location	Material and selection[b]	No. of sampling observations	Mean radioactivity concentration (fresh)[b], Bq kg^{-1}					
			^{3}H	^{14}C	^{54}Mn	^{90}Sr	^{95}Nb	^{99}Tc
Between Finlaystone and Woodhall	Mussels	1		16	<0.10		<0.23	2.7
Between Finlaystone and Woodhall	*Fucus vesiculosus*	1			<0.10		<0.10	27
Dalmuir Clydebank	Sediment	1		<15	<0.10		<0.10	
Downstream of Dalmuir	Freshwater	4			<0.10		<0.10	
River Clyde	Freshwater	4	<1.1			<0.016		
Firth of Forth	Freshwater	4	<1.0			<0.0050		
Daldowie	Sludge pellets	4			<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	<0.18	<29	<0.10	<0.12	<0.10	
Between Finlaystone and Woodhall	*Fucus vesiculosus*	1	<0.10	9.0	0.34	<0.10	<0.10	
Dalmuir Clydebank	Sediment	1	<0.17	0.27	5.4	<0.24	0.58	
Downstream of Dalmuir	Freshwater	4	<0.12	<0.10	<0.10	<0.14	<0.13	
River Clyde	Freshwater	4			<0.01			0.61
Firth of Forth	Freshwater	4			<0.01			4.9
Daldowie	Sludge pellets	4	<0.24	74	2.3	<0.54	<0.59	

[a] *Results are available for other radionuclides detected by gamma spectrometry. All such results are less than the limit of detection. No ^{32}P analyses were performed in 2019*

[b] *Except for water where units are Bq l^{-1}, and sludge pellets and sediment where dry concentrations apply*

7. Regional monitoring

Regional monitoring in areas remote from nuclear licensed sites has continued in 2019:

(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 2019

7.1 Channel Islands

Samples of marine environmental materials were provided by the Channel Island States and measured for a range of radionuclides. 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 2019 are given in Table 7.1. There was evidence of routine releases from the nuclear industry in some food and environmental samples (e.g. 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.

In 2019, the dose to a representative person, consuming large amounts of fish and shellfish 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. 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.

Collection of 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.

7.2 Isle of Man

The Environment Agency has carried out a review of its environmental monitoring on the Isle of Man. Following this review, the Environment Agency's marine monitoring on 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/**.

7.3 Northern Ireland

NIEA monitors the far-field effects of liquid discharges from Sellafield into the Irish Sea. The programme involved sampling fish, shellfish and indicator materials from a range of locations along the coastline (Figure 7.1). Gamma dose rates were measured over intertidal areas to assess the external exposure pathway. The results of monitoring are given in Tables 7.2(a) and (b).

In 2019, the main effect of discharges from Sellafield was observed in concentrations of technetium-99 in shellfish and seaweed samples. These were similar to

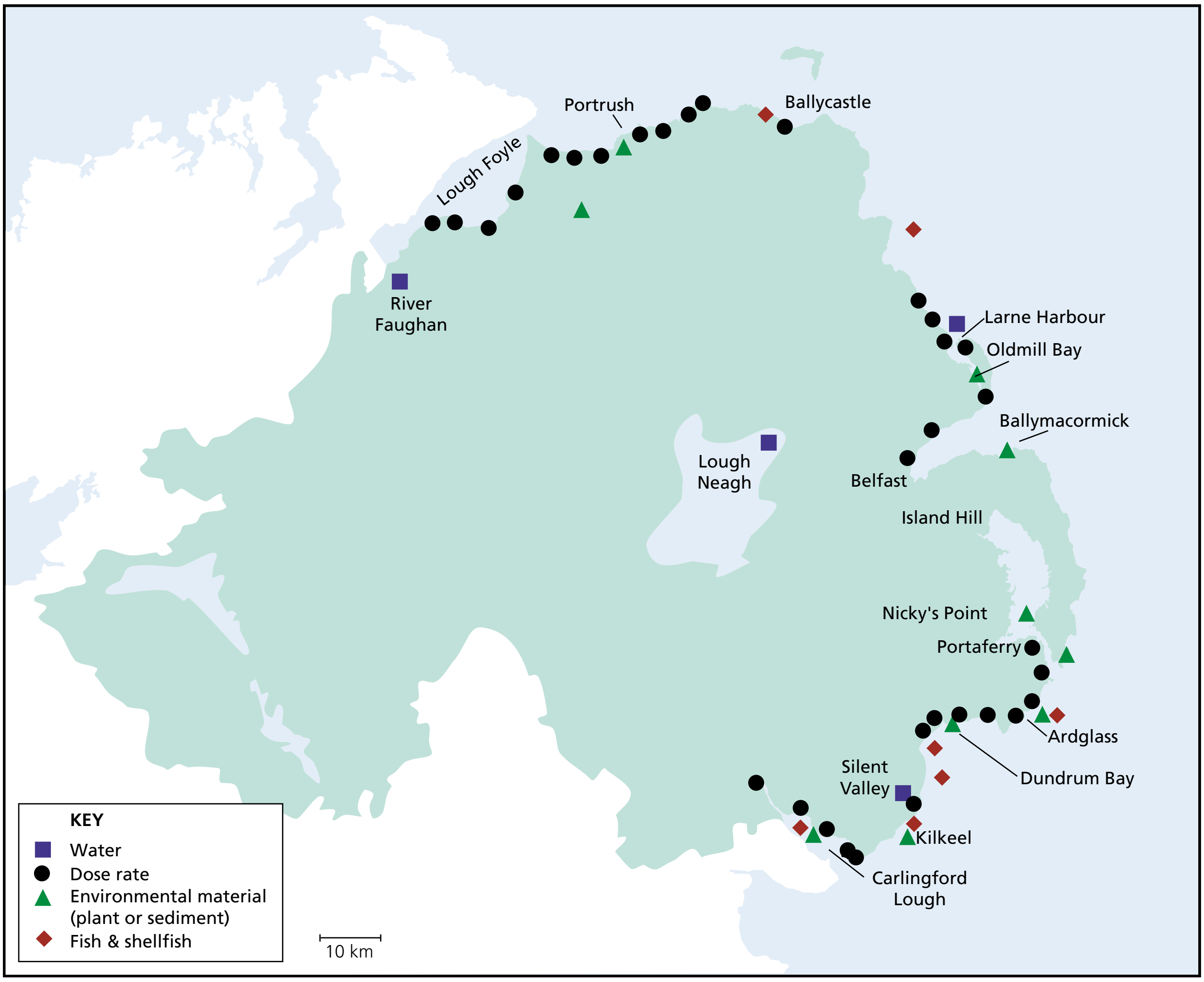


Figure 7.1. Monitoring locations in Northern Ireland, 2019

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 2018. As expected, low concentrations of transuranic radionuclides were also detected in 2019. Reported concentrations are less than those found nearer to Sellafield and continued to be low, as in recent years (Figure 7.2). 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 the habits of people consuming large quantities of fish and shellfish (Smith *et al*., 2002). Based on the monitoring results from the marine environment in 2019, the annual dose from the consumption of seafood and exposure over intertidal areas was 0.010 mSv (Table 2.16), or less than 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 7.

7.4 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 7.5 and 7.6) 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 2019, 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 7.3). Activity concentrations were generally similar to those in previous years.

7.5 Milk

The programme of milk sampling across dairies in the UK continued in 2019. The aim is to collect and analyse

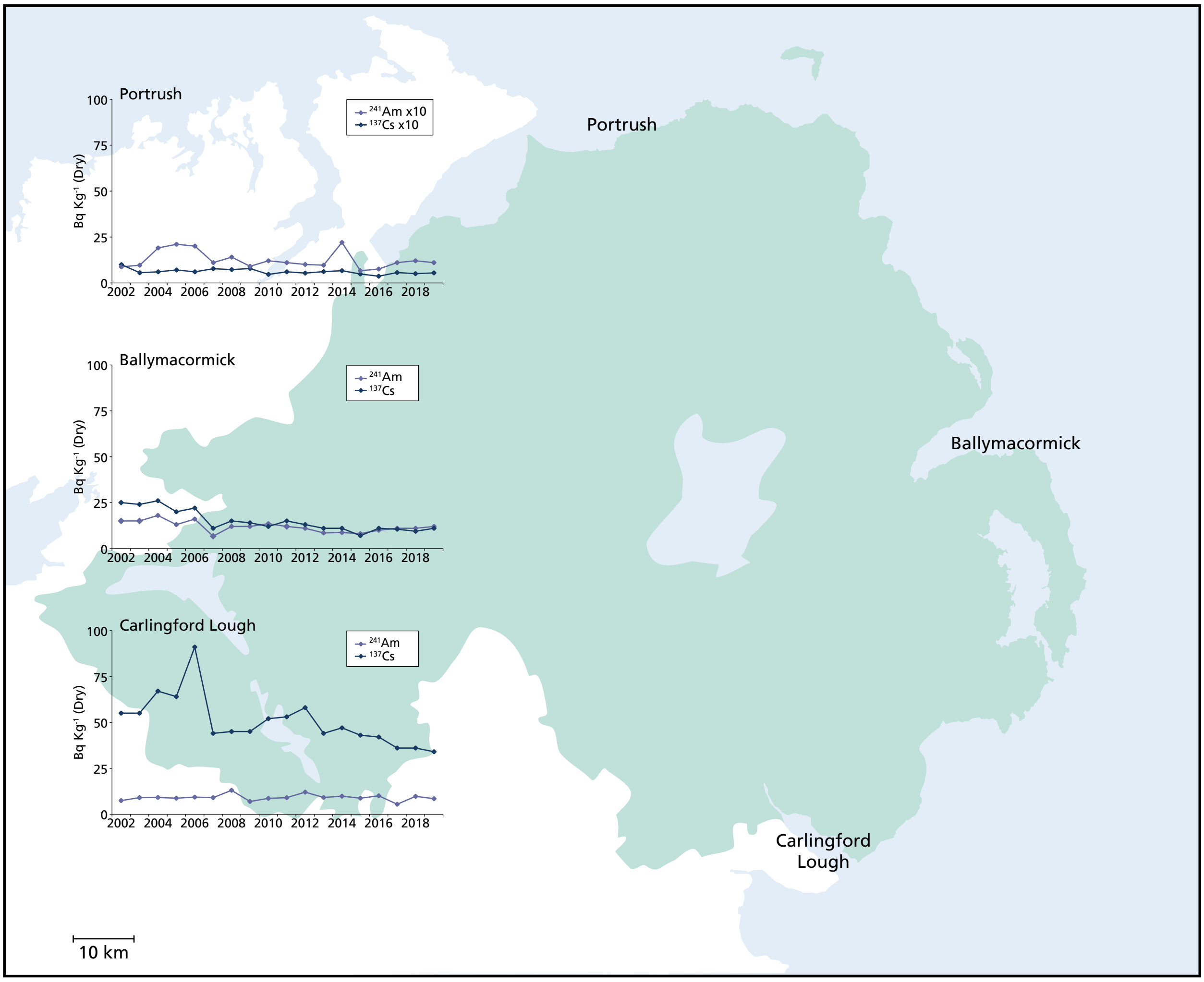


Figure 7.2. Concentrations of americium-241 and caesium-137 in coastal sediments in Northern Ireland, 2002-2019

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 2019 are summarised in Table 7.4. 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 (North Yorkshire), Northern Ireland (Co. Antrim), Wales (Gwynedd) and Scotland (Midlothian) were 20, 16, 16 and less than 17 Bq l^{-1}, respectively. As in previous years, tritium concentrations were reported as less than values at all remote sites. In 2019, strontium-90 concentrations were reported as less than values (or just above the less than value) and the mean concentration over the UK was less than 0.039 Bq l^{-1} in 2019 (0.036 Bq l^{-1} in 2018). In the past, the highest concentrations of radiocaesium in milk were 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 2019, 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 dominated by naturally occurring lead-210 and polonium-210, and man-made radionuclides would only contribute to less than 10 per cent of the contribution to the dose.

7.6 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).

7.7 Airborne particulate, rain, freshwater, groundwater and grass

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 7.5. 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. Tritium and caesium-137 concentrations in air and rainwater are reported as less than values in 2019. 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, 2002). 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 2019 (Figure 7.3). 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 7.6 to 7.8 (inclusive). Tritium concentrations were all substantially below the investigation level for drinking water of 100 Bq l^{-1} in the European Directive 2013/51 and all are reported as less than values (except for one result). At Gullielands Burn (Table 7.6a), which is near to the Chapelcross nuclear licensed site, the tritium concentration was 8.2 Bq l^{-1} in 2019 (similar to that in 2018).

A gross alpha concentration was positively detected in a surface water sample taken in 2018 from Loch Baligill,

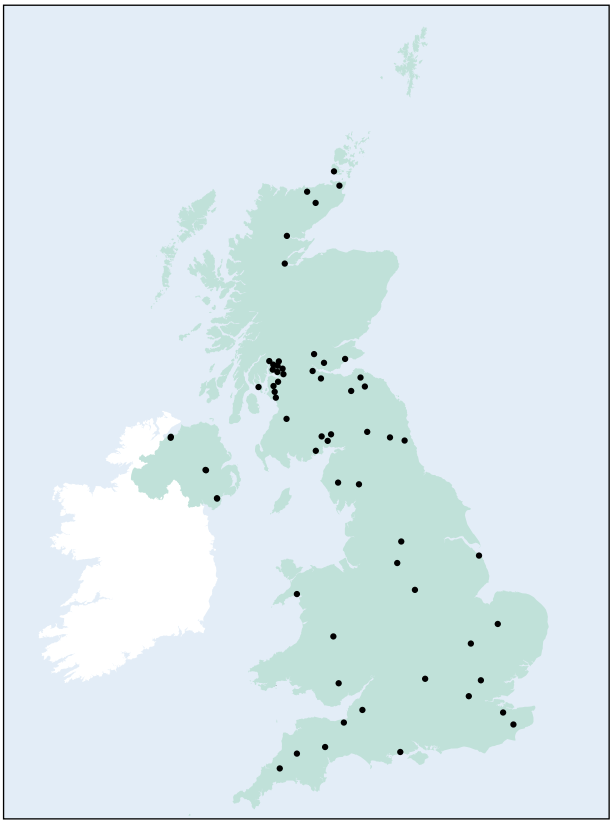


Figure 7.3. Drinking water sampling locations, 2019

Highland (Table 8.6, Environment Agency, FSA, FSS, NIEA, NRW and SEPA, 2019), just above the investigation levels for drinking water. As a consequence, SEPA sampled a total of 16 freshwater samples across the Caithness area, with 13 samples taken in the vicinity of Loch Baligill (four from the annual sampling programme and nine additional samples, as indicated in Table 7.6(a)) during July to December 2019. Concentrations of gross alpha and gross beta in all samples were below the drinking water investigation levels. The average gross alpha concentration was 0.019 Bq l^{-1} with a maximum of 0.049 Bq l^{-1} at Loch Baligill. The Loch is not currently a supplier of public water. However, it has potential for use as a private water supply and fishing loch. SEPA will continue to monitor the Loch in 2020. All other concentrations of gross alpha and gross beta (in Table 7.6(a)) were also 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 0.026 mSv in 2019 (Table 7.9), and higher than the mean annual dose in 2018 (0.018 mSv). The highest annual dose was estimated to be 0.040 mSv for drinking water from Matlock, Derbyshire. 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 2019, and the results are given in Table 7.10. 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.

Following a particularly dry and sunny April 2019, the Dounreay site operator promptly notified SEPA of increased beta activity in unfiltered space extract systems. The activity could not be linked to any facility and instead had an off-site component. The site operator also checked offsite emergency monitoring points and confirmed the same trend in elevated beta readings. SEPA changed medium volume air sampling filters around Dounreay and high-volume air samplers at Lerwick and Glasgow. In addition, SEPA also took several samples of grass from Inverness to the Dounreay site. The results of this grass sampling, given in Table 7.6(b) did not give any cause for concern. However, it was noted that activity may have been linked to several wildfires near the site that caused smoke to drift several miles away. Elevated beta activity was also noted in air filter measurements across Scotland during April 2019.

7.8 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, 2011a).

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) and amended in 2017 (Regulation EU/2058/2017). Certain measures apply to some feed and food originating in or consigned from specific prefectures of Japan. The 2016 regulation (amended in 2017) lifted restrictions on some or all agricultural and fisheries products from ten Japanese prefectures. 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 EC have recently reviewed the situation again and the legislation was amended in October 2019 (EC, 2019). The list of applicable feeds and foods from the prefectures can be found in Annex II of the legislation.

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 2019. 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 2019 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 2019, these instruments were not triggered by a food consignment at any point of entry into the UK.

7.9 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. 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 2019 are given in Figures 7.4 – 7.8.

A seawater survey of the Irish Sea was carried out in 2019. As in previous surveys, a band of slightly higher concentrations of caesium-137 was observed along the coast to the north and south of Sellafield, with levels generally decreasing with distance from the coast (Figure 7.4). The 2019 survey recorded concentrations of up to 0.06 Bq l^{-1} in the eastern Irish Sea (0.06 Bq l^{-1} in 2017). For the remainder of the Irish Sea, caesium-137 concentrations were reported as less than values (0.02 Bq l^{-1}). Overall, concentrations were similar to those reported in the previous Irish Sea survey in 2017 (Environment Agency, FSA, FSS, NIEA, NRW and SEPA, 2018). Caesium-137 concentrations in the Irish Sea were only a very small percentage of those prevailing in the late 1970s (typically up to 30 Bq l^{-1}, Baxter *et al*., 1992), when discharges were substantially higher.

The predominant source of caesium-137 to the Irish Sea is considered to be 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 decrease in caesium-137 concentrations in shoreline seawater at St Bees (Figure 7.9). 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 7.9.

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

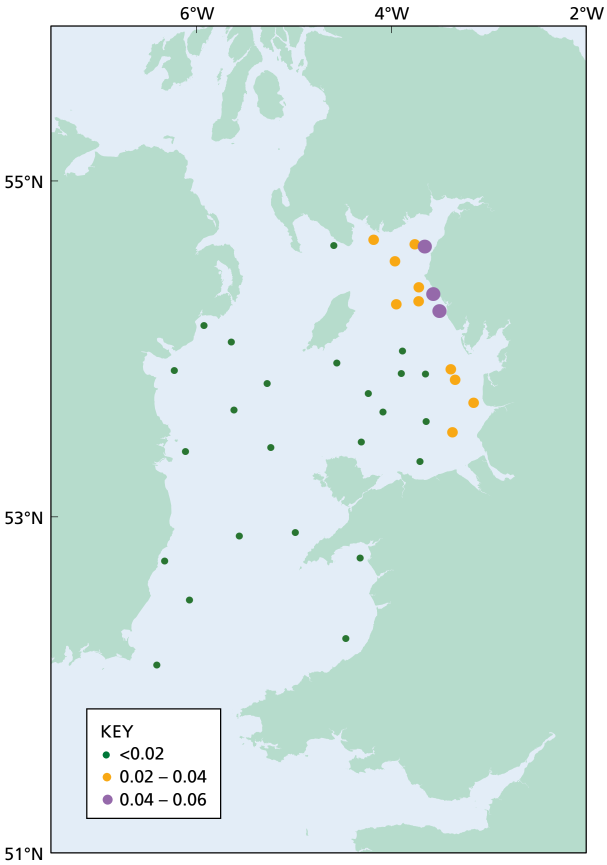


Figure 7.4. Concentrations (Bq l^{-1}) of caesium-137 in filtered surface water from the Irish Sea, March-April 2019

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).

In 2018, very low concentrations (up to 0.006 Bq l^{-1}) were found throughout most of the North Sea survey area (Environment Agency, FSA, FSS, NIEA, NRW and SEPA, 2018). 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. 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).

In 2019, caesium-137 concentrations were reported as less than values (or close to the less than value) in the western English Channel (including those near the Channel Islands) and were not distinguishable from the background of fallout from nuclear weapons testing (Figure 7.5).

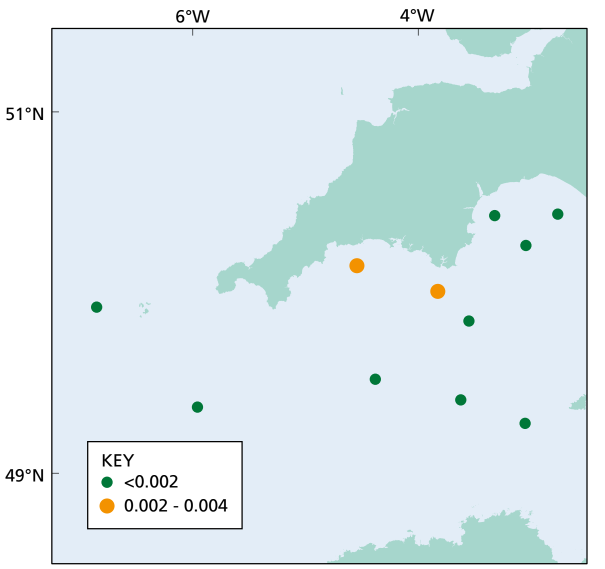


Figure 7.5. Concentrations (Bq l-1) of tritium in surface water from the English Channel, March-April 2019

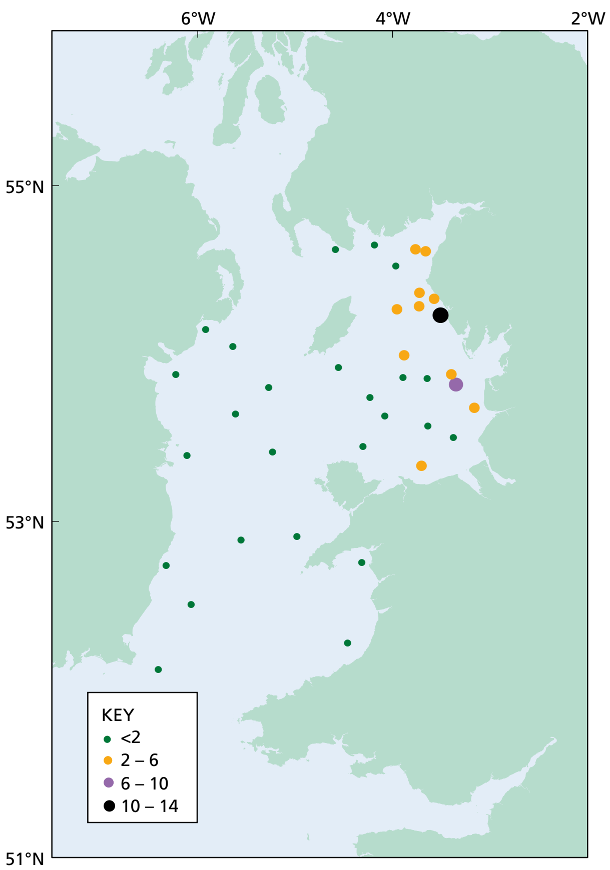


Figure 7.6. Concentrations (Bq l-1) of tritium in surface water from the Irish Sea, September-October 2019

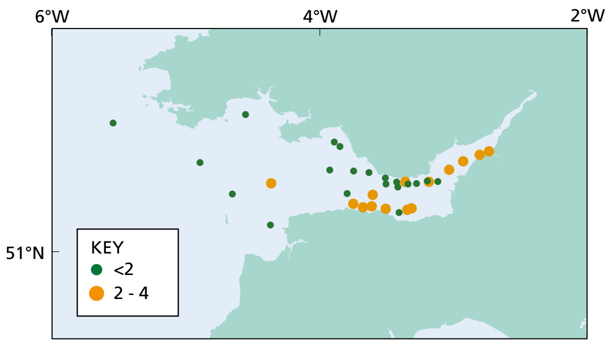


Figure 7.7. Concentrations (Bq l-1) of tritium in surface water from the Bristol Channel, September-October 2019

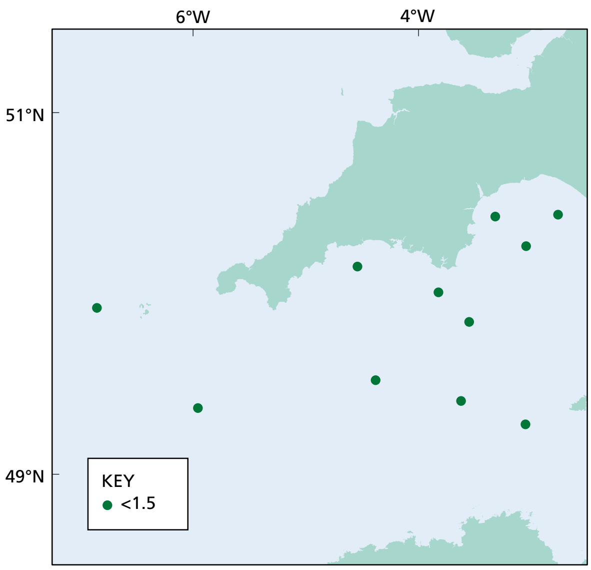


Figure 7.8. Concentrations (Bq l-1) of tritium in surface water from the English Channel, March-April 2019

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 Irish Sea seawater in 2019 are shown in Figure 7.6. As expected, these are higher (by small amounts) than those observed in the North Sea in 2018 (Figure, 8.6, Environment Agency, FSA, FSS, NIEA, NRW and SEPA, 2019) due to the influence of discharges from Sellafield and other nuclear licensed sites. As in previous Irish Sea surveys, tritium concentrations to the south and west of the Isle of Man, including along the coastline of Ireland, were mostly reported as below (or close to) a less than value.

In the Bristol Channel, the combined effect of historical tritium discharges from Cardiff, and those from Berkeley, Oldbury and Hinkley Point, is shown in Figure 7.7. Tritium concentrations in the Bristol Channel were very low in 2019. Most results are reported as less than values (or close to the less than value) in the vicinity of the Welsh coast. Overall, tritium concentrations were lower in the inner region of the Bristol Channel, in comparison to recent 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 7.8).

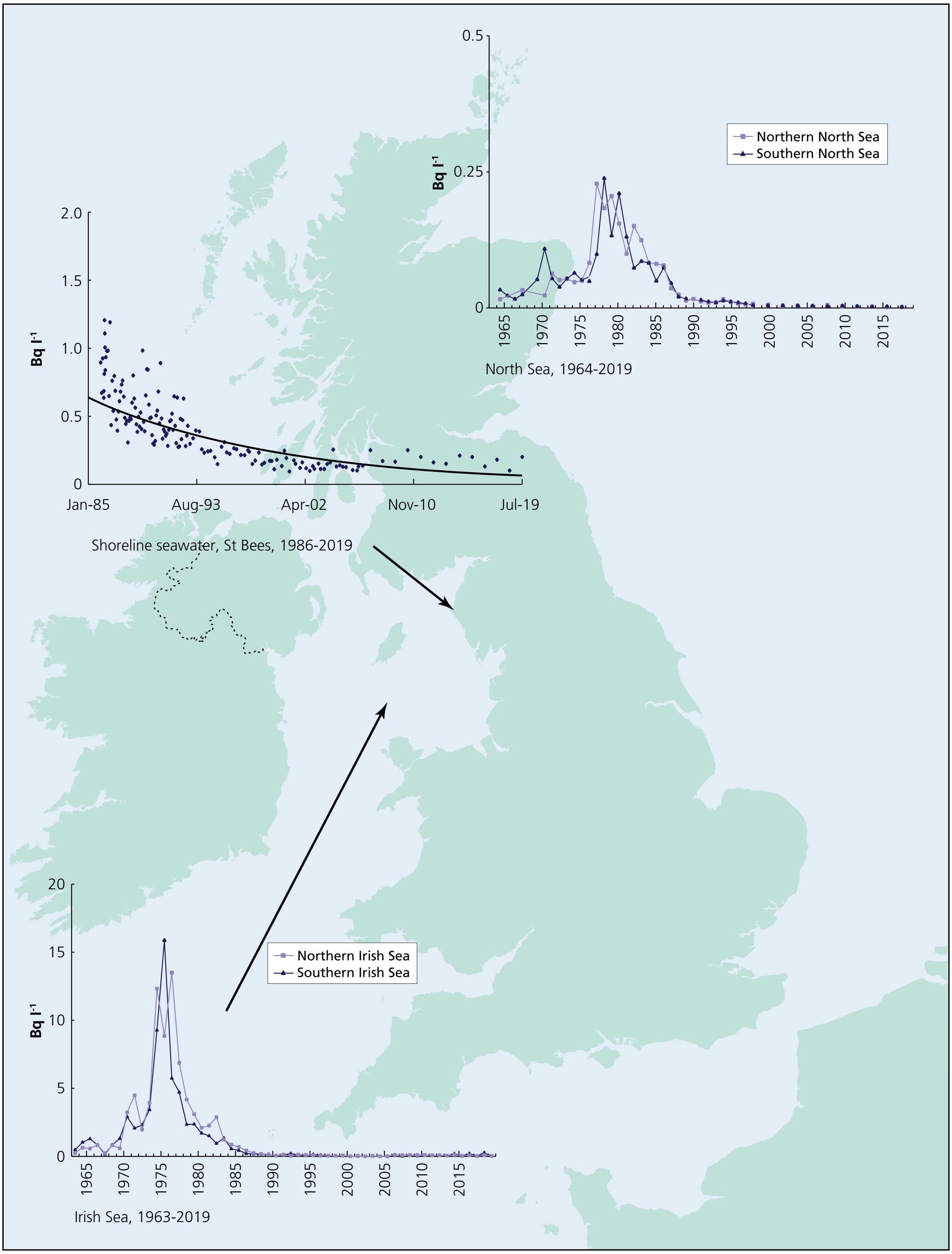


Figure 7.9. Concentration of caesium-137 in the Irish Sea, North Sea and in shoreline seawater close to Sellafield at St. Bees
(Note different scales used for activity concentrations)

Technetium-99 concentrations in seawater have decreased following the substantial reduction in discharges resulting from Environment Agency requirements for discharge abatement. This followed 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 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; 2010). 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 7.11. Most radionuclides are reported as less than values. Tritium and caesium-137 concentrations remote from site discharge points are consistent with those in Figures 7.4 – 7.8.

In 2019, SEPA took a series of marine sediment and seawater samples from across Scotland and the results are given in Table 7.12. All radionuclides were reported as less than values in seawater. Caesium-137, europium-155 and americium-241 were positively detected in some sediment samples. The results are generally consistent with those to be expected from measurements at nuclear licensed sites in this report (see, for example, Section 3). Overall, the results support the concept of a reducing trend in concentration with distance from the Sellafield site, albeit confounded by natural variability due to sediment type.

7.10 Bottled water

In order to check compliance with the Council Directive 2013/51/EURATOM, laying down requirements for the protection of the health of the general public with regard to radioactive substances in water intended for human consumption, FSS and SEPA commissioned PHE to survey bottled water from producers across Scotland.

In 2019, samples from eight producers of bottled water and spring water (natural mineral water is exempt from the Directive) were analysed for total alpha, total beta and radionuclides specified in the Directive. The results are given in Table 7.13. Most analyses were reported as less than values, although naturally occurring radionuclides (including lead-210, radon-222, radium-226, radium-228 and uranium-234) were positively detected at low concentrations. Total alpha and total beta analyses were all reported as less than values, and therefore were below the investigation levels (0.1 Bq l^{-1} and 1.0 Bq l^{-1}, respectively) for drinking water in the European Directive 2013/51. The results of the survey indicate that radionuclides in these bottled waters is not a health concern and no further investigation is required (in accordance with the Directive).

Table 7.1 Concentrations of radionuclides in seafood and the environment near the Channel Islands, 2019

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				<0.06			<0.54	<0.05
	Lobsters	1				<0.05			<0.44	<0.04
	Limpets	1				<0.04			<0.34	<0.04
	Pacific Oysters	1				<0.06			<0.52	<0.05
	Scallops	1				<0.04			<0.41	<0.04
St. Sampson's Harbour	Sand	1				<0.14			<1.3	0.27
	Seawater	2								0.0021
Jersey										
	Crabs	1				<0.04			<0.37	<0.04
	Spiny spider crabs	1				<0.04			<0.33	<0.04
	Lobsters	1				<0.04		0.22	<0.43	<0.04
La Rocque	Oysters	1				<0.03			<0.25	<0.02
Plemont Bay	*Porphyra*	2				<0.05			<0.37	<0.04
La Rozel	*Fucus vesiculosus*	4				<0.05	0.027	2.3	<0.39	<0.05
Gorey	*Ascophyllum nodosum*	4				<0.06			<0.51	<0.07
Alderney										
	Crabs	2	<25	<25	36	<0.07		<0.25	<0.57	<0.06
	Spiny spider crabs	1				0.06			<0.35	<0.04
	Lobsters	1				<0.04			<0.31	<0.04
	Toothed winkles	1	<25	<25	25	<0.05	<0.12		<0.46	<0.05
	Fucus vesiculosus[b]	2								
Quenard Point	*Fucus serratus*	4				<0.05	0.018	0.76	<0.29	<0.04
Quenard Point	*Laminaria digitata*	4				<0.04			<0.36	<0.05
Little Crabbe Harbour	Sand	1				<0.14			<1.3	0.90
	Seawater	4		<3.5						0.002

Table 7.1 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	<0.16	0.00014	0.00092	0.0017	*	0.000083	95
	Lobsters	1	<0.20			<0.05			73
	Limpets	1	<0.12			<0.13			71
	Pacific Oysters	1	<0.15			<0.24			48
	Scallops	1	<0.10	0.00061	0.0024	0.00091	*	0.000075	99
St. Sampson's Harbour	Sand	1	<0.55	0.022	0.077	0.080	*	0.0039	550
Jersey									
	Crabs	1	<0.13	0.000016	0.00013	0.0013	*	0.00012	110
	Spiny spider crabs	1	<0.11			<0.12			110
	Lobsters	1	<0.15	0.00016	0.00067	0.0030	*	0.000090	94
La Rocque	Oysters	1	<0.06	0.00088	0.0027	0.0028	0.000017	0.00019	32
Plemont Bay	*Porphyra*	2	<0.11			<0.16			93
La Rozel	*Fucus vesiculosus*	4	<0.19	0.0051	0.014	0.0047	0.000040	0.00039	190
Gorey	*Ascophyllum nodosum*	4	<0.14			<0.15			180
Alderney									
	Crabs	2	<0.16	0.00019	0.00048	0.0022	0.000025	0.00049	100
	Spiny spider crabs	1	<0.12	0.00058	0.0016	0.0026	0.000019	0.00033	77
	Lobsters	1	<0.12	0.00014	0.00077	0.0045	0.000048	0.00038	88
	Toothed winkles	1	<0.11	0.0052	0.015	0.021	0.00018	0.0021	72
Quenard Point	*Fucus serratus*	4	<0.10	0.0033	0.010	0.0063	0.000068	0.00014	140
Quenard Point	*Laminaria digitata*	4	<0.10			<0.13			110
Little Crabbe Harbour	Sand	1	<1.3			<1.5			540

* *Not detected by the method used*

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

[b] *The concentration of ^{129}I based on two observations in* Fucus vesiculosus *is 0.90 Bq kg^{-1}*

Table 7.2(a) Concentrations of radionuclides in seafood and the environment in Northern Ireland, 2019[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	20	<0.05		<0.12	<0.05	0.67
Plaice	Kilkeel	4		<0.05		<0.13	<0.06	0.26
Haddock	Kilkeel	4		<0.05		<0.12	<0.05	0.34
Herring	Ardglass	2		<0.08		<0.19	<0.08	0.37
Lesser spotted dogfish	North coast	2		<0.09		<0.23	<0.13	0.56
Nursehound	North coast	1		<0.11		<0.29	<0.11	0.70
Spurdog	North coast	1		<0.11		<0.28	<0.10	0.70
Skates / rays	Kilkeel	4		<0.06		<0.14	<0.06	0.67
Crabs	Kilkeel	4		<0.05		<0.14	<0.05	0.14
Lobsters	Ballycastle	2		<0.10	8.1	<0.38	<0.10	<0.13
Lobsters	Kilkeel	4		<0.05	8.9	<0.18	<0.05	0.19
Nephrops	Kilkeel	4		<0.08	5.0	<0.17	<0.07	0.53
Winkles	Minerstown	3		<0.07		<0.17	<0.06	<0.17
Mussels	Carlingford Lough	2		<0.11	3	<0.21	<0.10	0.47
Scallops	County Down	2		<0.06		<0.10	<0.04	0.15
Toothed winkles	Minerstown	1		<0.04		<0.11	<0.04	0.17
Fucus spp.	Carlingford Lough	2		<0.06	36	<0.15	<0.06	0.26
Fucus vesiculosus	Carlingford Lough	2		<0.04		<0.09	<0.04	0.25
Fucus serratus	Portrush	2		<0.06		<0.13	<0.09	<0.07
Fucus spp.	Portrush	2		<0.07		<0.13	<0.06	<0.07
Ascophyllum nodosum	Ardglass	2		<0.05		<0.10	<0.05	0.21
Fucus vesiculosus	Ardglass	2		<0.04	8.9	<0.09	<0.06	0.33
Rhodymenia spp.	Portaferry	4		<0.08	0.29	<0.15	<0.07	0.36
Mud	Carlingford Lough	2		<0.26		<0.86	<0.67	34
Mud	Ballymacormick	2		<0.19		<0.53	<0.33	11
Sandy mud	Dundrum Bay	1		<0.20		<0.48	<0.51	4.6
Mud	Dundrum Bay	1		<0.18		<0.55	<0.44	4.3
Mud	Strangford Lough – Nicky's Point	2		<0.21		<0.59	<0.36	13
Mud	Oldmill Bay	2		<0.23		<0.65	<0.41	25
Sand	Portrush	2		<0.16		<0.42	<0.19	0.54
Sandy mud	Carrichue	1		<0.18		<0.46	<0.47	2.1
Shells and sand	Carrichue	1		<0.13		<0.40	<0.15	0.96
Seawater	North of Larne	4			0.00088		*	0.0074

Table 7.2(a) continued

Material	Location	No. of sampling observations	Mean radioactivity concentration (fresh)[b], Bq kg^{-1}					
			^{155}Eu	^{238}Pu	^{239}Pu + ^{240}Pu	^{241}Am	^{242}Cm	^{243}Cm + ^{244}Cm
Cod	Kilkeel	4	<0.14			<0.14		
Plaice	Kilkeel	4	<0.14			<0.17		
Haddock	Kilkeel	4	<0.12			<0.14		
Herring	Ardglass	2	<0.19			<0.18		
Lesser spotted dogfish	North coast	2	<0.21			<0.39		
Nursehound	North coast	1	<0.26			<0.29		
Spurdog	North coast	1	<0.26			<0.29		
Skates / rays	Kilkeel	4	<0.13			<0.13		
Crabs	Kilkeel	4	<0.15			<0.14		
Lobsters	Ballycastle	2	<0.24			<0.41		
Lobsters	Kilkeel	4	<0.13			<0.13		
Nephrops	Kilkeel	4	<0.15	0.0025	0.015	0.091	*	0.000046
Winkles	Minerstown	3	<0.17	0.027	0.17	0.11	*	*
Mussels	Carlingford Lough	2	<0.17			0.18		
Scallops	County Down	2	<0.12			<0.17		
Toothed winkles	Minerstown	1	<0.12			0.19		
Fucus spp.	Carlingford Lough	2	<0.21			<0.22		
Fucus vesiculosus	Carlingford Lough	2	<0.19			<0.18		
Fucus serratus	Portrush	2	<0.13			<0.23		
Fucus spp.	Portrush	2	<0.19			<0.25		
Ascophyllum nodosum	Ardglass	2	<0.12			<0.13		
Fucus vesiculosus	Ardglass	2	<0.10			<0.12		
Rhodymenia spp.	Portaferry	4	<0.13	0.058	0.39	0.78	*	0.0025
Mud	Carlingford Lough	2	<1.9	1.9	12	8.5	*	*
Mud	Ballymacormick	2	<0.87			12		
Sandy mud	Dundrum Bay	1	<1.2			2.8		
Mud	Dundrum Bay	1	<1.5			2.5		
Mud	Strangford Lough – Nicky's Point	2	<1.2			5.5		
Mud	Oldmill Bay	2	<0.91			7.9		
Sand	Portrush	2	<0.52			1.1		
Sandy mud	Carrichue	1	<0.59	0.090	0.71	1.4	*	*
Shells and sand	Carrichue	1	<0.52			<1.3		
Seawater	North of Larne	4						

* *Not detected by the method used*

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

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

Table 7.2(b) Monitoring of radiation dose rates in Northern Ireland, 2019[a]

Location	Ground type	No. of sampling observations	Mean gamma dose rate in air at 1m, µGy h^{-1}
Lisahally	Mud	1	0.058
Donnybrewer	Shingle	1	0.048
Carrichue	Mud	1	0.067
Bellerena	Mud	1	0.057
Benone	Sand	1	0.057
Castlerock	Sand	1	0.056
Portstewart	Sand	1	0.055
Portrush, Blue Pool	Sand	1	0.054
Portrush, White Rocks	Sand	1	0.053
Portballintrae	Sand	1	0.052
Giant's Causeway	Sand	1	0.050
Ballycastle	Sand	1	0.053
Half Way House	Sand	1	0.053
Ballygally	Sand	1	0.051
Drains Bay	Sand	1	0.055
Larne	Sand	1	0.056
Whitehead	Sand	1	0.058
Carrickfergus	Sand	1	0.057
Jordanstown	Sand	1	0.058
Helen's Bay	Sand	1	0.060
Groomsport	Sand	1	0.068
Millisle	Sand	1	0.065
Ballywalter	Sand	1	0.060
Ballyhalbert	Sand	1	0.063
Cloghy	Sand	1	0.064
Portaferry	Shingle and sand	1	0.082
Kircubbin	Sand	1	0.082
Greyabbey	Sand	1	0.089
Ards Maltings	Mud	1	0.076
Island Hill	Mud	1	0.070
Nicky's Point	Mud	1	0.089
Strangford	Shingle and stones	1	0.093
Kilclief	Sand	1	0.072
Ardglass	Mud	1	0.084
Killough	Mud	1	0.079
Ringmore Point	Sand	1	0.075
Tyrella	Sand	1	0.077
Dundrum	Sand	1	0.090
Newcastle	Sand	1	0.11
Annalong	Sand	1	0.11
Cranfield Bay	Sand	1	0.084
Mill Bay	Sand	1	0.098
Greencastle	Sand	1	0.081
Rostrevor	Sand	1	0.11
Narrow Water	Mud	1	0.090

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

Table 7.3 Concentrations of radionuclides in diet, 2019[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		99	<0.022	<0.06
Northern Ireland	5		110	<0.024	<0.10
Scotland	12	40	120	<0.025	<0.02
Wales	5		90	0.017	<0.09

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		85	<0.10	<0.05
East Lothian North Berwick	4		81	<0.15	<0.05
Renfrewshire Paisley	4		85	<0.11	<0.07
Ross-shire Dingwall	4		85	<0.10	<0.07

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

Table 7.4 Concentrations of radionuclides in milk remote from nuclear sites, 2019

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		2		16	<0.026	<0.05
	max				<0.027	<0.07
Ceredigion		1			0.041	<0.04
Cheshire		1		13	0.028	<0.03
Clwyd		1		8.5	<0.024	<0.04
Cornwall		1		10	<0.031	<0.04
Devon		1		13	0.024	<0.04
Dorset		1		10	<0.028	<0.04
Co. Down		1			<0.029	<0.04
Dumfriesshire		1	<5.0	<15	<0.10	<0.05
Co. Fermanagh		1			<0.030	<0.03
Gloucestershire		1		12	<0.021	<0.04
Gwynedd		1		16	0.034	<0.04
Hampshire		1		10	<0.022	<0.04
Humberside		1		19	<0.027	<0.04
Kent		1		6.8	<0.029	<0.03
Lanarkshire		1	<5.0	<15	0.017	0.02
Lancashire		1		11	<0.028	<0.04
Leicestershire		1		15	<0.028	<0.03
Middlesex		1		8.7	<0.025	<0.04
Midlothian		1	<5.0	<17	<0.10	<0.05
Nairnshire		1	<5.0	<15	<0.10	<0.05
Norfolk		1		18	<0.029	<0.04
North Yorkshire		1		20	0.032	<0.04
Renfrewshire		1	<5.0	<15	<0.10	<0.05
Suffolk		1		9.3	<0.030	<0.04
Co. Tyrone		2		15	<0.028	<0.05
	max				<0.032	
Mean Values						
England				13	<0.027	<0.04
Northern Ireland				16	<0.028	<0.04
Wales				12	<0.033	<0.04
Scotland			<5.0	<15	<0.083	<0.04
United Kingdom			<5.0	<13	<0.039	<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 7.5 Concentrations of radionuclides in rainwater and air, 2019

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	<1.8	1.0			<0.0080	
	Air	4		0.0033			<5.2 10^{-7}	
Co. Down								
Conlig	Rainwater	4		0.87			<0.0079	
	Air	4		0.0045			<7.8 10^{-7}	
Dumfries and Galloway								
Eskdalemuir	Rainwater	12	<1.0	1.5		<0.0050	<0.010	
	Air	11		0.0028			<1.0 10^{-5}	
Newton Stewart	Air	8		0.0025			<1.0 10	
City of Edinburgh								
Edinburgh Silvan	Air	10		0.0025			<1.0 10^{-5}	
North Lanarkshire								
Holytown	Rainwater	12	<1.0	0.42		<0.0059	<0.011	
	Air	11		0.0017			<1.0 10^{-7}	
North Yorkshire								
Dishforth/Leeming	Rainwater	4		1.2			<0.011	
	Air	4		0.0025			<7.0 10^{-7}	
Oxfordshire								
Chilton	Rainwater	4		1.2	1.5	<0.00033[b]	<0.013	0.00024
	Air	12			0.0028		<4.5 10^{-7}	
Shetland								
Lerwick	Rainwater	12	<1.0	1.8		<0.0050	<0.010	
	Air	12		0.0023			<1.0 10^{-5}	
Suffolk								
Orfordness	Rainwater	4	<1.7	1.9			<0.012	
	Air	4		0.0038			<5.2 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}	1.2 10^{-5}		
	Air	4	<4.1 10^{-10}	<2.9 10^{-9}	<2.0 10^{-9}		
Dumfries and Galloway							
Eskdalemuir	Air	11					<0.00021
Newton Stewart	Air	8					<0.00023
City of Edinburgh							
Edinburgh Silvan	Air	10					<0.00019
North Lanarkshire							
Holytown	Air	11					<0.00021
Oxfordshire							
Chilton	Rainwater	4				0.12[d]	0.37[d]
Shetland							
Lerwick	Air	12					<0.00021

[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 7.6(a) Concentrations of radionuclides in sources of drinking water in Scotland, 2019

Area	Location or selection[a]	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	<0.011	0.025
Argyll and Bute	Auchengaich	1	<1.0		<0.01	<0.010	0.013
Argyll and Bute	Helensburgh Reservoir	1	<1.0		<0.01	<0.010	0.014
Argyll and Bute	Loch Ascog	1	<1.0		<0.01	0.010	0.092
Argyll and Bute	Loch Eck	1	<1.0		<0.01	<0.010	0.021
Argyll and Bute	Lochan Ghlas Laoigh	1	<1.0		<0.01	<0.010	0.031
Argyll and Bute	Loch Finlas	1	<1.0		<0.01	<0.010	0.023
Clackmannanshire	Gartmorn Dam	1	<1.0		<0.01	0.010	0.15
Dumfries and Galloway	Black Esk	1	<1.0		<0.01	0.011	0.017
Dumfries and Galloway	Gullielands Burn	1	8.2		<0.05	<0.010	0.088
Dumfries and Galloway	Purdomstone	1	<1.0		<0.05	<0.010	0.056
Dumfries and Galloway	Winterhope	1	<1.0		<0.05	<0.010	0.033
East Lothian	Hopes Reservoir	1	<1.0		<0.05	<0.010	0.026
East Lothian	Thorters Reservoir	1	<1.0		<0.05	<0.010	0.058
East Lothian	Whiteadder	1	<1.0		<0.05	<0.010	0.038
East Lothian	Thornton Loch Burn	1	<1.0		<0.05	0.011	0.081
Fife	Holl Reservoir	1	<1.0		<0.01	0.11	0.17
Highland	Loch Baligill[b]	4	<1.0		<0.02	0.028	0.10
	max					0.049	0.14
Highland	Loch Calder	1	<1.0		<0.01	<0.010	0.060
Highland	Loch Glass	4	<1.0	<0.016	<0.01	<0.010	0.028
Highland	Loch Shurrerey	1	<1.0		<0.01	<0.010	0.048
North Ayrshire	Camphill	1	<1.0		<0.01	<0.010	0.020
North Ayrshire	Knockendon Reservoir	1	<1.0		<0.01	<0.010	0.024
North Ayrshire	Munnoch Reservoir	1	<1.0		<0.01	<0.010	0.081
North Ayrshire	Outerwards	1	<1.0		<0.01	<0.010	0.024
Orkney Islands	Heldale Water	1	<1.0		<0.01	<0.010	0.056
Perth and Kinross	Castlehill Reservoir	1	<1.0		<0.01	<0.010	0.033
Scottish Borders	Knowesdean	4	<1.0	<0.016	<0.01	<0.010	0.043
Stirling	Loch Katrine	12	<1.0	<0.0025	<0.001	<0.0088	0.021
West Dunbartonshire	Loch Lomond (Ross Priory)	1	<1.0		<0.01	<0.010	0.019
West Lothian	Morton No 2 Reservoir	1	<1.0		<0.01	<0.010	0.033
Additional samples[b]							
Highland	Allt na Cleitte (Achridigill) Portskerra	1			0.02	0.011	0.059
Highland	Achridigill, Melvich	1			0.02	0.029	0.069
Highland	Allt na Ceardaich, Strathy	1			<0.01	0.017	0.063
Highland	Allt na Tuchcaid, Strathy	1			0.01	0.015	0.069
Highland	Alltan Domhaich, Portskerra	1			0.02	0.015	0.063
Highland	Baligill Burn	1			0.02	0.022	0.057
Highland	Loch Beag, Melvich	1	<1.0		<0.01	0.026	0.069
Highland	Loch Dhu House, Bailigill	1	<1.0		<0.01	0.015	0.094
Highland	Loch Eracha	1	<1.0		<0.01	0.015	0.087

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

[b] *additional freshwater sampling has been undertaken in response to increased concentrations in Loch Baligill in 2018*

Table 7.6(b) Concentrations of radionuclides in grass in Scotland, 2019

Material	Location	No. of sampling observ-ations	Mean radioactivity concentration (fresh), Bq kg^{-1}						
			^{90}Sr	^{95}Nb	^{137}Cs	^{155}Eu	^{241}Am	Gross alpha	Gross beta
Ad hoc **grass samples – Caithness wildfires May 2019**									
Grass	A836 Parking Bay	1	0.21	<0.22	0.43	<0.72	<0.75	2.9	440
Grass	Achvarasdal	1	0.18	<0.18	<0.19	<0.48	<0.43		
Grass	Cromarty Firth	1	0.39	<0.21	<0.21	<0.63	<0.56	1.8	380
Grass	Latheron	1	0.15	<0.27	<0.29	<0.74	<0.63		
Grass	Melvich Bay	1	0.23	<0.18	<0.20	<0.68	<0.69	3.7	310
Grass	Sandside Bay	1	<0.10	<0.20	<0.21	<0.68	<0.68	2.2	320

Table 7.7 Concentrations of radionuclides in sources of drinking water in England and Wales, 2019

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	<3.2	0.36	<0.0010		<0.0012	<0.040	0.47	0.41
Cornwall	River Fowey	4	<3.1	0.044	<0.00079	<0.0018	<0.00076	0.042	0.083	0.067
County Durham	Honey Hill Water Treatment Works, Consett	4	<3.1	<0.027	<0.0011		<0.0016	0.15	0.21	0.18
County Durham	River Tees, Darlington	4	<3.1	<0.037	<0.00084	<0.0013	<0.00085	0.018	0.055	0.044
Cumbria	Ennerdale Lake	4	<3.3	<0.015	<0.0012		<0.00086	<0.011	0.040	0.032
Cumbria	Haweswater Reservoir	4	<2.9	<0.023	<0.0014		<0.0011	<0.011	0.059	0.048
Derbyshire	Arnfield Water Treatment Plant	4	<3.0	<0.023	<0.00079		<0.00082	<0.012	0.034	0.028
Derbyshire	Matlock, Groundwater[a]	4	<3.1	<0.027	<0.0015		<0.00083	0.16	0.12	0.095
Devon	River Exe, Exeter	4	<3.1	<0.048	<0.0014	<0.0017	<0.0015	<0.011	0.078	0.064
Devon	Roadford Reservoir, Broadwoodwidger	4	<3.3	0.055	<0.0011		<0.00079	<0.0088	0.099	0.077
Greater London	River Lee, Chingford	4	<3.1	0.31	<0.0010	<0.0015	<0.0011	<0.042	0.39	0.31
Hampshire	River Avon, Christchurch	4	<3.0	0.060	<0.0012	<0.0015	<0.00084	<0.022	0.075	0.060
Humberside	Littlecoates, Groundwater	4	<3.2	0.076	<0.0011		<0.0010	<0.034	0.11	0.090
Kent	Chatham, Deep Groundwater	4	<3.1	<0.031	<0.00089		<0.0011	<0.030	<0.055	<0.044
Kent	Denge, Shallow Groundwater	4	<3.1	0.082	<0.00090		<0.00084	<0.023	0.12	0.10
Norfolk	River Drove, Stoke Ferry	4	<3.0	<0.068	<0.00092	<0.0016	<0.00088	<0.044	0.14	0.11
Northumberland	Kielder Reservoir	4	<3.0	<0.030	<0.0014		<0.0017	<0.023	0.070	0.054
Oxfordshire	River Thames, Oxford	4	<3.0	0.12	<0.00094	<0.0014	<0.00080	<0.040	0.18	0.15
Somerset	Ashford Reservoir, Bridgwater	4	<3.2	<0.054	<0.0010		<0.0012	<0.035	0.098	0.081
Somerset	Chew Valley Lake Reservoir, Bristol	4	<3.3	0.11	<0.0012		<0.00089	<0.031	0.15	0.12
Surrey	River Thames, Walton	4	<3.4	0.19	<0.00079	<0.0016	<0.00093	<0.041	0.25	0.22
Wales										
Gwynedd	Cwm Ystradllyn Treatment Works	4	<3.2	<0.021	<0.0011		<0.00092	<0.00075	0.023	0.018
Mid-Glamorgan	Llwyn-on Reservoir	4	<3.1	<0.029	<0.0015		<0.0013	<0.017	0.033	0.027
Powys	Elan Valley Reservoir	4	<3.0	<0.018	<0.0013		<0.00090	0.012	0.020	0.018

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 <0.015, 0.011, 0.040, <0.0031 and 0.023 Bq l^{-1}, respectively*

Table 7.8 Concentrations of radionuclides in sources of drinking water in Northern Ireland, 2019

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	<5.1	0.0026	<0.002	0.0050	<0.02	0.0020	<0.0010	0.0030	<0.05	<0.26
Co. Antrim	Lough Neagh	4	<5.1	0.0027	<0.003	0.0030	<0.05	0.0030	<0.0010	0.0040	<0.05	<0.26
Co. Down	Silent Valley	4	<5.1	0.0019	0.003	0.0070	<0.04	0.010	<0.0010	0.0070	<0.05	<0.26

Table 7.9 Doses from radionuclides in drinking water, 2019[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	0.039	0.040	Matlock, Groundwater, Derbyshire	0.040
Wales[d]	<0.001			Llwyn-on Reservoir, Mid-Glamorgan	<0.001[d]
Northern Ireland	<0.001	0.021	0.021	Silent Valley, Co. Down	0.027
Scotland[d]	<0.001			Gullielands Burn, Dumfries and Galloway	<0.001[d]
UK	<0.001	0.026	0.026	Matlock, Groundwater, Derbyshire	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 7.10 Analysis of groundwater in Scotland, 2019

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	0.26
Clackmannanshire	Alva	1	<1.0	<0.10	0.10	0.48
Fife	St Andrews	1	<1.0	<0.10	0.10	0.24
Fife	Falkland	1	<1.0	<0.10	0.10	<0.10
Angus	Arbroath	1	<1.0	<0.10	0.10	<0.10
Angus	Montrose	1	<1.0	<0.10	0.10	<0.10
Angus	Brechin	1	<1.0	<0.10	0.10	<0.10
Angus	Forfar	1	<1.0	<0.10	0.10	0.11
Aberdeenshire	Mintlaw	1	<1.0	<0.10	0.10	0.10
Aberdeenshire	Delgaty	1	<1.0	<0.10	0.10	<0.10
Aberdeenshire	Huntly	1	<1.0	<0.10	0.10	0.12
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
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	1.6	<0.10	0.10	<0.10

Table 7.11 Concentrations of radionuclides in seawater, 2019

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			<0.63	<0.10	
Dounreay (Brims Ness)	2[S]	<1.0		<0.10			<0.43	<0.10	
Rosyth	2[S]	<1.0		<0.10			<0.30	<0.10	
Firth of Forth (Devon Confluence)	1[S]			<0.10			<0.23	<0.10	
Torness[a]	2[S]	<1.3		<0.10			<0.19	<0.10	
Hartlepool (North Gare)[b]	2	<2.7		<0.31			<2.1	<0.33	
Sizewell	2	<2.9	<3.1	<0.34			<2.4	<0.38	
Bradwell (Beach pipeline)	2	<2.8		<0.31			<2.1	<0.33	
Dungeness south	2	<2.8		<0.29			<2.1	<0.32	
Winfrith (Lulworth Cove)	1			<0.33			<2.2	<0.36	
Alderney	4[C]	<3.5							
Guernsey	2[C]								
Devonport (Millbrook Lake)	1	<3.0	<2.6	<0.33					
Devonport (Tor Point South)	1	<3.0	<2.6	<0.35					
Hinkley	1	24		<0.25	<0.031		<1.8	<0.27	
Berkeley and Oldbury	2	<2.7		<0.25			<1.9	<0.29	
Cardiff (West of sewage outfall)[c]	1	<2.6	<4.0						
Wylfa (Cemaes Bay)	2	<2.6		<0.23			<1.6	<0.25	
Heysham[d]	2	20		<0.27			<1.9	<0.31	
Seascale (Particulate)[e]	2			<0.03	<0.010		<0.21	<0.03	<0.024
Seascale (Filtrate)	2	<3.6	<4.4	<0.30	<0.031	<0.13	<2.1	<0.34	<0.29
St. Bees (Particulate)[f]	2			<0.02	0.0098		<0.18	<0.03	<0.018
St. Bees (Filtrate)	2	12	<5.9	<0.25	<0.033	<0.13	<1.7	<0.28	<0.30
Seafield (near Chapelcross)	2[S]	2.0		<0.10			<0.55	<0.10	
Southerness	2[S]	2.3		<0.10			<0.43	<0.10	
Auchencairn	2[S]	<1.2		<0.10			<0.47	<0.10	
Port Patrick	2[S]	<1.1		<0.10			<0.63	<0.11	
Hunterston[g]	2[S]	<1.0		<0.10			<0.47	<0.10	
North of Larne	4[N]					0.00088			
Faslane (Carnban)	2[S]	<1.0		<0.10			<0.49	<0.10	

Table 7.11 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	<0.35		<0.11		
Dounreay (Brims Ness)	2[S]	<0.10	<0.10	<0.27		<0.10		
Rosyth	2[S]	<0.10	<0.10	<0.19		<0.10		
Firth of Forth (Devon Confluence)	1[S]	<0.10	<0.10	<0.12		<0.10	<0.12	
Torness[a]	2[S]	<0.10	<0.10	<0.11		<0.10		
Hartlepool (North Gare)[b]	2	<0.30	<0.25	<0.91		<0.30	<4.6	16
Sizewell	2	<0.35	<0.28	<1.1		<0.35	<3.0	15
Bradwell (Beach pipeline)	2	<0.30	<0.24	<1.0		<0.33	<3.3	12
Dungeness south	2	<0.28	<0.24	<1.0		<0.31	<3.6	16
Winfrith (Lulworth Cove)	1	<0.32	<0.26	<0.98		<0.31	<4.5	13
Alderney	4[C]	*	0.0019					
Guernsey	2[C]	*	0.0021					
Devonport (Millbrook Lake)	1							
Devonport (Tor Point South)	1							
Hinkley	1	<0.27	<0.22	<1.0		<0.33	<4.2	11
Berkeley and Oldbury	2	<0.26	<0.21	<1.0		<0.32	<1.9	7.0
Cardiff (West of sewage outfall)[c]	1							
Wylfa (Cemaes Bay)	2	<0.23	<0.18	<0.78		<0.27	<1.6	8.3
Heysham[d]	2	<0.27	<0.24	<0.93		<0.30	<3.2	11
Seascale (Particulate)[e]	2	<0.03	<0.02	<0.09	<0.0012	<0.077	0.19	0.11
Seascale (Filtrate)	2	<0.30	<0.23	<0.81	<0.055	<0.26	<3.1	13
St. Bees (Particulate)[f]	2	<0.02	<0.02	<0.07	<0.0012	<0.037	0.095	0.084
St. Bees (Filtrate)	2	<0.24	<0.20	<0.81	<0.065	<0.25	<3.5	11
Seafield (near Chapelcross)	2[S]	<0.10	<0.10	<0.31		<0.10		
Southerness	2[S]	<0.10	<0.12	<0.26		<0.10		
Auchencairn	2[S]	<0.10	<0.10	<0.26		<0.10		
Port Patrick	2[S]	<0.10	<0.10	<0.34		<0.12		
Hunterston[g]	2[S]	<0.10	<0.10	<0.24		<0.11		
North of Larne	4[N]	*	0.0074					
Faslane (Carnban)	2[S]	<0.10	<0.10	<0.26		<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 <0.35 Bq l^{-1}*

c *The concentration of ^{3}H as tritiated water was <9.7 Bq l^{-1}*

d *The concentration of ^{35}S was <0.69 Bq l^{-1}*

e *The concentrations of ^{238}Pu, $^{239+240}Pu$ and ^{241}Pu were 0.0063, 0.036 and <0.24 Bq l^{-1}, respectively*

f *The concentrations of ^{238}Pu, $^{239+240}Pu$ and ^{241}Pu were <0.0029, 0.015 and <0.14 Bq l^{-1}, respectively*

g *The concentration of ^{35}S was <0.50 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*

Table 7.12 Concentrations of radionuclides in marine sediments and seawater - background survey in Scotland, 2019[a]

Sample location and type	Sample source	No. of sampling observ-ations	Mean radioactivity concentration, Bq kg^{-1} (dry)[b]									
			^{3}H	^{60}Co	^{95}Nb	^{110}Ag	^{125}Sb	^{137}Cs	^{155}Eu	^{241}Am	Gross alpha	Gross beta
Marine Sediments												
Firth of Forth	Dunmore	1	<5.0	<0.15	<3.0	<0.31	<0.44	12	1.3	1.4	230	1800
Firth of Forth	Lower Taylorton	1	<5.0	<0.14	<2.2	<0.26	<0.39	6.6	1.4	1.2	190	1700
Firth of Forth	Bannockburn	1	<5.0	<0.10	<1.6	<0.20	<0.28	5.6	1.6	0.85	190	1700
Firth of Forth	Devon Confluence	1	<5.0	<0.10	<3.0	<0.19	<0.36	6.0	1.2	0.86	200	1800
Forth Estuary	Swing Bridge	1	<5.0	<0.10	<2.2	<0.20	<0.26	2.8	0.92	<0.17	210	1500
Outer Clyde Estuary	Site 1	1	<5.0	<0.13	<1.7	<0.27	<0.42	36	1.6	12	220	1700
Outer Clyde Estuary	Site 2	1	<5.0	<0.10	<2.8	<0.26	<0.39	22	0.76	8.3	160	1500
Outer Clyde Estuary	Site 3	1	<5.0	<0.10	<2.5	<0.20	<0.38	25	<0.41	7.4	170	1400
Outer Clyde Estuary	Site 4	1	<5.0	<0.42	<1.9	<0.35	<0.51	48	1.7	13	290	1900
Outer Clyde Estuary	Site 5	1	<5.0	<0.13	<2.5	<0.27	<0.42	35	1.9	6.6	200	1600
Seawater												
Firth of Forth	Dunmore	1		<0.10	<0.90	<0.11	<0.22	<0.10	<0.19	<0.10	<0.53	
Firth of Forth	Lower Taylorton	1		<0.10	<0.29	<0.10	<0.10	<0.10	<0.10	<0.10	<0.13	
Firth of Forth	Bannockburn	1		<0.10	<0.31	<0.10	<0.10	<0.10	<0.10	<0.10	<0.14	
Firth of Forth	Devon Confluence	1		<0.10	<0.29	<0.10	<0.10	<0.10	<0.10	<0.10	<0.12	
Forth Estuary	Swing Bridge	1		<0.10	<0.84	<0.12	<0.20	<0.10	<0.17	<0.10	<0.46	
Outer Clyde Estuary	Site 1	1		<0.10	<0.99	<0.12	<0.22	<0.10	<0.15	<0.10	<0.48	
Outer Clyde Estuary	Site 2	1		<0.10	<1.0	<0.12	<0.22	<0.10	<0.18	<0.10	<0.51	
Outer Clyde Estuary	Site 3	1		<0.10	<1.0	<0.10	<0.17	<0.10	<0.18	<0.12	<0.50	
Outer Clyde Estuary	Site 4	1		<0.10	<1.0	<0.13	<0.24	<0.10	<0.18	<0.11	<0.56	
Outer Clyde Estuary	Site 5	1		<0.10	<1.1	<0.13	<0.23	<0.10	<0.18	<0.10	<0.55	

[a] *Results are available for other radionuclides detected by gamma spectrometry. All such results are less than the limit of detection*
[b] *Except for seawater where units are Bq l^{-1}*

Table 7.13 Concentrations of radionuclides in Scottish bottled water, 2019

Supplier	Mean radioactivity concentration (fresh), Bq l^{-1}									
	^{14}C	^{60}Co	^{90}Sr	^{131}I	^{134}Cs	^{137}Cs	^{210}Pb	^{210}Po	^{222}Rn	^{226}Ra
1	<20	<0.50	<0.40	<0.50	<0.50	<0.50	<0.024	<0.010	<10	<0.040
2	<20	<0.50	<0.40	<0.50	<0.50	<0.50	<0.026	<0.010	<10	<0.040
3	<20	<0.50	<0.40	<0.50	<0.50	<0.50	0.023	<0.010	68	0.045
5	<20	<0.50	<0.40	<0.50	<0.50	<0.50	<0.020	<0.010	12	<0.040
6	<20	<0.50	<0.40	<0.50	<0.50	<0.50	<0.020	<0.010	17	<0.040
7	<20	<0.50	<0.40	<0.50	<0.50	<0.50	<0.020	<0.010	15	<0.040
8	<20	<0.50	<0.40	<0.50	<0.50	<0.50	<0.020	<0.010	<10	<0.040
9	<20	<0.50	<0.40	<0.50	<0.50	<0.50	<0.020	<0.010	<10	<0.040

Supplier	Mean radioactivity concentration (fresh), Bq l^{-1}								
	^{228}Ra	^{234}U	^{235}U	^{238}U	^{238}Pu	^{239}Pu+^{240}Pu	^{241}Am	Gross alpha	Gross beta
1	0.022	<0.020	<0.020	<0.020	<0.040	<0.040	<0.060	<0.04	<0.40
2	<0.020	<0.020	<0.020	<0.020	<0.040	<0.040	<0.060	<0.04	<0.40
3	0.11	<0.020	<0.020	<0.020	<0.040	<0.040	<0.060	<0.04	<0.40
5	<0.020	0.022	<0.020	<0.020	<0.040	<0.040	<0.060	<0.04	<0.40
6	<0.020	<0.020	<0.020	<0.020	<0.040	<0.040	<0.060	<0.04	<0.40
7	<0.020	<0.020	<0.020	<0.020	<0.040	<0.040	<0.060	<0.04	<0.40
8	<0.020	<0.020	<0.020	<0.020	<0.040	<0.040	<0.060	<0.04	<0.40
9	<0.020	0.033	<0.020	<0.020	<0.040	<0.040	<0.060	<0.04	<0.40

8. 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, 2019

Establishment	Radioactivity	Discharge limit (annual equivalent) [a], Bq	Discharges during 2019	
			Bq	% of annual limit[b]
Nuclear fuel production and reprocessing				
Capenhurst (UNS Ltd)	Alpha	BAT	9.70E+04	NA
Other authorised outlets	Beta	BAT	3.23E+05	NA
Capenhurst	Uranium	7.50E+06	5.25E+05	7.0
(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,1]	Alpha	8.80E+08	7.57E+07	8.6
	Beta	4.20E+10	6.36E+08	1.5
	Tritium	1.10E+15	5.61E+13	5.1
	Carbon-14	3.30E+12	2.47E+11	7.5
	Krypton-85	4.40E+17	7.79E+15	1.8
	Strontium-90	7.10E+08	8.66E+06	1.2
	Ruthenium-106	2.30E+10	5.56E+08	2.4
	Antimony-125	3.00E+10	1.50E+09	5.0
	Iodine-129	7.00E+10	3.20E+09	4.6
	Iodine-131	3.70E+10	2.29E+08	<1
	Caesium-137	5.80E+09	6.88E+07	1.2
	Radon-222	5.00E+11	Nil	Nil
	Plutonium alpha	1.90E+08	1.22E+07	6.4
	Plutonium-241	3.00E+09	9.71E+07	3.2
	Americium-241 and curium-242	1.20E+08	1.10E+07	9.2
Springfields	Uranium	5.30E+09	1.20E+07	<1
Springfields (National	Tritium	1.00E+08	6.36E+05	<1
Nuclear Laboratory)	Carbon-14	1.00E+07	8.12E+00	<1
	Krypton-85[2]	7.20E+11	2.11E+11	29
	Other alpha radionuclides	1.00E+06	Nil	Nil
	Other beta radionuclides	1.00E+07	1.78E+00	<1
Research establishments				
Dounreay[d]	Alpha[e]	3.10E+07	1.10E+05	<1
	Non-alpha[f]	1.70E+09	1.10E+06	<1
	Tritium	1.72E+13	2.30E+10	<1
	Krypton-85[g]	5.69E+14	1.60E+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 2019	
			Bq	% of annual limit[b]
Harwell (Magnox)	Alpha	8.00E+05	2.40E+04	3.0
	Beta	2.00E+07	5.30E+05	2.7
	Tritium	1.50E+13	1.80E+11	1.2
	Krypton-85	2.00E+12	Nil	Nil
	Radon-220	1.00E+14	4.90E+12	4.9
	Radon-222	3.00E+12	2.20E+11	7.3
	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	2.39E+11	1.2
	Carbon-14	3.00E+10	Nil	Nil
	Other	1.00E+05	Nil	Nil
Winfrith (Magnox)	Alpha	2.00E+06	1.12E+03	<1
	Tritium	4.95E+13	6.51E+10	<1
	Carbon-14	5.90E+09	2.04E+08	3.5
	Other	5.00E+06	1.35E+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	2.88E+05	1.4
	Tritium	2.00E+10	6.34E+09	32
	Carbon-14	5.00E+09	6.13E+08	12
Bradwell[3]	Beta	2.00E+07	1.80E+05	<1
	Tritium	6.00E+11	6.10E+09	1.0
	Carbon-14	4.00E+10	4.20E+08	1.1
Chapelcross	Tritium	7.50E+14	2.95E+13	3.9
	All other nuclides	2.50E+09	1.48E+09	59
Dungeness A Station	Beta[i]	5.00E+08	1.05E+06	<1
	Tritium	2.60E+12	4.66E+10	1.8
	Carbon-14	5.00E+12	8.62E+08	<1
Dungeness B Station	Tritium	1.20E+13	1.19E+11	<1
	Carbon-14	3.70E+12	2.80E+11	7.6
	Sulphur-35	3.00E+11	2.89E+08	<1
	Argon-41	7.50E+13	Nil	Nil
	Cobalt-60[i]	1.00E+08	2.53E+06	2.5
	Iodine-131	1.50E+09	2.22E+07	1.5
Hartlepool	Tritium	1.00E+13	7.88E+11	7.9
	Carbon-14	4.50E+12	3.01E+12	67
	Sulphur-35	2.30E+11	2.76E+10	12
	Argon-41	1.50E+14	6.82E+12	4.5
	Cobalt-60[i]	1.00E+08	2.65E+07	27
	Iodine-131	1.50E+09	1.52E+08	10

Table A2.1 continued

Establishment	Radioactivity	Discharge limit (annual equivalent) [a], Bq	Discharges during 2019	
			Bq	% of annual limit[b]
Heysham	Tritium	1.00E+13	9.86E+11	9.9
Station 1	Carbon-14	4.50E+12	2.17E+12	48
	Sulphur-35	2.00E+11	3.01E+10	15
	Argon-41	1.50E+14	1.10E+13	7.3
	Cobalt-60[i]	1.00E+08	7.18E+06	7.2
	Iodine-131	1.50E+09	5.58E+07	3.7
Heysham	Tritium	1.00E+13	2.09E+12	21
Station 2	Carbon-14	3.70E+12	2.09E+12	56
	Sulphur-35	2.30E+11	1.58E+10	6.9
	Argon-41	7.50E+13	1.04E+13	14
	Cobalt-60[i]	1.00E+08	9.52E+06	9.5
	Iodine-131	1.50E+09	7.48E+07	5.0
Hinkley Point	Beta	5.00E+07	2.15E+05	<1
A Station	Tritium	7.50E+11	1.33E+10	1.8
	Carbon-14	5.00E+10	6.07E+08	1.2
Hinkley Point	Tritium	1.20E+13	1.57E+12	13
B Station	Carbon-14	3.70E+12	1.95E+12	53
	Sulphur-35	3.50E+11	6.89E+10	20
	Argon-41	1.00E+14	9.71E+12	9.7
	Cobalt-60[i]	1.00E+08	6.85E+06	6.9
	Iodine-131	1.50E+09	4.00E+06	<1
Hunterston	Tritium	2.00E+10	4.83E+08	2.4
A Station	Carbon-14	2.00E+09	6.20E+07	3.1
	All other radionuclides	3.00E+06	4.49E+05	15
Hunterston	Particulate beta	5.00E+08	3.26E+07	6.5
B Station[d]	Tritium	1.50E+13	7.59E+11	5.1
	Carbon-14	4.50E+12	3.82E+11	8.5
	Sulphur-35	5.00E+11	8.24E+09	1.6
	Argon-41	1.50E+14	1.11E+12	<1
	Iodine-131	2.00E+09	Nil	Nil
Oldbury	Beta	1.00E+08	1.44E+05	<1
	Tritium	9.00E+12	2.62E+10	<1
	Carbon-14	4.00E+12	2.18E+09	<1
Sizewell	Beta	8.50E+08	1.97E+04	<1
A Station	Tritium	3.50E+12	2.49E+10	<1
	Carbon-14	1.00E+11	9.12E+08	<1
Sizewell	Noble gases	3.00E+13	2.68E+12	8.9
B Station	Particulate Beta	1.00E+08	3.00E+06	3.0
	Tritium	3.00E+12	3.96E+11	13
	Carbon-14	5.00E+11	2.58E+11	52
	Iodine-131	5.00E+08	1.80E+07	3.6
Torness	Particulate beta	4.00E+08	7.41E+06	1.9
	Tritium	1.10E+13	1.11E+12	10
	Carbon-14	4.50E+12	1.36E+12	30
	Sulphur-35	3.00E+11	4.18E+10	14
	Argon-41	7.50E+13	7.29E+12	9.7
	Iodine-131	2.00E+09	1.73E+06	<1

Table A2.1 continued

Establishment	Radioactivity	Discharge limit (annual equivalent) [a], Bq	Discharges during 2019	
			Bq	% of annual limit[b]
Trawsfynydd	Particulate Beta	5.00E+07	2.80E+05	<1
	Tritium	3.75E+11	2.26E+10	6.0
	Carbon-14	1.00E+10	1.15E+09	12
Wylfa[4]	Particulate Beta	7.00E+08	2.74E+06	<1
	Tritium	1.80E+13	9.00E+10	<1
	Carbon-14	2.30E+12	6.90E+08	<1
Defence establishments				
Aldermaston[j]	Alpha	1.65E+05	2.22E+04	13
	Particulate Beta	6.00E+05	2.37E+04	3.9
	Tritium	3.90E+13	9.30E+11	2.4
	Carbon-14	6.00E+06	Nil	Nil
	Activation products[k]	BAT	6.09E+07	NA
	Volatile beta[4,5]	1.00E+08	1.70E+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	1.37E+03	27
Coulport	Tritium	5.00E+10	2.05E+09	4.1
Derby[i,m]	Alpha[n]	3.00E+06	9.71E+05	32
	Alpha[o,p]	2.40E+04	4.10E+01	<1
	Beta[o, p]	1.80E+06	3.40E+04	1.9
Devonport[q]	Beta[i]	3.00E+05	1.52E+04	5.1
	Tritium	4.00E+09	1.73E+09	4.3
	Carbon-14	6.60E+10	2.50E+08	<1
	Argon-41	1.50E+10	5.09E+06	<1
Dounreay[d]	All other radionuclides[6]	5.10E+06	1.14E+06	22
(Vulcan)	Noble gases	5.00E+09	Nil	Nil
Rosyth[d,r]	Tritium	1.00E+07	1.04E+05	1.0
	Carbon-14	5.00E+07	2.02E+05	<1
	Other radionuclides	1.00E+05	2.45E+04	25
Radiochemical production				
Amersham (GE Healthcare)	Alpha	2.25E+06	1.56E+04	<1
	Radionuclides T1/2<2hr	7.50E+11	3.84E+09	<1
	Tritium	2.00E+12	1.60E+11	8.0
	Radon-222	1.00E+13	1.62E+12	16
	Other including selenium-75 and iodine-131	1.60E+10	1.58E+06	<1
Cardiff (GE Healthcare)[7]	Tritium	6.00E+12	4.45E+10	<1
	Carbon-14	1.10E+12	1.42E+09	<1

Table A2.1 continued

Establishment	Radioactivity	Discharge limit (annual equivalent) [a], Bq	Discharges during 2019	
			Bq	% of annual limit[b]
Industrial and landfill sites				
LLWR	Alpha	BAT	3.86E+03	NA
	Beta	BAT	3.56E+04	NA
Lillyhall (Cyclife UK Limited)	Alpha (particulate)	5.00E+05	4.46E+03	<1
	Beta (particulate)	5.00E+05	2.04E+04	<1

* *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*
[1] *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*
[2] *Discharge permit revised with effect from September 2017*
[3] *Discharge permit revised with effect 1 May 2019*
[4] *Discharge permit revised with effect 1 November 2019, the discharge limits for sulphur-35 and argon-41 were removed*
[5] *Discharge permit revised with effect from June 2018*
[6] *Letter of agreement revised with effect from 1 January 2017*
[7] *Discharge permit revoked 17 December 2019*
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, 2019

Establishment	Radioactivity	Discharge limit (annual equivalent)[a], Bq	Discharges during 2019	
			Bq	% of annual limit[b]
Nuclear fuel production and reprocessing				
Capenhurst	Uranium	7.50E+08	6.34E+06	<1
(Urenco UK Ltd)	Uranium daughters	1.36E+09	3.26E+06	<1
	Non-uranic alpha	2.20E+08	8.97E+06	4.1
	Technetium-99	1.00E+09	2.57E+06	<1
Sellafield[c]	Alpha	9.00E+11	1.34E+11	15
	Beta	1.80E+14	6.81E+12	3.8
	Tritium	1.80E+16	4.23E+14	2.4
	Carbon-14	2.10E+13	2.76E+12	13
	Cobalt-60	3.60E+12	1.62E+10	<1
	Strontium-90	4.50E+13	1.16E+12	2.6
	Zirconium-95 + Niobium-95	2.80E+12	5.17E+10	1.8
	Technetium-99	1.00E+13	9.41E+11	9.4
	Ruthenium-106	5.10E+13	4.62E+11	<1
	Iodine-129	2.00E+12	4.46E+10	2.2
	Caesium-134	1.60E+12	2.01E+10	1.3
	Caesium-137	3.40E+13	1.63E+12	4.8
	Cerium-144	4.00E+12	6.81E+10	1.7
	Neptunium-237	7.30E+11	3.43E+10	4.7
	Plutonium alpha	7.00E+11	1.12E+11	16
	Plutonium-241	2.50E+13	1.22E+12	4.9
	Americium-241	3.00E+11	1.54E+10	5.1
	Curium-243+244	5.00E+10	1.28E+09	2.6
	Uranium (in kg)[d]	2.00E+03	2.60E+02	13
Springfields	Alpha	1.00E+11	9.80E+09	9.8
	Beta	2.00E+13	1.10E+11	<1
	Technetium-99	6.00E+11	3.55E+09	<1
	Thorium-230	2.00E+10	2.82E+08	1.4
	Thorium-232[e]	1.50E+10	2.51E+07	<1
	Neptunium-237	4.00E+10	9.68E+07	<1
	Other transuranic radionuclides	2.00E+10	2.31E+08	1.2
	Uranium	4.00E+10	8.36E+09	21
Research establishments				
Dounreay[e]	Alpha[f]	3.40E+09	1.70E+08	5.0
	Non-alpha[g]	4.80E+10	8.80E+09	18
	Tritium	6.90E+12	2.10E+10	<1
	Strontium-90	1.77E+11	5.20E+10	29
	Caesium-137	6.29E+11	4.00E+09	<1
Harwell (Lydebank Brook)	Alpha	3.00E+07	3.42E+06	11
	Beta	3.00E+08	6.74E+06	2.2
	Tritium	2.00E+10	4.84E+08	2.4
Harwell (sewer)	Alpha	1.00E+07	1.14E+05	1.1
	Beta	6.00E+08	3.68E+06	<1
	Tritium	1.00E+11	1.92E+08	<1
	Cobalt-60	5.00E+06	4.50E+05	9.0
	Caesium-137	2.00E+08	3.61E+06	1.8

Table A2.2 continued				
Establishment	Radioactivity	Discharge limit (annual equivalent)[a], Bq	Discharges during 2019	
			Bq	% of annual limit[b]
Winfrith (inner pipeline)[h,1]	Alpha	1.40E+10	1.10E+06	<1
	Tritium	4.00E+13	1.17E+09	<1
	Caesium-137	1.98E+12	1.99E+08	<1
	Other radionuclides	9.80E+11	2.62E+07	<1
Winfrith (outer pipeline)	Alpha	2.00E+09	9.64E+05	<1
	Tritium	1.50E+11	9.06E+07	<1
	Other radionuclides	1.00E+09	2.03E+06	<1
Winfrith (River Frome)	Tritium	7.50E+11	Nil	Nil
Minor sites				
Imperial College Reactor Centre Ascot	Tritium	4.00E+07	5.61E+05	1.4
	Other radioactivity	1.00E+07	2.40E+02	<1
Nuclear power stations				
Berkeley	Tritium	1.00E+12	5.16E+07	<1
	Caesium-137	2.00E+11	3.89E+08	<1
	Other radionuclides	2.00E+11	3.85E+07	<1
Bradwell[2]	Tritium	7.00E+10	1.20E+09	1.7
	Caesium-137	7.00E+09	4.50E+07	<1
	Other radionuclides	7.00E+09	1.70E+08	2.4
Chapelcross	Alpha	1.00E+09	1.33E+04	<1
	Non-alpha[i]	1.00E+12	6.32E+06	<1
	Tritium	6.50E+12	1.02E+07	<1
Dungeness A Station	Tritium	8.00E+12	4.42E+09	<1
	Caesium-137	1.10E+12	1.02E+10	<1
	Other radionuclides	8.00E+11	1.32E+11	17
Dungeness B Station	Tritium	6.50E+14	1.14E+13	1.8
	Sulphur-35	2.00E+12	1.52E+09	<1
	Cobalt-60	1.00E+10	2.45E+08	2.5
	Caesium-137	1.00E+11	7.35E+08	<1
	Other radionuclides	8.00E+10	9.48E+08	1.2
Hartlepool	Tritium	6.50E+14	3.33E+14	51
	Sulphur-35[3]	3.60E+12	1.27E+12	35
	Cobalt-60	1.00E+10	1.90E+08	1.9
	Caesium-137	1.00E+11	2.90E+09	2.9
	Other radionuclides	8.00E+10	2.14E+09	2.7
Heysham Station 1	Tritium	6.50E+14	2.86E+14	44
	Sulphur-35	2.00E+12	4.07E+11	20
	Cobalt-60	1.00E+10	2.97E+08	3.0
	Caesium-137	1.00E+11	7.42E+08	<1
	Other radionuclides	8.00E+10	5.17E+09	6.5

Table A2.2 continued

Establishment	Radioactivity	Discharge limit (annual equivalent)[a], Bq	Discharges during 2019	
			Bq	% of annual limit[b]
Heysham Station 2	Tritium	6.50E+14	3.69E+14	57
	Sulphur-35	2.00E+12	1.82E+11	9.1
	Cobalt-60	1.00E+10	1.00E+08	1.0
	Caesium-137	1.00E+11	7.07E+08	<1
	Other radionuclides	8.00E+10	1.28E+10	16
Hinkley Point A Station	Tritium	1.00E+12	1.08E+09	<1
	Caesium-137	1.00E+12	6.45E+07	<1
	Other radionuclides	7.00E+11	1.14E+08	<1
Hinkley Point B Station	Tritium	6.50E+14	2.17E+14	33
	Sulphur-35	2.00E+12	3.37E+11	17
	Cobalt-60	1.00E+10	7.52E+07	<1
	Caesium-137	1.00E+11	3.67E+08	<1
	Other radionuclides	8.00E+10	2.78E+09	3.5
Hunterston A Station	Alpha	2.00E+09	4.30E+07	2.2
	All other non-alpha[j]	6.00E+10	1.42E+08	<1
	Tritium	3.00E+10	8.60E+07	<1
	Caesium-137	1.60E+11	1.19E+08	<1
	Plutonium-241	2.00E+09	9.00E+06	<1
Hunterston B Station	Alpha	1.00E+09	1.86E+07	1.9
	All other non-alpha	1.50E+11	5.42E+09	3.6
	Tritium	7.00E+14	2.11E+13	3.0
	Sulphur-35	6.00E+12	1.00E+10	<1
	Cobalt-60	1.00E+10	2.00E+08	2.0
Oldbury	Tritium	1.00E+12	7.00E+10	7.0
	Caesium-137	7.00E+11	2.47E+10	3.5
	Other radionuclides	7.00E+11	3.13E+10	4.5
Sizewell A Station	Tritium	5.00E+12	1.01E+11	2.0
	Caesium-137	1.00E+12	2.96E+10	3.0
	Other radionuclides	7.00E+11	3.66E+10	5.2
Sizewell B Station	Tritium	8.00E+13	2.80E+13	35
	Caesium-137	2.00E+10	2.73E+08	1.4
	Other radionuclides	1.30E+11	1.20E+10	9.2
Torness	Alpha	5.00E+08	1.61E+06	<1
	All other non-alpha	1.50E+11	4.38E+09	2.9
	Tritium	7.00E+14	3.23E+14	46
	Sulphur-35	3.00E+12	8.45E+11	28
	Cobalt-60	1.00E+10	2.47E+08	2.5
Trawsfynydd	Tritium	3.00E+11	1.11E+09	<1
	Caesium-137	1.50E+10	1.68E+08	1.1
	Other radionuclides[k]	3.00E+10	3.88E+08	1.3
Wylfa	Tritium	1.50E+13	8.56E+10	<1
	Other radionuclides	1.10E+11	3.88E+09	3.5

Table A2.2 continued

Establishment	Radioactivity	Discharge limit (annual equivalent)[a], Bq	Discharges during 2019	
			Bq	% of annual limit[b]
Defence establishments				
Aldermaston (Silchester)[l]	Alpha	1.00E+07	1.72E+06	17
	Other beta emitting radionuclides	2.00E+07	2.30E+06	12
	Tritium	2.50E+10	2.10E+08	<1
Aldermaston (to Stream)[l,m]	Tritium	NA	2.00E+08	NA
Barrow[n]	Tritium	1.20E+10	1.90E+06	<1
	Carbon-14	2.95E+08	1.40E+04	<1
	Cobalt-60	1.34E+07	3.70E+04	<1
	Other gamma emitting radionuclides	3.50E+06	5.20E+04	1.5
Derby[o]	Alpha[p]	2.00E+09	3.18E+07	1.6
	Alpha[q]	3.00E+05	3.67E+03	1.2
	Beta[q]	3.00E+08	1.38E+05	<1
Devonport (sewer)[r]	Tritium	2.00E+09	3.96E+07	2.0
	Cobalt-60	3.50E+08	2.43E+06	<1
	Other radionuclides	6.50E+08	6.15E+07	9.5
Devonport (estuary)[r]	Tritium	7.00E+11	4.98E+09	<1
	Carbon-14	1.70E+09	2.60E+07	1.5
	Cobalt-60	8.00E+08	2.27E+06	<1
	Other radionuclides	3.00E+08	3.15E+06	1.1
Faslane	Alpha	2.00E+08	6.80E+04	<1
	Beta[i,s]	5.00E+08	6.80E+05	<1
	Tritium	1.00E+12	6.51E+09	<1
	Cobalt-60	5.00E+08	3.40E+05	<1
Rosyth[e,t]	Tritium	3.00E+08	2.40E+07	8.0
	Cobalt-60	1.00E+08	3.60E+05	<1
	Other radionuclides	1.00E+08	3.10E+06	3.1
Radiochemical production				
Amersham (GE Healthcare)[s]	Alpha	3.00E+08	3.10E+06	1.0
	Tritium	1.41E+11	1.40E+06	<1
	Other radionuclides	6.50E+10	1.21E+08	<1
Industrial and landfill sites				
LLWR	Alpha	BAT	4.34E+07	NA
	Beta	BAT	7.85E+08	NA
	Tritium	BAT	4.09E+10	NA

Table A2.2 continued				
Establishment	Radioactivity	Discharge limit (annual equivalent)[a], Bq	Discharges during 2019	
			Bq	% of annual limit[b]
Lillyhall (Cyclife UK Limited)	Alpha	5.00E+05	1.68E+03	<1
	Beta	5.00E+05	1.41E+04	2.8

[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 per cent*
[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] *Excluding Tritium, caesium-137 and plutonium-241*
[k] *Including strontium*
[l] *Discharges were made by AWE plc*
[m] *The discharge limit has been replaced by an activity notification level of 30 Bq l^{-1}*
[n] *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*
[o] *Discharges were made by Rolls Royce Marine Power Operations Ltd*
[p] *Discharge limit is for Nuclear Fuel Production Plant*
[q] *Discharge limit is for Neptune Reactor Raynesway Site*
[r] *Discharges were made by Devonport Royal Dockyard Ltd*
[s] *Excluding cobalt-60*
[t] *Discharges were made by Rosyth Royal Dockyard Ltd*
[1] *The discharge permit was revised with effect from 1 January 2018. Inutec Limited were granted a site licence in February 2019*
[2] *Discharge permit revised with effect 1 May 2019*
[3] *The discharge permit was revised with effect from 9 October 2017: the limit for sulphur-35 was revised. The percentage of annual limit is based on the revised limit*
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 2019/20

Radionuclide or group of radionuclides	Total vault disposed[a] waste FY19/20 (Bq)	Cumulative total vault disposed[a,b] waste (Bq)
Tritium	1.27E+11	2.77E+13
Carbon-14	8.20E+09	4.98E+11
Chlorine-36	3.49E+08	7.15E+11
Calcium-41	0.00E+00	1.20E+10
Selenium-79	0.00E+00	4.90E+02
Molybdenum-93	0.00E+00	1.40E+06
Zirconium-93	0.00E+00	3.83E+10
Niobium-94	1.69E+07	6.94E+09
Technetium-99	4.96E+08	3.04E+12
Silver-108m	3.54E+08	1.16E+10
Iodine-129	7.36E+06	3.33E+09
Caesium-135	0.00E+00	5.25E+08
Radium-226	9.00E+07	7.33E+10
Thorium-229	0.00E+00	5.38E+05
Thorium-230	6.23E+05	7.05E+09
Thorium-232	2.15E+06	3.57E+10
Protactinium-231	0.00E+00	2.44E+09
Uranium-233	0.00E+00	5.69E+10
Uranium-234	1.38E+09	4.66E+11
Uranium-235	4.45E+07	3.19E+10
Uranium-236	2.36E+08	2.77E+10
Uranium-238	1.22E+09	5.27E+11
Neptunium-237	2.94E+07	4.30E+10
Plutonium-238	3.23E+09	2.26E+11
Plutonium-239	9.10E+09	5.12E+11
Plutonium-240	5.99E+09	3.29E+11
Plutonium-241	6.47E+10	9.84E+12
Plutonium-242	4.21E+06	9.92E+08
Americium-241	2.18E+10	1.39E+12
Americium-242m	0.00E+00	5.87E+10
Americium-243	2.67E+06	5.63E+08
Curium-243	1.34E+07	3.35E+09
Curium-244	1.23E+08	2.05E+10
Curium-245	5.09E+04	5.52E+06
Curium-246	Nil	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*	2.38E+11	6.51E+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*

[b] *the quoted radioactivity's exclude any Waste Consignment Information (WCI) form resubmissions made by consignors as part of ongoing investigations. Refer to Section 5 of the 2018/19 Environmental Safety Case Annual Review for specific consignment details (report ref; LLWR/ESC/R(19)10103).*

* *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.*

Table A2.3 continued				
Year	Actual receipt data[a,b]		Projected data[c]	
	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	2.00E+04	4.31E+05
2018/19	1.72E+03	2.51E+05	2.31E+04	4.54E+05
2019/20	6.93E+02	2.51E+05	2.39E+04	4.78E+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*

[b] *'disposed waste' volumes refer to the gross package volume of each container or cumulative gross package volume of all containers received at LLWR site*

[c] *'projected data' volumes quoted within this report are different to those quoted for the same period in previous RIFE reports. Refer to LLWR Learning Report reference LR004845, raised on the 23rd July 2019.*

Table A2.4 Solid waste transfers from nuclear establishments in Scotland, 2019*

Establishment Transfer from	Volume m^3	Total Activity Bq	Alpha Bq	Beta/Gamma Bq
Research establishments				
Dounreay	3.85E+02		3.52E+09	1.50E+10
Nuclear Power Stations				
Chapelcross[a]	2.07E+02	3.67E+10		
Hunterston A	9.50E+01	2.22E+09		
Hunterston B	7.18E+01	5.65E+09	2.66E+08	5.38E+09
Torness	2.02E+01		1.72E+07	6.93E+09
Defence establishments				
Coulport	Nil		Nil	Nil
Dounreay (Vulcan)	Nil		Nil	Nil
Faslane	1.53E+01		Nil	3.60E+07
Rosyth[b]	1.14E+02			

* *As reported by site operators to SEPA*

[a] *Reported as total activity only*

[b] *Transfers of cobalt-60 and 'all other radionuclides' were 6.27E+08 and 2.01E+10 Bq, respectively*

Table A2.5 Summary of unintended leakages, spillages, emissions or unusual findings of radioactive substances from nuclear licensed sites in the UK in 2019

Site	Month/Year	Summary of incident	Consequences and action taken
Dounreay	February 2019	A contamination incident occurred within a facility in the Fuel Cycle Area (FCA). The cause of the incident was a valve operational failure during the testing of a ventilation system. This resulted in disturbance of radioactively contaminated dust within the ventilation system and subsequent discharge into the facility and through a gaseous discharge stack to atmosphere.	The increased discharge of radioactivity to the environment as a result of the contamination incident was calculated to be less than one per cent of the relevant authorised gaseous discharge limit and there was no breach of discharge limits. Although the environmental impact of the discharge is considered to be very low, SEPA's investigation into the incident concluded that DSRL contravened multiple conditions of its authorisation under EASR 18. SEPA issued a Regulatory Notice to DSRL that outlines the steps DSRL is required to take to address the identified contraventions.
	September 2019	SEPA undertook a compliance inspection of DSRL's implementation of standards and codes of practice, which form part of the site's management system. The inspection identified a number of shortcomings in the implementation of site standards relating to the inspection, maintenance and use of equipment which are relied upon for environmental compliance. The inspection also identified that DSRL contravened multiple conditions of its authorisation under EASR 18.	SEPA issued a Regulatory Notice to DSRL that outlines the steps DSRL is required to take to address the identified contraventions.
Regional Monitoring (Scotland)	April 2019	Following a particularly dry period, the Dounreay site operator promptly notified SEPA of increased beta activity in unfiltered space extract systems. The activity could not be linked to any facility and instead had an off-site component.	The site operator checked the offsite emergency monitoring points and confirmed the same trend in elevated beta readings. SEPA changed medium volume air sampling filters around Dounreay and high-volume air samplers at Lerwick and Glasgow. In addition, SEPA also took several samples of grass from Inverness to the Dounreay site (Table 7.6b). The results of this grass sampling did not give any cause for concern. However it was noted that activity may have been linked to several wildfires near the site that caused smoke to drift several miles away. Elevated beta activity was also noted in air filter measurements across Scotland during April.
Sellafield	February 2019	In July 2018, Sellafield Limited notified the Environment Agency that the alpha levels within the THORP Feed Pond were increasing, giving rise to an increase in discharges.	The reprocessing schedule did not adequately mix corroded and failed fuels with intact fuels. This, coupled with a lack of container flushing resulted in elevated alpha discharges. Whilst this incident constituted a breach in permit conditions, the environmental impact was considered to be minor. The Environment Agency provided advice and guidance. An action was placed on Sellafield Limited to produce a route map that identifies all of the key environmental information that supports effective oversight of liquid effluent discharges.
	March 2019	Over the period, July 2018 to March 2019, a number of containment defects were identified on the external ducting of the ventilation system for the Analytical Services and Special Nuclear Materials North facilities.	These defects constituted breaches to a number of permit conditions. In November 2018, the Environment Agency served an Enforcement Notice in response to these events. Under this notice, Sellafield Limited were required to repair the defects, improve maintenance and develop a programme of inspection and repair of the remaining ducting. The environmental impact of these events was minor.

Table A2.5 continued

Site	Month/Year	Summary of incident	Consequences and action taken
Sellafield	April 2019	A liquor leak occurred from the pressure wash equipment associated with the Redundant Sludge Tanks, within the first-generation Magnox Storage Pond. A proportion of the liquor was discharged to sea via the lagoon drainage system.	This event breached a number of permit conditions. In response, Sellafield Limited proposed a number of actions, via a management investigation, that will help to prevent a recurrence of this type of event. The Environment Agency required Sellafield Limited to investigate the contamination of the drains leading to the lagoon and clean-out these out as appropriate. In addition, the Environment Agency provided further advice and guidance to ensure appropriate design and hazard identification processes are followed. The environmental impact of this event was considered to be minor.
	October 2019	In October 2019, Sellafield Limited identified a leak of contaminated water from a redundant open-air concrete settling tank on the Sellafield site.	Sellafield Limited has now completed work to retrieve the inventory (solid and sludge) and seal the tank with grout. The leakage rate is now no greater than that expected from evaporation. The Environment Agency and ONR are investigating this event to determine what enforcement action may be necessary.
	November 2019	In November 2019, Sellafield Limited notified ONR and the Environment Agency that the liquor balance model for the Magnox Swarf Storage Silo (MSSS) indicated an ongoing loss of contaminated water from the MSSS building.	This is an on-going event that is being investigated by the Environment Agency and ONR. The radioactive liquor that leaks to ground is expected to remain in the soil immediately around the facility and therefore not represent a risk to public health. Options to prevent and mitigate the leak are currently being investigated.

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
GRR	Guidance on Requirements for Release of Nuclear Sites from Radioactive Substances Regulation
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
JWMP	Joint Waste Management Plan
LGC	Laboratory of the Government Chemist
LLLETP	Low Level Liquid Effluent Treatment Plant
LLW	Low Level Waste
LLWF	Low Level Radioactive Waste Facility
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.
Nuclear Sites	Nuclear Licensed sites
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
Soil and herbage survey	UKRSR01 and SCO00027	E, S	Q4, 2020
Offshore Dose Assessment Model	N/A	S	Q4, 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	Q4, 2020
FSS/SEPA Bottled Water Study	N/A	S	Published 2020, RIFE 25, 2020
Clyde Estuary Assessment	N/A	S	Q4, 2020
Dounreay Habits Survey	N/A	S	Q4, 2020

E Environment Agency
S Scotland and Northern Ireland Forum for Environmental Research or SEPA

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

Food Standards Agency
Food Policy Division
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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