RIFE - 27

Radioactivity in Food and the Environment, 2021

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Radioactivity in Food and the Environment, 2021

RIFE 27

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

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

Foreword

The UK's environmental regulators and food safety agencies are delighted to present the 27th edition of the Radioactivity in Food and the Environment (RIFE) report.

Radioactive substances and radiation have had many beneficial uses including their use 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. This also fulfils a vital role in providing reassurance to members of the public.

In common with previous issues of this report, RIFE 27 sets out the findings of the monitoring programmes of radioactivity in food and the environment carried out in 2021 throughout the UK. These monitoring programmes are undertaken by the Environment Agency, Food Standards Agency, Food Standards Scotland, Northern Ireland Environment Agency, Natural Resources Wales and the Scottish Environment Protection Agency.

The monitoring results and subsequent assessments presented in this report 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 far below legal limits in 2021.

The RIFE monitoring programme supports the requirements of the permitting legislation across the UK, together with other national and international agreements, policies, regulations and standards.

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 as well as the air we breathe. We are also exposed to artificial sources of radioactivity, such as in medical applications used in hospitals and nuclear power. It is a legal requirement to make sure the amount of artificial radioactivity that people are exposed to from discharges is kept within a safe limit. Around the world, strict regulations and recommendations are in place to protect the public and the environment.

In the UK, the exposure to artificial radioactivity in the environment mainly comes from permitted or authorised releases from UK nuclear sites. In addition to these sites, there are other users of radioactivity, such as hospitals, research or industrial facilities. These other facilities are generally known as the non-nuclear industries. Releases from hospital and research sites are significantly lower than from nuclear sites. The Radioactivity in Food and the Environment (RIFE) report is published each year by the environmental regulators and food standards agencies. This report brings together all the results of monitoring of radioactivity in food and the environment by the RIFE partners (Environment Agency, Food Standards Agency, Food Standards Scotland, Northern Ireland Environment Agency, Natural Resources Wales and the Scottish Environment Protection Agency).

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

An additional comparison can be made with the exposure from natural radioactivity using a different approach to those estimated for people who live or work near nuclear and other sites. Public Health England (now UK Health Security Agency) has published estimates of exposures to the UK population from naturally occurring and artificial sources of radioactivity. The most recent values show that naturally occurring sources, particularly radon gas, accounted for around 84% of the exposure from all sources of radioactivity, with medical radiation contributing around 16%. Artificial radioactivity in the environment, from the nuclear industry and from past testing of nuclear weapons, accounted for less than 0.2% of the exposure to the UK population (See Figure GS).

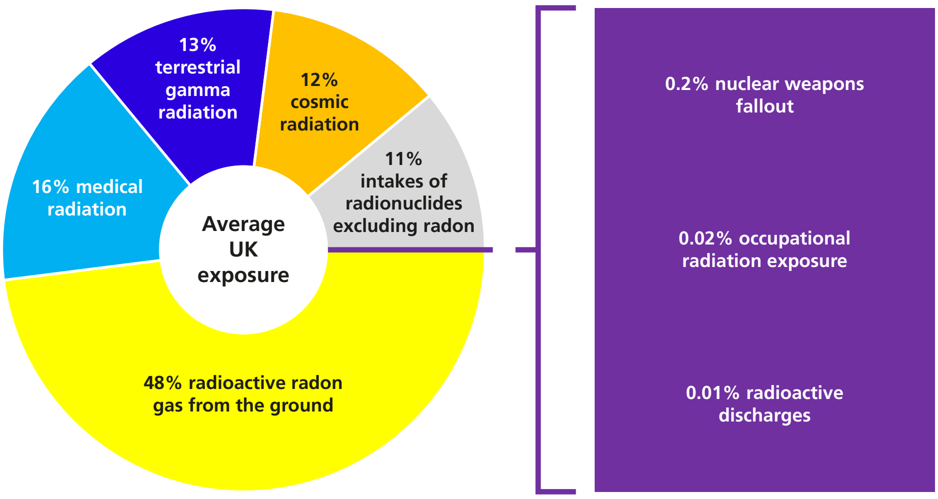

Figure GS Average UK population exposure from natural and man-made sources of radioactivity [29]

The headlines from the 2021 RIFE programme are:

For all sites

- exposure to the public from all sources of artificial radioactivity in food and the environment was low and well within the legal limit of 1 millisievert (mSv) per year[1], demonstrating that radioactivity in food and the environment is safe
- overall, between 2020 and 2021 there were no significant changes to the radioactivity measured in food and the environment

For nuclear sites

- in 2021, people living around the Cumbrian coast (near Sellafield), Capenhurst and Amersham were the most exposed from releases of radioactivity. The highest exposure was 21% of the legal limit in 2021 due to people eating locally produced seafood (fish and crustacean) around the Cumbrian coast. This is down from 31% of the legal limit in 2020
- 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 2021 was approximately 6% 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 in Wales was for those people living near the former Trawsfynydd nuclear power station, which is being decommissioned. This was due to them consuming locally produced food (milk), containing radioactivity released from past discharges from the station. The exposure was approximately 4% of the legal limit

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

For other areas

- in Northern Ireland, exposure to the public from artificial radioactivity in 2021 was estimated to be less than 1% of the legal limit
- 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% 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 artificial radionuclides in people's general diet was very small (less than 0.5% of the legal limit) in 2021

Overall, between 2020 and 2021 there have been no significant changes to the radioactivity measured in food and the environment around UK nuclear sites and other locations remote from these sites. Exposure from all sources of naturally occurring and artificial 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 divided into the following topics to highlight the scope of this report. These are:

- radiation exposures (doses) to people living near UK nuclear licensed sites
- radioactivity concentrations in samples collected near UK nuclear licensed sites
- external dose rates measured near UK nuclear licensed sites
- UK nuclear licensed site incidents and non-routine surveys
- habits surveys near UK nuclear licensed sites
- monitoring of radioactivity at locations remote from UK nuclear licensed sites (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 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. Where monitoring data are not available, some environmental concentrations are estimated by environmental transfer modelling of reported discharges. People's exposure to radiation (doses) can vary from year to year, due to changes in radionuclide concentrations and external dose rates. Changes in habits data and information, in particular food consumption, can also cause the estimates of dose to vary year on year.

The dose quantity presented in this summary is known as the 'total dose'. This is made up of contributions from all sources of radioactivity from man-made processes. Source specific dose assessments are also carried out in some cases to provide additional information and to compare with the 'total dose' assessment method.

Figure S and Table S show the assessed 'total doses' in 2021, due to the combined effects of authorised/permitted waste discharges and direct exposure from the site ('direct radiation') on those people most exposed to radiation near all major nuclear licensed sites in the UK.

Figure S 'Total doses' in the UK due to radioactive waste discharges and direct radiation, 2021. (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, 2021[a]

Establishment	Exposure, mSv[b] per year	Contributors[c]
Nuclear fuel production and processing		
Capenhurst	0.17	Direct radiation
Springfields	0.031	Gamma dose rate over salt marsh
Sellafield[d]	0.21	Crustaceans, ^{210}Po
Research establishments		
Dounreay	0.026	Meat - game, ^{137}Cs
Harwell	<0.005	Gamma dose rate over riverbank
Winfrith	0.006	Direct radiation
Nuclear power stations		
Berkeley and Oldbury	0.013	Direct radiation
Bradwell	0.006	Direct radiation
Chapelcross	0.018	Milk, ^{35}S, ^{90}Sr, ^{241}Am[e]
Dungeness	0.012	Direct radiation, gamma dose rate over sediment
Hartlepool	0.012	Direct radiation, gamma dose rate over sediment
Heysham	0.015	Gamma dose rate over sediment
Hinkley Point	0.030	Gamma dose rate over sediment
Hunterston	0.006	Molluscs, ^{238}Pu, $^{239+240}Pu$, ^{241}Am
Sizewell	0.016	Direct radiation
Torness	0.005	Domestic fruit, wild fruit, meat - game, root vegetables, ^{14}C, ^{90}Sr
Trawsfynydd	0.010	Direct radiation, exposure over sediment
Wylfa	0.005	Direct radiation, milk, ^{14}C
Defence establishment		
Aldermaston and Burghfield	0.008	Milk, ^{234}U, ^{238}U
Barrow[g]	0.044	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, ^{137}Cs, ^{241}Am[e]
Rosyth	0.011	Gamma dose rate over sediment
Radiochemical production		
Amersham	0.083	Direct radiation
Industrial and landfill		
LLWR near Drigg[d]	0.21	Crustaceans, ^{210}Po
Whitehaven[d]	0.21	Crustaceans, ^{210}Po

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

[b] Committed effective dose calculated using methodology of ICRP 60 to be compared with the 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 0.019 and 0.19mSv, 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

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

Doses to individuals are determined for those people most exposed to radiation ('representative person'[2]). 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 developing a series of habits profiles of people living and consuming food grown (or sourced) 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 2021, radiation doses from authorised/permitted releases of radioactivity to people living around nuclear licensed sites, remained well below the UK national 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 2021 were similar to those in 2020. These were the Cumbrian coastal community[3] near Sellafield (0.21mSv), Capenhurst (0.17mSv) and Amersham (0.083mSv). The doses received near Capenhurst and Amersham were dominated by direct radiation from sources on the sites.

The highest dose to the Cumbrian coastal community near Sellafield was mostly due to historical liquid discharges. In 2021, the representative person from the Cumbrian coastal community, was a high-rate crustacean consumer (who also consumed significant quantities of other seafood) and a change from that in 2020 (adult consuming molluscan shellfish). The estimated dose was 0.21mSv in 2021. Most of this dose (0.19mSv) 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 (0.019mSv) was due to the permitted discharges of artificial radionuclides by the nuclear industry. In the previous year (for 2020), the representative person received a dose of 0.31mSv (including a contribution of 0.25mSv and 0.058mSv related to the former phosphate processing plant and the nuclear industry, respectively). The decrease in 'total dose' in 2021 was mostly attributed to the revision of habits information, particularly the consumption rates and breadth of species consumed, in comparison to 2020. The largest contribution to dose

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[2] International Commission on Radiological Protection (ICRP) recommendations [1] 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'.

[3] 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.

to seafood consumers in the Cumbrian coastal community was from the radionuclide polonium-210.

Polonium-210 is a significant contributor of the dose to the most exposed members of the public because it has a relatively high dose coefficient (a factor used to convert an intake of radioactivity into a radiation dose) as recommended by the ICRP. Polonium-210 is present in the environment from natural sources and from TENORM which used to be discharged from the former phosphate processing plant (near Whitehaven). Nevertheless, polonium-210 concentrations in crustacean samples continued to be within or close to the expected range due to natural sources in 2021. From a radiological assessment perspective, the effects from the Sellafield site and the former 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[4] from authorised releases of radioactivity. The dose to adults was 0.056mSv in 2021, an increase from 2020 (0.027mSv). As in previous years, most of the dose in 2021 was due to the effects of historical discharges from the Sellafield site (see Section 2.3 for more information).

The highest dose in Wales was near the Trawsfynydd nuclear power station. This site is being decommissioned. The representative person was a consumer of locally produced foodstuffs and the dose was due to past permitted discharges. The source specific dose[4] to 1-year-old infants was 0.040mSv in 2021; a slight increase from 2020 (0.039mSv).

Radioactivity concentrations in samples collected near UK nuclear licensed sites

There were no major variations in environmental concentrations of radioactivity in 2021 compared to those in 2020. Near Sellafield, the environmental concentrations of most radionuclides have declined over the past 3 decades, albeit much slower in recent years. However, in 2021, mean concentrations of caesium-137, plutonium-239+240 and americium-241 in lobsters (Sellafield coastal), and of caesium-137 in winkles (Nethertown), were the lowest reported values in recent years.

In 2018, a review of the 2009 UK Radioactive Discharge strategy was published [2]. 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[5] radioactive substances strategy (RSS). Specifically, significant progress has been made

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[4] See Section 1.3, Appendix 1 (Annex 3) and Appendix 3 for more information.

[5] The Oslo and Paris Convention for the protection of the marine environment of the North-East Atlantic.

towards achieving progressive and substantial reductions in radioactive discharges. Progress is also being made to achieving progressive reductions in concentrations of radionuclides in the marine environment and in achieving progressive reductions in human exposures to ionising radiation, as a result of planned reductions in discharges.

The OSPAR Radioactive Substances Committee published its Fifth Periodic Evaluation in 2022, which demonstrated that Contracting Parties, including the UK, have successfully fulfilled the objectives of the OSPAR RSS for 2020 under the North-East Atlantic Environment Strategy (NEAES) 2010 – 2020 and have made significant progress against the ultimate aim of radionuclide concentrations in the environment near background values for naturally occurring radionuclides and close to zero for artificial radionuclides (see Section 1.4.2 for further details). [53]

External dose rates measured near UK nuclear licensed sites

Radioactivity in sediments in intertidal areas can potentially make a significant contribution to 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 2021 compared with 2020. At most locations, the external dose rates were close to background rates. Rates were higher in some estuaries near Sellafield (up to twice the background rate) and in the Ribble Estuary.

UK nuclear licensed sites incidents and non-routine surveys

During 2021, as a result of an ongoing programme of monitoring by the operator, radioactive items (particles and objects[6]) from Sellafield were detected on Cumbrian beaches and removed (94 in 2021 calendar year). The advice from the UK Health Security Agency (UKHSA) (formerly, Public Health England (PHE)) and the Food Standards Agency (FSA) is that the risk to the public from the radioactive particles and larger objects found on West Cumbrian beaches is very low. Therefore, measures to protect the public are not needed. 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

[6] "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 (less than 2 mm in diameter). "Objects" are larger radioactive artefacts and stones which have radioactive contamination on their surface and are larger than 2 mm in size. Particles can be compared according to the hazard posed.

estimated in the UKHSA risk assessment. PHE (now UKHSA) published a summary report of assessing the risk to people's health from radioactive objects on beaches around the Sellafield site in February 2020 [3].

At Dounreay, the comprehensive beach monitoring programme continued for fragments of irradiated nuclear fuel (particles). Last year, the number of particles recovered and the range in radioactivity content were similar to that observed in recent years. Fishing restrictions in a specific area around Dounreay are still in force under the Food and Environment Protection Act (FEPA) 1985 [4].

Special (or 'ad hoc') sampling related to nuclear licensed site operation is carried out at sites when needed or to provide one-off data sets. No such need arose in 2021.

Habits surveys near UK nuclear licensed sites

For 'total dose' assessments, habits data are used to define the exposure pathways (such as, eating locally produced food and time spent on beaches) for members of the public. Habits data are used to define one or more hypothetical individuals[7] (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 2021, the regular programmes of habits surveys, in England and Wales, resumed albeit using a combination of outdoor face-to-face and telephone interviews in-line with restrictions and measures associated with the COVID-19 pandemic. Surveys were carried out at Capenhurst, Derby and Sellafield in England.

These habits surveys give site-specific information on the diet and occupancy habits of people near nuclear licensed sites. 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.

[7] A hypothetical individual is used in radiological impact assessments as it is often not possible to identify a specific member of a population whose habits are likely to result in them receiving a dose towards the upper end of the range seen in that population when variability and uncertainty in exposure pathways and source of radiation are considered. Use of the concept of the representative person has been recommended by the ICRP and UKHSA as a practical approach to assess the radiological impact of exposure to a source of radiation.

Monitoring of radioactivity at locations remote from UK nuclear licensed sites

Additional monitoring in the UK and surrounding seas was carried out 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. These 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 radioactive decay of 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 occurring radioactivity. Concentrations have declined significantly since the plant ceased operations in 1992. Since then, polonium-210 and lead-210 have been within or close to the expected natural background concentration ranges. 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 0.21mSv in 2021, 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 nuclear 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 2021 and into 2022. 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. Together with stakeholders, work continues towards the implementation of the preferred management option for the remediation works. The Scottish Environment Protection Agency (SEPA) is continuing to work with the Ministry of Defence (MOD) and their contractors with regard to the remediation methodology for the site. The remediation contract was awarded by the MOD in February 2020 and an Environmental Authorisations (Scotland) Regulation (EASR) permit for the required work was granted in May 2021. Remediation work is now underway at Dalgety Bay and is expected to be completed by the end of 2023.

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 continued in 2021 to (i) establish the extent of 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 the OSPAR Convention.

From the monitoring of artificial radioactivity in Northern Ireland, consumer doses were estimated to be less than 1% of the annual limit of 1mSv for members of the public in 2021. 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% 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. In 2021, 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% of the legal limit.

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 2009 (MCAA) [5]. In 2021, no requests were received by the Marine Management Organisation (MMO) to apply for additional licences for the disposal of dredged material (containing radioactivity) 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 into the air and sea. Controls on imported food and animal feed products from Japan continued in 2021, under retained European Union (EU) regulations. 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 EU were monitored at ports of entry. None of the imports to the UK contained radioactivity exceeding the maximum permissible levels in 2021. The public doses received due to the imports were of negligible radiological significance. In June 2022, the EU retained regulations on Fukushima import controls were revoked for England, Scotland and Wales. In Northern Ireland, European Regulations continue to apply under the terms of the UK's withdrawal agreement from the EU.

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 2021, 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, FSA, FSS, Natural Resources Wales (NRW), Northern Ireland Environment Agency (NIEA) and SEPA 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 & Industrial Strategy (BEIS), Department for Environment, Food & Rural Affairs (Defra), NRW and the Welsh Government. The monitoring programmes involve 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 2021. The analytical results of the environmental radioactivity monitoring programmes are reported in tables in the relevant sections (Sections 2 to 7). The values provided in the tables are given in three different forms, (i) measurable values (referred to as 'positively detected'), (ii) less than values (that is, the lowest activity concentration, or dose rate measurement, that can be reliably detected for a given analytical method), and (iii) not detected (ND) values (meaning that 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 (both positively detected and less than values), or all are 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 manageable. For example, gamma-ray spectrometry can provide a large number of less than values and may not be reported. To identify the most relevant values, to be included in each individual table, one or more of the following conditions is required:

- 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, Table A2.1 and Table A2.2)
- all radionuclide results (both positively detected and less than values) are reported that have been analysed using a radiochemistry method (for example plutonium radionuclides)
- 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 (they are only excluded from the table after 5 continuous years of reporting 'less than values')
- 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
- naturally occurring radionuclides measured by gamma-ray spectrometry (for example potassium-40) are not usually reported unless the intention is to establish whether there is any enhancement above the expected background concentrations (for example from landfill sites)

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

1. Introduction

Overview

- The Radioactivity in Food and the Environment (RIFE) report represents the collaboration between the Environment Agency, Northern Ireland Environment Agency (NIEA), Natural Resources Wales (NRW) and Scottish Environmental Protection Agency (SEPA) referred to together as the environment agencies in this report, Food Standards Agency (FSA) and Food Standards Scotland (FSS) across the UK, independent of the nuclear industry.
- RIFE provides an open check on food safety and the public's exposure to radiation according to the Ionising Radiation (Basic Safety Standards) (Miscellaneous Provisions) (Amendment) (EU Exit) Regulations 2018 and the Environmental Permitting Regulations 2019 (as amended), retained from the EU Basic Safety Standards Directive 2013 (BSSD 13).
- The monitoring programme results support the UK in meeting its international treaty obligations.
- Annual radiation doses are summarised for major industrial sites; all doses were below the legal limit of 1mSv in 2021.

This section (i) describes the purpose and scope of the UK monitoring programmes for RIFE, (ii) provides a summary of the key results in terms of radiation exposures at each major industrial site in 2021 and (iii) gives an overview of the main sources of radiation in a regulatory context.

1.1 Scope and purpose of the monitoring programmes

In England and Wales, the FSA and the Environment Agency[8] carry out food and non-food (including seawater, sediments, dose rate) monitoring, respectively. SEPA (working closely with FSS on its programme) and the NIEA both undertake food and non-food monitoring in Scotland and Northern Ireland, respectively. Food monitoring includes the collection and analysis of cow's milk (unless otherwise specified in this report). Surveillance of imports through points of entry continued in 2021. 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

[8] 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 (RSR).

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.

The FSA has responsibility for food safety in England, Northern Ireland and Wales, and FSS has responsibility in Scotland. The environment agencies are responsible for regulating 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 current UK legislation, relating to radioactivity, provides uniform safety standards to protect the health of workers and members of the general public. These basic safety standards are retained from European Council (EC) Directives, the most recent one being the Basic Safety Standards Directive 2013 or 'BSSD 13' [6]. This lays down basic safety standards for protecting people against the dangers arising from exposure to ionising radiation. The RIFE report and the associated monitoring programmes were designed to conform to the requirements of Article 36 of the Euratom Treaty (see Section 7 and Appendix 1 in previous RIFE reports, for more details). Specifically, it provides estimates of annual doses to members of the public from authorised practices and enables these results to be made available to stakeholders. Following its withdrawal from the Euratom agreement, the UK is no longer required to report these data to the EC and has agreed a nuclear cooperation agreement (NCA) with the EU, ensuring both parties continue working together on civil nuclear matters including safeguards, safety and security. In late December 2020, BEIS published its transboundary directions to the environment agencies, available from https://www.gov.uk/guidance/transboundary-impacts-of-radioactive-waste-disposal-reporting-and-notification-obligations-euratom-article-37. These directions replace the requirements of Article 37 (related to the transboundary radiological impact of releases during normal operation) of the Euratom treaty following the UK withdrawal from the Euratom Treaty.

The Ionising Radiation (Basic Safety Standards) (Miscellaneous Provisions) (Amendment) (EU Exit) Regulations 2018 [7] came into force to transpose parts of BSSD 13, not already covered 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 to raise awareness and issue guidance about orphan sources (which are not under regulatory control but pose a radiological hazard).

The requirements for regulating 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) [8], in particular Schedule 23 'radioactive substances activities'. These regulations were amended in 2018 by the Environmental Permitting (England and Wales) (Amendment) (No. 2) Regulations 2018 (EPR 18) [9] 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 [10]. This was to ensure that the regulations remain fully operable at the end of the transition period following the UK's exit from the EU. Further changes were made in the Waste and Environmental Permitting etc. (Legislative Functions and Amendment etc.) (EU Exit) Regulations 2020, which transfers some functions from the European Commission to the Secretary of State and the devolved administrations [11].

In 2018, the Radioactive Substances (Modification of Enactments) Regulations (Northern Ireland) 2018 (RSR 18) came into force for radioactive substances activities in Northern Ireland [12] by amending the Radioactive Substances Act 1993 (RSA 93) [13]. 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 [14].

The requirements for regulating public exposure from the disposal of radioactive waste in Scotland is set out in the Environmental Authorisations (Scotland) Regulations 2018 (EASR18) [15], in particular Schedule 8 'radioactive substances activities'. EASR18 currently applies to both offshore and onshore activities in Scotland. A guidance document has also been published to support the implementation of the regulations. There are four types of authorisation under EASR18: 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 provide 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 substance activities.

In order to transpose the requirements of BSSD 13, the Ionising Radiations Regulations 2017 (IRR 17) [16] came into force in 2018 (replacing the Ionising Radiations Regulations 1999). The Health and Safety Executive (HSE) has also provided practical advice (Code of Practice) to help operators comply with their duties under IRR 17 [17]. IRR 17 controls the radiation exposure of workers and the public apart from that resulting from the permitted disposal of radioactive waste, which is regulated by the environment agencies under the various permitting legislation described previously. The Ionising Radiation (Basic Safety Standards) (Miscellaneous Provisions) Regulations 2018 [18] transposes Directive 2013/59/EU to ensure the United Kingdom is committed to maintaining high safety standards for protection against exposure to ionising radiation and includes updated scientific methods.

The Environment Agency and SEPA also have broader responsibilities under the Environment Act 1995 [19] 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 near, and at distance from, nuclear licensed sites;
- the results are also used to confirm the safety of the food chain; and
- 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 away from nuclear licensed sites is also carried out, giving information on background concentrations of radionuclides. In previous years, the Environment Agency, the FSA, FSS and SEPA have all completed reviews of their environmental radioactivity monitoring programmes. Further information is available in earlier RIFE reports (for example, [20]). Reviews are carried out to ensure the monitoring programmes are appropriate and are consistent with advice in the joint agency technical guidance [21] [22], resulting in an adjustment and consolidation of the monitoring around some sites. Year on year, the monitoring programmes are also affected by sample availability. The Environment Agency, FSA, FSS, NRW, NIEA, SEPA and BEIS have also published a RIFE summary report [23]. This summary report was combined with the UK report on the application of Best Available Techniques (BAT) in civil nuclear facilities (2012 to 2016), which was submitted to the Radioactive Substances Committee of the OSPAR Commission as the UK statement on the implementation of Paris Commission (PARCOM) Recommendation 91/4 on Radioactive Substances. The UK is expected to present its next statement, currently in preparation, on the implementation of OSPAR recommendation 2018/01 on radioactive discharges to the Radioactive Substances Committee in early 2023.

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 and Aquaculture Science (Cefas)
- UK Health Security Agency (UKHSA)
- SOCOTEC UK Limited

Appendix 1 is in a separate file that accompanies the main report. It gives details of the 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 is given in the Section 1.3.

1.2 Coronavirus (COVID-19) impacts in 2021

During 2021, the restrictions and measures implemented in the response to the COVID-19 pandemic were still in force. These restrictions and measures have had a minor impact on the monitoring programmes and a full programme of habits surveys in England was performed (Sellafield review, Capenhurst and Derby), albeit using a combination of outdoor face-to-face and telephone interviews.

More detail on the response and actions of environment agencies to the COVID-19 pandemic are reported in RIFE 26 [24].

In response to anecdotal evidence that occupancy and consumption habits were changing across Scotland due to people spending more time at home and food availability changing due to local restrictions, SEPA undertook a postal and online survey to determine if urgent changes were required to the environmental monitoring programme. The report from the survey is currently in draft format and will be made available via the SEPA website (https://www.sepa.org.uk/environment/radioactive-substances/environmental-monitoring-and-assessment/reports/). The main conclusions from the report were that SEPA's monitoring programme remains fit for purpose, but that small increases to outdoor occupancy rates had been observed that were likely to continue post-lockdown. Additionally, many people surveyed were keen to increase their self-sufficiency in food grown at home [25].

The 2021 monitoring programmes were affected by the restrictions and measures associated with the COVID-19 pandemic. Some samples could not be collected (for example, milk samples due to some farm closures in Wales and Northern Ireland) or were delayed. The 2021 monitoring programmes were more complete than those in 2020, therefore there was no significant impact on dose assessments.

1.3 Summary of radiation doses

1.3.1 The assessment process

Most of the monitoring was carried out to determine 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 2021 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, 2 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 near the nuclear licensed sites. The 'total dose' assessment is the main method for estimating radiation exposure to the public.

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

Exposure from direct radiation may be a significant contributor to dose, close to a nuclear site, due to radiation emitting from sources on the site[9]. The Office for Nuclear Regulation (ONR) is responsible for regulating direct radiation. In 2018, Électricité de France (EDF) Energy revised its 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 [26]. 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

[9] 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 for the purpose of assessing direct radiation exposure to the other station. Doses to workers are considered differently to those for the public and therefore are not included in 'total dose' assessments.

given previously. The operators of nuclear licensed sites provide estimates of direct radiation doses to the 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 [27].

The second type of assessment estimates annual dose from specific sources and associated exposure pathways (see Appendix 1, Annex 3 and Appendix 3 for more information). These dose assessments provide a check on the adequacy of the annual 'total dose' method (which is the preferred assessment type [28]) and provide information for a range of additional exposure pathways. The sum of the doses from specific sources (terrestrial and aquatic) cannot be directly compared to 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 (the 'representative person'). The results from both types of assessments are compared with legal limits. The effective doses (defined in Appendix 3) are calculated and compared with the legal dose limit of 1mSv per year for members of the public. All legal radiation dose limits in the UK are based on recommendations made by the ICRP [1], which are consistent with BSSD 13 [6]. 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 was estimated by PHE (now UKHSA) to be approximately 2.3mSv per year [29].

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 gaseous and liquid waste disposals from 2004 to 2008 [30].

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 inadvertently exposed as a result of their work. These, for example, include fishermen, farmers, and sewage workers. It is appropriate to compare their doses to the dose limit for members of the public [31]. Those people who specifically work with ionising radiation have their radiation doses assessed and recorded as part of their employer's programme to assess occupational exposure [16].

1.3.2 ‘Total dose’ results for 2021

The results of the assessment for each site are summarised in Table 1.2 (see also Figure S and Table S in the Technical Summary). These data are presented in three parts. The representative person receiving the highest annual doses from the pathways mainly 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 front or back covers of this report.

In all cases, doses estimated for 2021 were much less than the annual limit of 1mSv for members of the public. The people most affected from gaseous discharges and direct radiation varied from site to site but the dominant pathway was often direct radiation (from the relevant site), where it was applicable. The people most affected from liquid discharges were generally adults eating seafood or people who spend long periods of time over contaminated sediments, which are coastal (or other) areas that are impacted by liquid discharges.

The representative person who received the highest annual ‘total dose’ (0.021mSv), is from the Cumbrian coastal community (near Sellafield), who consumed crustaceans 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 (0.17mSv), and Amersham (0.083mSv) sites; these doses were almost entirely due to direct radiation from the sites and were a small fraction of the dose limit.

1.3.3 ‘Total dose’ trends

A time-series of annual ‘total dose’ from 2010 to 2021 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 (time spent on beaches and mud/salt marsh areas) were recorded at high rates. After Magnox reactors (and to a lesser extent AGRs) stopped power generation (for example, at Dungeness), direct radiation has reduced at these sites.

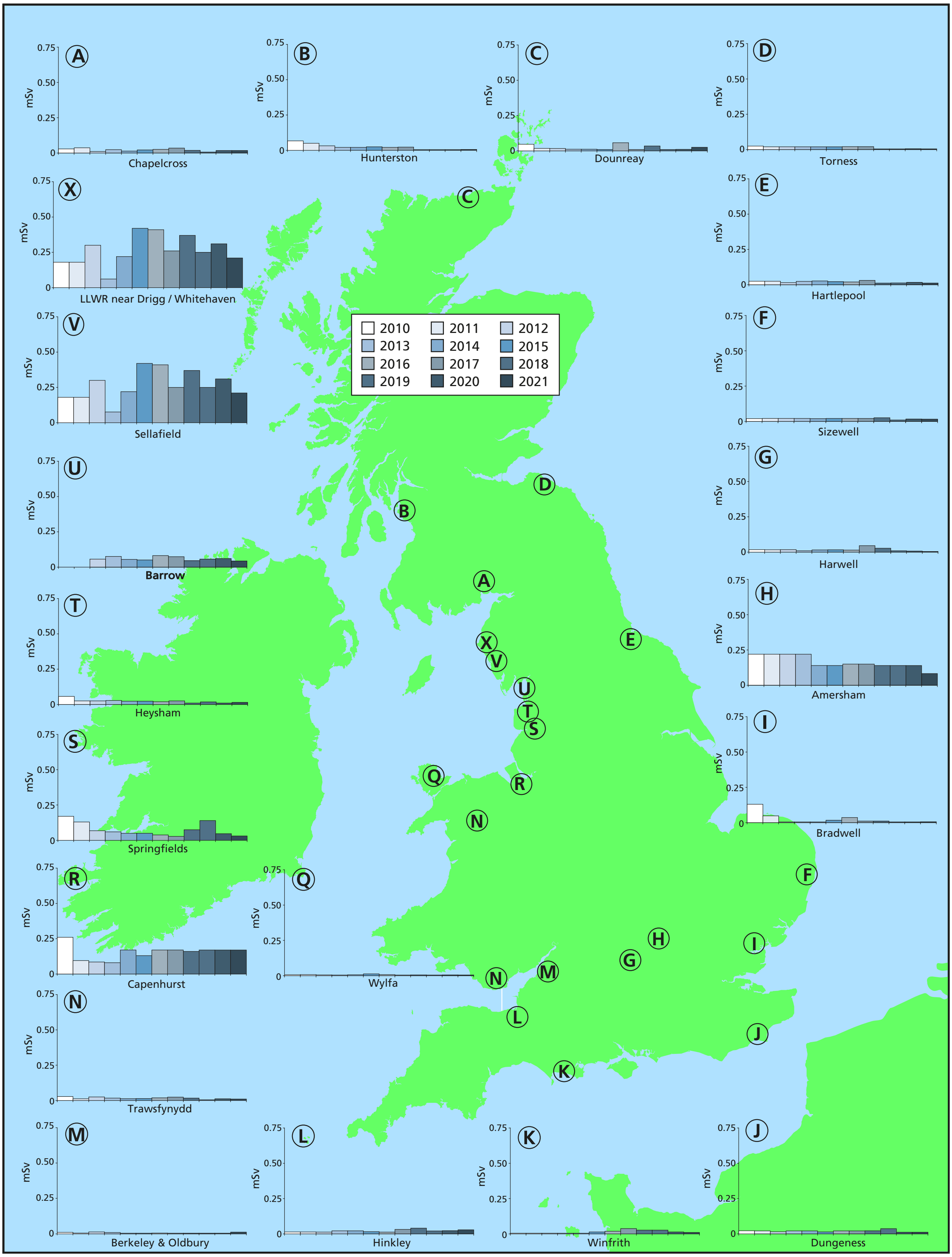


Figure 1.2 'Total doses' around the UK's nuclear sites due to radioactive waste discharges and direct radiation (2010–2021). (Exposures at Sellafield/Whitehaven/ LLWR receive a significant contribution to the dose from technologically enhanced naturally occurring radionuclides from previous non-nuclear industrial operations.)

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, the former phosphate processing plant at 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, 2018 and 2021 was mostly due to the concentration of caesium-137 found in venison (game) being included, which had not been sampled in 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' over 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. In all cases doses were well below the legal limit of 1mSv.

1.3.4 Source specific dose results for 2021

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. These assessments focus on the effect of gaseous or liquid waste discharges, unlike the assessment of 'total dose' which includes all sources including the effect of direct radiation.

The most significant exposures from seafood (fish and crustacean shellfish) consumption were to the Cumbrian coastal community (at the LLWR near Drigg, and near Sellafield and near the former phosphate processing plant at Whitehaven). The majority of the dose was from non-nuclear industrial operations, resulting in TENORM 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'.

Figure 1.3 Source specific doses in the UK, 2021. (Exposures at Whitehaven and Sellafield receive a significant contribution to the dose from technologically enhanced naturally occurring radionuclides from previous non-nuclear industrial operations.)

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 2 assessment approaches. 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 all age groups (see Appendix 1, Section 3 for the age groups used), calculated using the source-specific method, were all found to be well below the legal limit of 1mSv per year.

1.3.5 Protecting the environment

This report focusses on the risk to the public (in other words, to ensure that radiation doses remain below limits). However, the environment agencies also consider the protection of wildlife and the environment from radiation exposure caused by human activity. The 2007 recommendations of the ICRP concluded that a systematic approach to the radiological assessment of non-human species was required to support the management of radiation effects in the environment [1]. The ICRP, therefore, introduced the concept of Reference Animals and Plants (RAPs) for a system of radiological environmental protection [32]. The ICRP has published its aims covering (i) prevention or reduction of the frequency of deleterious (harmful) radiation effects on biota (animals and plants) 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 [33].

In the UK, the current legislative measures for protecting of wildlife from radiation are retained from the European Commission directives, on the conservation of wild birds [34] and the conservation of natural habitats and wild flora and fauna [35]. These are implemented through The Conservation of Habitats and Species (Amendment) (EU Exit) Regulations 2019, known as the 'Habitats Regulations' [36].

Under the 'Habitats Regulations', the Environment Agency, NRW and SEPA are required to review existing authorisations/permits to ensure that no authorised activity or permission has an adverse effect, either directly or indirectly, on the integrity of Natura 2000[10] habitat sites. Similarly, for any new or varied authorisation/permit, whereby the applicant must assess the potential impact of the discharges on reference organisms that represent species which may be adversely affected.

[10] Natura 2000 is made up of sites designated as Special Areas of Conservation (SACs) and Special Protection Areas (SPAs). SACs and SPAs in the UK no longer form part of the EU's Natura 2000 ecological network. The 2019 Regulations have created a national site network on land and at sea, including both the inshore and offshore marine areas in the UK.

The Environment Agency has assessed the dose rates to reference organisms and feature species for regulated radioactive waste discharges. It has concluded that the radiation dose to the worst affected organism was less than the agreed dose guideline ($40 \mu Gy\ h^{-1}$) and therefore, that there was likely to be no significant impact on the integrity of habitat sites or their conservation objectives [37] [38]. The assessment of impacts on wildlife and plants (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 (for example, [39]).

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.

In May 2019, SEPA published its nuclear power generation and decommissioning sector plan and this is available on SEPA's website: https://sectors.sepa.org.uk/nuclear-power-generation-and-decommissioning-sector-plan/.

1.4 Sources of radiation exposure

1.4.1 Radioactive waste disposal from nuclear licensed sites

The permits[11] and authorisations issued by the environment agencies to nuclear sites require operators to minimise the amount of all forms of radioactive waste generated. They also limit any liquid or gaseous discharges and ensure that solid low-level waste (LLW) is sent to a suitable disposal site.

Solid LLW from nuclear licensed sites may be transferred to the LLWR near Drigg for a range of treatments or disposal. Solid wastes containing low quantities of radioactivity can also be disposed of at permitted landfill sites (see Section 6). Solid LLW from Dounreay, intended for disposal, can be transferred to the Dounreay LLW facility.

[11] 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. In Scotland, the term 'permit' replaced 'authorisation' under the Environmental Authorisations (Scotland) Regulations (EASR), irrespective of whether the period includes activities prior to EASR coming into force in 2018. 'Authorisation' remains the relevant term for Northern Ireland.

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 [40]. The monitoring programmes reported here cover all these sites.

Figure 1.4 Principal nuclear sources of radioactive waste disposal in the UK, 2021. (Showing main initial operation. Some operations are undergoing decommissioning)

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 2021, 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 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 or other treatment/disposal methods). 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 the environment agencies do not usually carry out monitoring to protect public health. However, some routine monitoring programmes are undertaken in Lancashire and Northamptonshire (Section 6). In Scotland, SEPA carries out 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 2021, are given in Appendix 2 (Table A2.1 to Table 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 2021, 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. Using this conservative assumption, discharge limits are set so that doses to the public will be below the source and site dose constraints of 0.3 and 0.5mSv per year, respectively [28]. The determination of discharge limits considers a comprehensive range of pathways including the consumption of food. When determining the limits, the effect of the planned discharges on the environment and wildlife is also taken into account. In addition, the regulations require 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 [41].

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 the food standards agencies. In cases where there has been a breach of limits, or if appropriate actions have not been carried out 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 2021.

1.4.2 UK radioactive discharges (international agreements and new build)

This section gives information on the context of UK radioactive discharges as they relate to international agreements and the future building of new nuclear power stations.

International agreements

The UK is a contracting party to the Convention for the Protection of the Marine Environment of the North-East Atlantic (the 'OSPAR Convention'). This provides a framework for preventing and eliminating pollution in the north-east Atlantic, including the seas around the UK [42]. In 1998, UK government ministers agreed a long-term RSS and signed the Sintra statement which included the following commitment [43]:

> "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 [44], to describe how the UK would implement the ministerial agreements reached at the 1998 and subsequent meetings of OSPAR. This strategy was revised in 2009 to include gaseous discharges, from decommissioning as well as operational activities, and from the non-nuclear as well as the nuclear industry sectors [45]. 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. These are summarised in earlier RIFE reports (for example, [46]).

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 and individually) have issued guidance and developed environmental principles. These are also summarised in earlier RIFE reports (for example, [47]).

In 2018, the UK government published its review of the 2009 UK strategy for radioactive discharges [2]. This 2018 review 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 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 [48] [49]. The agreement on monitoring (Coordinated Environmental Monitoring Programme), relevant to OSPAR, was revised [50]. The programme includes sampling in 15 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 [51] [52]. The UK submission concerning the implementation of the principle of using BAT has also been published [23]. The Fifth Periodic Evaluation [53], represents the final assessment against the objectives of the RSS and will form the basis of the next OSPAR Quality Status Report, which is expected to be published in 2023. It demonstrated that Contracting Parties have successfully fulfilled the objectives of the OSPAR RSS for 2020 under the North-East Atlantic Environment Strategy (NEAES) 2010 – 2020 and have made significant progress towards fulfilling the ultimate aim of radionuclide concentrations in the environment near background values for naturally occurring radionuclides and close to zero for artificial radionuclides [53].

In October 2021, the Contracting Parties to OSPAR, which includes the UK, agreed the NEAES 2030 [54] and signed the Cascais Declaration [55], setting OSPAR's strategic direction up to 2030. The NEAES includes the new strategic objective (S3):

"OSPAR will prevent pollution by radioactive substances in order to safeguard human health and to protect the marine environment, with the ultimate aim of achieving and maintaining concentrations in the marine environment at near background values for naturally occurring radioactive substances and close to zero for human made radioactive substances."

The work for NEAES 2030 will be taken forward through the delivery of four operational objectives:

- S3.O1: On an ongoing basis, OSPAR will further prevent, progressively reduce or, where that is not practicable, minimise discharges of radioactive substances through the application of BAT, taking into account technical feasibility, radiological impact and legitimate uses of the sea.
- S3.O2: By 2025, OSPAR will identify and consider any obstacles in achieving further reductions in environmental concentrations of radioactive substances in the marine environment and examine possible solutions where appropriate.
- S3.O3: By 2025, OSPAR will identify the different types of loss of radioactive substances that may contribute to pollution of the marine environment. By 2027, OSPAR will determine if any additional measures are required to prevent such pollution, to the extent that such pollution is not already the subject of effective measures agreed by other international organisations or prescribed by other international conventions.
- S3.O4: By 2028, OSPAR will, following the outcome of the Quality Status report 2023, address, where appropriate, any uncertainties by reviewing and updating methodologies to better determine the possible impact of releases, emissions and losses of radioactive substances on marine ecosystems.

The importance of an integrated approach to stewardship of the marine environment has long been established in the UK. The reports ‘Safeguarding Our Seas’ [56] and ‘Charting Progress 2’ [57], provided an initial strategy and assessment on the state of the UK seas. Further information concerning other individual and fully integrated assessments is available in earlier RIFE reports (for example, [47]).

In 2010, the Marine Strategy Regulations 2010 came into force. These Regulations require us to take action to achieve or maintain good environmental status (GES) in our seas (subject to certain exceptions) through the production of a “Marine Strategy” for all UK waters and that this is coordinated across the 4 UK Administrations. The UK Marine Strategy provides the framework for assessing and taking measures to achieve and maintain GES in our seas. It covers a wide range of biodiversity and marine environment descriptors including contaminants and contaminants in seafood.

The UK published an initial assessment of UK seas in 2012 (Part One of the UK Marine Strategy) [58], followed by publication of Part Two, setting out the UK marine monitoring programmes, and Part Three, our Programme of Measures, in 2014 and 2015, respectively [59] [60]. In October 2019, following a public consultation, the UK published an update to the UK 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 [61]. The updated UK Marine Strategy Part Two, which sets out the monitoring programmes that we will use to assess the status of UK seas in respect to these targets and indicators was published in March 2021 [62]. The UK Marine Strategy Part Three, which sets out our Programmes of Measures designed to help us achieve or maintain GES, is currently being updated. Further details on the UK Marine Strategy can be found on: https://moat.cefas.co.uk/.

Nuclear new build

In the 2008 white paper 'Meeting the Energy Challenge' [63], 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 about 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 (for example, [64]). The UK government has further set out its current position on energy policy in the December 2020 white paper, "Powering our Net Zero Future" [65]. In this white paper, the UK government highlights the need to address climate change urgently and it sets out the strategy for wider energy systems so as to achieve the UK's target of net zero greenhouse gas emissions by 2050. The strategy includes a continuing and future role for nuclear generation to provide reliable clean electricity and it sees a potential additional role for advanced modular reactors (AMR) to provide high temperature process heat in the future. The eight nuclear sites, assessed as being potentially suitable for the development of new nuclear power stations, are shown in Figure 1.5. Three of these sites (Hinkley Point C, Sizewell C, and Bradwell B) were being actively pursued in 2021. The UK government re-affirmed its position on nuclear power generation as part of the 2022 British Energy Security Strategy, with an aim of generating up to 25% of the projected 2050 UK demand through a mix of small modular reactors (SMR) and large-scale nuclear power stations [66].

As regulators of the nuclear industry, the 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. In January 2022, the ONR and the Environment Agency completed its generic design assessment (GDA) on the China General Nuclear Power Corporation (CGN) designed UK HPR1000 (intended for deployment at Bradwell B in Essex), following the completion of a public consultation held in the first half of 2021. The steps undertaken by the regulators are described in previous RIFE reports [24]. The regulators concluded that the UK HPR1000 design should be capable of meeting UK safety, security, and environmental protection requirements.

Figure 1.5 Potential sites for new nuclear power stations

Following a request from BEIS, the ONR, the Environment Agency and NRW began the GDA process on the 470MW Small Modular Reactor in April 2022. The requesting party for this GDA is Rolls-Royce SMR Ltd. An outline 53-month programme for the three-step assessment process has been proposed for this GDA. Further information will be reported in subsequent RIFE reports.

The construction of Nuclear New Build Generation Company's (NNB GenCo's) new twin UK European Pressurised Reactor™ (EPR™) nuclear power station continues at Hinkley Point C in Somerset. The ONR continues to be engaged in carrying out 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 for construction-related discharges. The development of NNB GenCo is of interest to both regulators to ensure that the company has the competences and resources required to secure safety, security and environment protection throughout construction and as it prepares itself to be an operator.

The 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 (SZC) Limited, UK EPR™ design)
- Bradwell B, Essex (Bradwell B Power Generation Company Limited, UK HPR1000 design)

In 2020, the ONR and Environment Agency received applications from NNB GenCo (SZC) Limited for the Sizewell C nuclear site licence and radioactive substances activities permit. The applications are currently under consideration by the ONR and the Environment Agency.

The possible radiological impact from routine radiological discharges has been assessed for proposed nuclear power stations in England and Wales [67].

1.4.3 Managing radioactive liabilities in the UK

The UK government has been managing radioactive waste for many decades in accordance with the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management [68]. This convention aims 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 (for example, [69]).

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 is to manage radioactive waste and dispose of it where possible, or place it in safe, secure and suitable storage, in line with the UK and devolved administrations' policies. The Energy Act 2004 [70] requires the NDA to review and publish its strategy every 5 years. Its most recent strategy was published in 2021 [71] and the business plan for 2022 to 2025 is available [72]. In 2019, the NDA published an inventory and forecast of radioactive wastes in the UK (as of 1 April 2019) jointly with BEIS [73] and a Mission Progress Report in 2021 [74].

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 [75]. Following the introduction of the LLW policy, the UK LLW Strategy was published in 2010 [76]. A new UK LLW Strategy was published in 2016 [77]. 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. In January 2022, Nuclear Waste Services (NWS) was launched, which brings together the operator of the LLWR, geological disposal facility (GDF) developer Radioactive Waste Management Limited and the NDA group's integrated waste management programmes into a single organisation. NWS have assumed responsibility for the development of a GDF.

The NDA are responsible for implementing 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 HAW should be in near-surface facilities. Facilities should be located as near to the site where the waste is produced as possible. Guidance to site operators and regulatory position statements on the management of HAW on licensed sites has been issued by the Environment Agency, NRW, SEPA and the ONR [78] [79].

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 GDF at some point in the future [80]. 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 [81]. Following completion of the initial actions in the 2014 white paper and subsequent consultation, BEIS published a policy update in 2018 [82]. This replaces the 2014 white paper in England and also describes the positions of the Devolved Administrations: 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 [81], however following a national geological screening exercise, RWM/NWS have re-started the process to engage with communities across England to host a GDF. Further information on the aspects of GDF is also available on the website:

https://www.gov.uk/government/collections/geological-disposal-facility-gdf-for-high-activity-radioactive-waste.

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 2020 to 2021 [83], proposed work programme for 2021 [84] and a preliminary position paper on radioactive wastes from fusion energy [85] and its response on the consultation [86], 'towards fusion energy' run by BEIS in 2021 [87].

Guidance on requirements for authorisation for geological and near-surface disposal facilities has been published [88] [89] [90]. SEPA has issued a policy statement on how it will regulate the disposal of LLW from nuclear licensed sites [91] and published joint guidance with the Environment Agency and NRW on the surrender of nuclear site permits that include how potential onsite disposals of radioactive waste should be considered by site operators [92]. In May 2019, SEPA issued guidance on the decommissioning of non-nuclear facilities (for example, a single laboratory) from radioactive use [93].

Decommissioning of many nuclear sites in Great Britain is currently 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 was used to refine the structure and clarity of the guidance. This was published in 2018 [92]. This guidance describes what operators must do 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.

Naturally occurring radioisotopes are enhanced in some wastes (TENORM) and those wastes are 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 (for example, [47]).

1.4.4 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 [43]. The environmental impact of the deep ocean disposals was assessed by detailed mathematical modelling and has been shown to be negligible [94]. 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 confirms that the radiological impact of these disposals was insignificant.

In England, the MMO administers a range of statutory controls that apply to marine works on behalf of the Secretary of State for Environment, Food and Rural Affairs. This includes issuing licences under the Marine and Coastal Access Act 2009 (MCAA) [5] 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 DAERA, 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 [95]. The International Atomic Energy Agency (IAEA) has published a system of assessment that can be applied to dredged spoil disposal [96] [97] and which has been adapted to reflect operational practices in England and Wales [98]. In 2021, no new requests were received to apply for additional licences for the disposal of dredged material (containing radioactivity) at sea.

1.4.5 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. UKHSA has assessed incidents involving the transport of radioactive materials in the UK [99]. UKHSA 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 0.001mSv per year [100]. Submarine berths in the UK are monitored by the MOD (for example, [101]). 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 2021. 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 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 to naturally occurring radioactivity for the public and workers. 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 naturally occurring radioactive material (NORM). The environment agencies, FSA or FSS do not currently monitor radioactivity in the environment and food from the exploration and extraction of shale gas.

In November 2019, the UK government announced “an indefinite suspension” of fracking, after a report by the Oil and Gas Authority, an independent subsidiary of BEIS, found it was not possible to predict the probability or size of tremors caused by the practice. In late 2019, the Scottish Government finalised its policy position of no support for unconventional oil and gas development in Scotland.

As part of the British Energy Security Strategy [65], BEIS launched a scientific review of shale gas extraction in April 2022 to advise on the latest scientific evidence and developments in relation to shale gas extraction. In September 2022, the UK government lifted its moratorium on UK shale gas production. This will enable developers to seek planning permission where there is local support.

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 (for example, [69]).

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 II A of the Environmental Protection Act 1990, but there must be reasonable grounds for inspecting land for radioactivity. Reasonable grounds are defined in the statutory guidance. Once it is 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 [102]. The Environment Agency has issued a series of briefing notes that provide information on land contaminated with radioactivity in England and Wales [103]. In 2018, BEIS carried out a targeted consultation process on proposed updates to 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 [104]. 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 [105] [106].

In 2007, the Radioactive Contaminated Land (Scotland) Regulations came into force by amending Part II 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) of receiving the dose should be considered 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 [107]. 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 UKHSA, the most recent report was published in 2016 [29]. The most significant source of exposure was from natural radiation (radon and thoron gases). Figure 1.6 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 2.7mSv per year, the same as that reported in the previous review [108]. The dose from radiation in the environment was about 2.3mSv per year, or about 84% 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% of the annual dose was from artificial 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% to the total dose. The average individual dose from medical sources was about 0.4mSv per year, or about 16% of the dose from all sources of radiation. Occupational exposure contributed significantly less than 1% 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 UKHSA website: [https://www.ukhsaprotectionservices.org.uk/radiationandyou/.](https://www.ukhsaprotectionservices.org.uk/radiationandyou/)

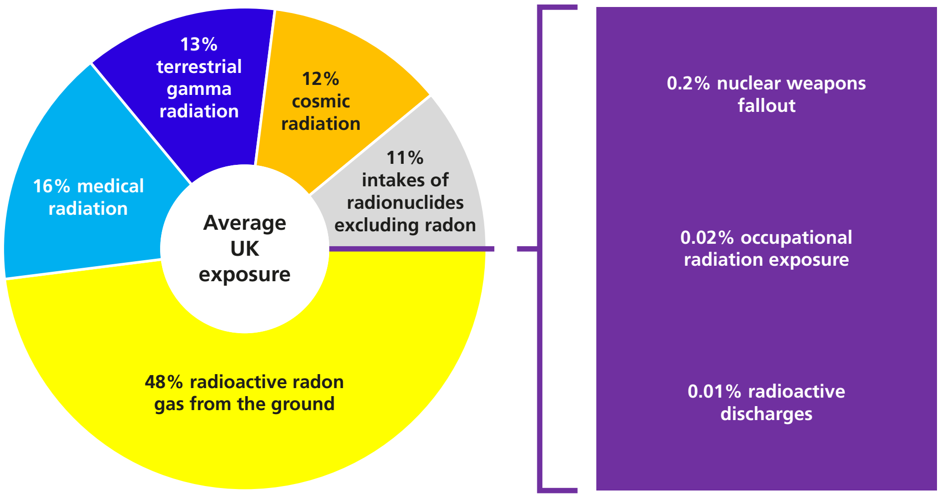


Figure 1.6 Average UK population exposure from natural and man-made sources of radioactivity [29]

The RIFE report is directed at establishing the exposure of people who might receive the highest possible doses due to regulated 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 law.

Table 1.1 Individual doses - direct radiation pathway, 2021*

Site	Exposure [a] mSv
Nuclear fuel production and reprocessing	
Capenhurst	0.17
Sellafield	0.003
Springfields	0.017
Research establishments	
Dounreay	0.008
Harwell	0.001
Winfrith (Magnox)	0.006
Nuclear power stations	
Berkeley	0.013
Bradwell	0.006
Chapelcross	0.006
Dungeness	0.010[c]
Hartlepool	0.006
Heysham	0.003[d]
Hinkley Point	0.001[e]
Hunterston	0.003[f]
Oldbury	0.001
Sizewell	0.015[g]
Torness	0.004
Trawsfynydd	0.004
Wylfa	0.003
Defence establishments	
Aldermaston	0.005
Barrow	Bgd[b]
Burghfield	0.005
Derby	Bgd[b]
Devonport	Bgd[b]
Faslane	<0.001
Rosyth	0.002
Dounreay (Vulcan)	Bgd[b]
Radiochemical production	
Amersham	0.080
Industrial and landfill sites	
LLWR near Drigg	0.027
Lillyhall (Cycliffe UK limited)	<0.001
Tradebe-Inutec (Winfrith)	0.003[h]

* 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. Doses to workers are considered differently to those for the general public and therefore are not included in 'total dose' assessments

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 (0.0032) not used. The dose to workers at Dungeness A from Dungeness B was 0.0032. The dose to workers at Dungeness B from Dungeness A was 0.024

d Value for Heysham 2. Heysham 1 (0.0023) not used

e Value for Hinkley B. Hinkley A (Bgd[b]) not used. The dose to workers at Hinkley A from Hinkley B was 0.0014. 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 A. Hunterston B (0.0030) not used. The dose to workers at Hunterson A from Hunterson B was 0.0009. The dose to workers at Hunterston B from Hunterston A was 0.0033

g Value for Sizewell B. Sizewell A (0.0010) not used. The dose to workers at Sizewell A from Sizewell B was 0.015. The dose to workers at Sizewell B from Sizewell A was Bgd[b]

h The dose to workers at Winfrith (Magnox) from Tradebe-Inutec (Winfrith) was 0.0085

Table 1.2 'Total doses' integrated across pathways, 2021

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	0.008[d]	Milk, ^{234}U, ^{238}U
Amersham	Local adult inhabitants (0-0.25km)	0.083[d]	Direct radiation
Barrow	Prenatal children of potato consumers	<0.005	Gamma dose rate over sediment, potatoes, ^{3}H[e]
Berkeley & Oldbury	Infant local inhabitants (0-0.25km)	0.013	Direct radiation
Bradwell	Prenatal children of local inhabitants (0-0.25km)	0.006	Direct radiation
Capenhurst	Infant poultry meat consumers	0.17[d]	Direct radiation
Chapelcross	Infant milk consumers	0.018	Milk, ^{35}S, ^{90}Sr, ^{241}Am[e]
Derby	Children potato consumers	<0.005[d]	Potatoes, ^{234}U[e], ^{238}U
Devonport	Adult potato consumers	<0.005	Potatoes, ^{14}C, ^{241}Am[e]
Dounreay	Adult game meat consumers	0.026	Meat - game, ^{137}Cs
Dungeness	Local adult inhabitants (0.25-0.5km)	0.012	Direct radiation, gamma dose rate over sediment
Faslane	Adult domestic fruit consumers	<0.005	Domestic Fruit, ^{137}Cs, ^{241}Am[e]
Hartlepool	Local adult inhabitants (0-0.25km)	0.012	Direct radiation, gamma dose rate over sediment
Harwell	Local adult inhabitants (0-0.25km)	<0.005	Direct radiation, external and inhalation,
Heysham	Local adult inhabitants (0-0.25km)	0.005	Direct radiation, gamma dose rate over sediment, external and inhalation, ^{14}C
Hinkley Point	Infant milk consumers	0.005	Milk, ^{14}C, ^{35}S[e], ^{60}Co[e]
Hunterston	Local adult inhabitants (0.5-1km)	<0.005	Direct radiation, extermal and inhalation, ^{14}C
LLWR near Drigg	Infant local inhabitants (0.5-1km)	0.029	Direct radiation
Rosyth	Local adult inhabitants (0.5-1km)	0.008	Direct radiation, gamma dose rate over sediment
Sellafield	Adult root vegetable consumers	0.009[d]	Direct radiation, gamma dose rate over sediment, potatoes, root vegetables, ^{241}Am
Sizewell	Local adult inhabitants (0-0.25km)	0.016	Direct radiation
Springfields	Local infant inhabitants (0.5-1km)	0.017	Direct radiation
Torness	Prenatal children of wild fruit and nut consumers	0.005	Domestic fruit, wild fruit, meat - game, root vegetables, ^{14}C, ^{90}Sr
Trawsfynydd	Prenatal children of local inhabitants (0.5-1km)	<0.005	Direct radiation
Winfrith	Local adult inhabitants (0-0.25km)	0.006	Direct radiation
Wylfa	Infant local inhabitants (0.25-0.5km)	0.005	Direct radiation, milk, ^{14}C
B Liquid releases from the site			
Aldermaston & Burghfield	Adult occupants over riverbank	<0.005	Direct radiation
Amersham	Adult occupants over riverbank	<0.005	Gamma dose rate over riverbank
Barrow[j]	Adult occupants on houseboats	0.044	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	0.090	Direct radiation
Chapelcross	Adult wildfowl consumers	0.006	Molluscs, $^{239+240}Pu$, ^{241}Am
Derby	Infant 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	0.011	Gamma dose rate over sediment
Dungeness	Adult occupants over sediment	0.008	Direct radiation, gamma dose rate over sediment
Faslane	Adult fish consumers	0.007	Fish, ^{137}Cs, ^{241}Am[e]
Hartlepool	Adult occupants over sediment	0.011	Direct radiation, gamma dose rate over sediment
Harwell	Prenatal children of occupants over riverbank	<0.005	Gamma dose rate over riverbank
Heysham	Adult occupants over sediment	0.015	Gamma dose rate over sediment
Hinkley Point	Adult occupants over sediment	0.030	Gamma dose rate over sediment
Hunterston	Adult mollusc consumers	0.006	Molluscs, ^{238}Pu, $^{239+240}Pu$, ^{241}Am
LLWR near Drigg[f]	Adult crustacean consumer	0.21	Crustaceans, ^{210}Po
Rosyth	Adult occupants over sediment	0.011	Gamma dose rate over sediment
Sellafield[f]	Adult crustacean consumer	0.21	Crustaceans, ^{210}Po

Table 1.2 continued

Site	Representative person[a]	Exposure[b], mSv Total	Dominant contributions[c]
Sizewell	Adult occupants over sediment	0.006	Direct radiation, gamma dose rate over sediment, ^{241}Am
Springfields	Adult occupants over salt marsh	0.031	Gamma dose rate over salt marsh
Torness	Adult mollusc consumers	<0.005	Fish, molluscs, ^{241}Am
Trawsfynydd	Adult occupants over sediment	0.010	Direct radiation, exposure over sediment
Whitehaven[f]	Adult crustacean consumer	0.21	Crustaceans, ^{210}Po
Winfrith	Adult occupants over sediment	<0.005	Gamma dose rate over sediment
Wylfa	Adult occupants over sediment	<0.005	Gamma dose rate over sediment
C All sources			
Aldermaston & Burghfield	Infant milk consumers	0.008[d]	Milk, ^{234}U, ^{238}U
Amersham	Local adult inhabitants (0-0.25km)	0.083[d]	Direct radiation
Barrow[j]	Adult occupants on houseboats	0.044	Gamma dose rate over sediment
Berkeley & Oldbury	Infant local inhabitants (0-0.25km)	0.013	Direct radiation
Bradwell	Prenatal children of local inhabitants (0-0.25km)	0.006	Direct radiation
Capenhurst	Local child inhabitants (0.5-1km)	0.17[d]	Direct radiation
Chapelcross	Infant milk consumers	0.018	Milk, ^{35}S, ^{90}Sr, ^{241}Am[e]
Derby	Infant 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 game meat consumers	0.026	Meat - game, ^{137}Cs
Dungeness	Local adult inhabitants (0.25-0.5km)	0.012	Direct radiation
Faslane	Adult fish consumers	0.007	Fish, ^{137}Cs, ^{241}Am[e]
Hartlepool	Local adult inhabitants (0-0.25km)	0.012	Direct radiation, gamma dose rate over sediment
Harwell	Prenatal children of occupants over riverbank	<0.005	Gamma dose rate over riverbank
Heysham	Adult occupants over sediment	0.015	Gamma dose rate over sediment
Hinkley Point	Adult occupants over sediment	0.030	Gamma dose rate over sediment
Hunterston	Adult mollusc consumers	0.006	Molluscs, ^{238}Pu, $^{239+240}Pu$, ^{241}Am
LLWR near Drigg[f]	Adult crustacean consumer	0.21	Crustaceans, ^{210}Po
Rosyth	Adult occupants over sediment	0.011	Gamma dose rate over sediment
Sellafield[f]	Adult crustacean consumer	0.21	Crustaceans, ^{210}Po
Sizewell	Local adult inhabitants (0-0.25km)	0.016	Direct radiation
Springfields	Adult occupants over salt marsh	0.031	Gamma dose rate over salt marsh
Torness	Prenatal children of wild fruit and nut consumers	0.005	Domestic fruit, wild fruit, meat - game, root vegetables, ^{14}C, ^{90}Sr
Trawsfynydd	Adult occupants over sediment	0.010	Direct radiation, exposure over sediment
Whitehaven[f]	Adult crustacean consumer	0.21	Crustaceans, ^{210}Po
Winfrith	Local adult inhabitants (0.5-1km)	0.006	Direct radiation
Wylfa	Infant local inhabitants (0.25-0.5km)	0.005	Direct radiation, milk, ^{14}C

[a] Selected on the basis of providing the highest dose from the pathways associated with the sources as defined in A, B or C
[b] 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 0.019 and 0.19mSv 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
[j] Exposures at Barrow are largely due to discharges from the Sellafield site

Table 1.3 Trends in 'total doses' (mSv) from all sources[a], 2004–2021

Site	2004	2005	2006	2007	2008	2009	2010	2011	2012
Aldermaston & 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	0.22
Barrow[e]									0.057
Berkeley & Oldbury	**0.12**	**0.090**	**0.042**	0.061	0.041	0.058	0.011	0.006	0.014
Bradwell	**0.09**	**0.067**	**0.075**	0.070	0.070	0.098	0.13	0.048	<0.005
Capenhurst	**0.080**	**0.080**	**0.085**	**0.12**	0.17	0.19	0.26	0.095	0.085
Chapelcross	0.022	0.023	0.024	0.019	0.021	0.017	0.029	0.037	0.011
Derby						<0.005	<0.005	<0.005	<0.005
Devonport	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Dounreay	0.011	0.043	0.029	0.059	0.078	0.063	0.047	0.018	0.017
Dungeness	**0.48**	0.55	0.63	0.28	0.40	0.32	0.022	0.021	0.015
Faslane	**<0.005**	**<0.005**	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Hartlepool	0.020	0.021	0.021	0.021	0.026	0.027	0.025	0.025	0.015
Harwell	**0.017**	**0.022**	**0.026**	0.022	0.020	0.023	0.018	0.017	0.018
Heysham	**0.036**	**0.028**	0.037	0.038	0.046	0.049	0.057	0.025	0.025
Hinkley Point	**0.026**	**0.027**	0.048	0.035	0.045	0.055	0.014	0.014	0.013
Hunterston	0.10	0.090	0.074	0.090	0.077	0.067	0.067	0.050	0.032
LLWR near Drigg[b]	0.58	0.40	0.43	0.37	0.47	0.28	0.18	0.18	0.30
Rosyth	**<0.005**	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Sellafield[b]	0.58	0.40	0.43	0.37	0.47	0.28	0.18	0.18	0.30
Sizewell	**0.045**	0.086	0.090	<0.005	0.031	0.026	0.020	0.021	0.021
Springfields	**0.17**	**0.15**	0.13	0.11	0.16	0.15	0.17	0.13	0.068
Torness	**0.024**	**0.025**	0.024	0.022	0.022	0.022	0.025	0.020	0.020
Trawsfynydd	**0.032**	0.021	0.028	0.018	0.031	0.018	0.028	0.012	0.025
Whitehaven[b]	0.58	0.40	0.43	0.37	0.47	0.28	0.18	0.18	0.30
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	0.006

Site	2013	2014	2015	2016	2017	2018	2019	2020	2021
Aldermaston & Burghfield	<0.005	<0.005	<0.005	<0.005	0.010	0.010	<0.005	<0.005	0.008
Amersham	0.22	0.14	0.14	0.15	0.15	0.14	0.14	0.14	0.083
Barrow[e]	0.076	0.055	0.051	0.082	0.074	0.046	0.057	0.061	0.044
Berkeley & Oldbury	0.010	<0.005	<0.005	0.006	<0.005	<0.005	<0.005	<0.005	0.013
Bradwell	<0.005	<0.005	0.017	0.036	0.011	0.011	<0.005	<0.005	0.006
Capenhurst	0.080	0.17	0.13	0.17	0.17	0.16	0.17	0.17	0.17
Chapelcross	0.024	0.014	0.022	0.026	0.035	0.019	0.007	0.018	0.018
Derby	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Devonport	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Dounreay	0.012	0.012	0.010	0.058	0.010	0.035	0.01	0.009	0.026
Dungeness	0.021	0.021	0.014	0.021	0.021	0.022	0.037	0.012	0.012
Faslane	<0.005	<0.005	<0.005	0.009	<0.005	0.010	0.007	0.008	0.007
Hartlepool	0.024	0.027	0.022	0.020	0.031	0.012	0.013	0.017	0.012
Harwell	0.010	0.016	0.017	0.015	0.046	0.028	0.010	0.008	<0.005
Heysham	0.028	0.023	0.023	0.019	0.025	0.010	0.018	0.010	0.015
Hinkley Point	0.022	0.022	0.016	0.013	0.032	0.041	0.021	0.023	0.030
Hunterston	0.021	0.021	0.025	0.021	0.023	<0.005	<0.005	0.005	0.006
LLWR near Drigg[b]	0.061	0.22	0.42	0.41	0.25	0.37	0.24	0.31	0.21
Rosyth	<0.005	<0.005	0.006	0.017	0.026	0.010	<0.005	<0.005	0.011
Sellafield[b]	0.076	0.22	0.42	0.41	0.25	0.37	0.24	0.31	0.21
Sizewell	0.021	0.020	0.021	0.021	0.021	0.026	0.010	0.017	0.016
Springfields	0.060	0.050	0.050	0.038	0.028	0.075	0.14	0.047	0.031
Torness	0.020	0.020	0.020	0.021	0.021	<0.005	<0.005	0.006	0.005
Trawsfynydd	0.017	0.013	0.014	0.019	0.024	0.017	0.005	0.012	0.010
Whitehaven[b]	0.061	0.22	0.42	0.41	0.25	0.37	0.24	0.31	0.21
Winfrith	<0.005	<0.005	0.014	0.019	0.038	0.038	0.027	0.014	0.006
Wylfa	<0.005	0.007	0.013	0.008	<0.005	0.006	<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 bold 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

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

Table 1.4 Source specific doses due to discharges of radioactive waste in the United Kingdom, 2021

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[e]	G	<0.005[g]	^{3}H[h], ^{234}U
Springfields	Fish and shellfish consumption and external in intertidal areas	L	0.015	Ext
	Terrestrial foods, external and inhalation near site[e]	G	<0.005[g]	^{14}C, ^{90}Sr[h], ^{234}U, ^{238}U, ^{241}Pu[h]
	External in intertidal areas (children playing)[d,i]	L	<0.005	Ext
	Occupancy of houseboats	L	0.028	Ext
	External in intertidal areas (farmers)	L	0.031	Ext
	Wildfowl consumers	L	<0.005	Ext
Sellafield[l]	Fish and shellfish consumption and external in intertidal areas (2017-2021 surveys) (excluding naturally occurring radionuclides)[m]	L	0.058	Ext, ^{241}Am
	Fish and shellfish consumption and external in intertidal areas (2017-2021 surveys) (including naturally occurring radionuclides)[n]	L	0.25	^{210}Po
	Fish and shellfish consumption and external in intertidal areas (2021 surveys) (excluding naturally occurring radionuclides)[m]	L	0.032	Ext, ^{129}I[h], ^{241}Am
	Mollusc consumption (2021 surveys) (excluding naturally occurring radionuclides)[m]	L	0.012	$^{239+240}Pu$, ^{241}Am
	Terrestrial foods, external and inhalation near Sellafield[e]	G	0.010	^{14}C, ^{90}Sr, ^{106}Ru[h], ^{129}I[h]
	Terrestrial foods at Ravenglass[e]	G/L	0.009	^{90}Sr, ^{106}Ru[h]
	External in intertidal areas (Ravenglass)[i]	L	0.019	Ext, ^{241}Am
	Occupancy of houseboats (Ribble estuary)	L	0.028	Ext
	Occupancy of houseboats (Barrow)[s]	L	0.043	Ext
	External (skin) to bait diggers	L	0.061[j]	Beta
Research establishments				
Culham	Water consumption[k]	L	<0.005	^{137}Cs[h]
Dounreay	Fish and shellfish consumption and external in intertidal areas	L	0.021	Ext , $^{239+240}Pu$, ^{241}Am
	Terrestrial foods, external and inhalation near site	G	0.017	^{129}I[h], ^{137}Cs, ^{238}Pu[h], $^{239+240}Pu$, ^{241}Am[h]
Harwell	Fish consumption and external to anglers	L	<0.005	Ext
	Terrestrial foods, external and inhalation near site[e]	G	<0.005	^{222}Rn
Winfrith	Fish and shellfish consumption and external in intertidal areas	L	<0.005	Ext, ^{241}Am
	Terrestrial foods, external and inhalation near site[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	0.025	Ext
	Terrestrial foods, external and inhalation near site[e]	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	0.006	^{14}C
Chapelcross	Wildfowl, fish and mollusc consumption and external in intertidal areas	L	0.006	$^{239+240}Pu$ ^{241}Am
	Crustacean consumption	L	<0.005	^{90}Sr[h], ^{137}Cs[h], $^{239+240}Pu$, ^{241}Am
	Terrestrial foods, external and inhalation near site[e]	G	0.015	^{90}Sr, ^{241}Am[h]
Dungeness	Fish and shellfish consumption and external in intertidal areas	L	0.008	Ext, ^{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	0.010	Ext, ^{131}I[h], ^{241}Am
	Terrestrial foods, external and inhalation near site[e]	G	0.005	^{14}C, ^{35}S[h]
Heysham	Fish and shellfish consumption and external in intertidal areas	L	0.019	Ext
	External in intertidal areas (turf cutters)	L	<0.005	Ext
	Terrestrial foods, external and inhalation near site[e]	G	0.006	^{14}C
Hinkley Point	Fish and shellfish consumption and external in intertidal areas	L	0.018	Ext
	Terrestrial foods, external and inhalation near site[e]	G	<0.005	^{14}C, ^{35}S[h], ^{60}Co[h]
Hunterston	Fish and shellfish consumption and external in intertidal areas	L	0.011	Ext, $^{239+240}Pu$, ^{241}Am
	Terrestrial foods, external and inhalation near site[e]	G	0.008	^{14}C, ^{35}S, ^{90}Sr

Table 1.4 continued

Establishment	Radiation exposure pathways	Gaseous or liquid source[a]	Exposure, mSv[b] per year	Contributors[c]
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	0.008	^{14}C, ^{35}S, ^{90}Sr
Trawsfynydd	Fish consumption and external to anglers	L	0.008	Ext,
	Terrestrial foods, external and inhalation near site[e]	G	0.040	^{14}C, ^{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	0.006	^{14}C
Defence establishments				
Aldermaston & Burghfield	Fish consumption and external to anglers	L	<0.005[i]	Ext
	Terrestrial foods, external and inhalation near site[e]	G	<0.005[i]	^{234}U, ^{238}U
Barrow	Occupancy of houseboats[s]	L	0.043	Ext
	Terrestrial food consumption	G	<0.005	^{3}H[h]
Derby	Water consumption, fish and shellfishconsumption 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	^{3}H[h]
Faslane	Fish and shellfish consumption and external in intertidal areas	L	0.008	^{137}Cs, ^{241}Am[h]
	Terrestrial food consumption	G	<0.005	^{137}Cs, ^{241}Am[h]
Holy Loch	External in intertidal areas	L	0.007	Ext
Rosyth	Fish and shellfish consumption and external in intertidal areas[q]	L	0.014	Ext, ^{241}Am[h]
Radiochemical production				
Amersham	Fish consumption and external to anglers	L	<0.005	Ext
	Terrestrial foods, external and inhalation near site[e]	G	0.006	^{222}Rn
Industrial and landfill				
LLWR near Drigg	Terrestrial foods[e]	G	0.007	^{14}C, ^{90}Sr, ^{129}I[h]
	Fish and shellfish consumption and external in intertidal areas (2017-2021 surveys) (including naturally occurring radionuclides)[l, n]	L	0.25	^{210}Po
	Water consumption[k]	L	<0.005	^{134}Cs[h], ^{137}Cs[h], ^{241}Pu[h]
Whitehaven	Fish and shellfish consumption and external in intertidal areas (2017-2021 surveys) (excluding artificial radionuclides)[l,o]	L	0.19	^{210}Po
	Fish and shellfish consumption and external in intertidal areas (2017-2021 surveys) (including artificial radionuclides)[l,p]	L	0.25	^{210}Po

* 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

s Exposures at Barrow are largely due to discharges from the Sellafield site

2. Nuclear fuel production and reprocessing

Highlights

- ‘total doses’ for the representative person were 21% (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 2020, but remained well below the legal limit

Capenhurst, Cheshire

- ‘total dose’ for the representative person was 0.17mSv and unchanged from 2020

Springfields, Lancashire

- ‘total dose’ for the representative person was 0.031mSv and decreased in 2021
- gaseous discharges of krypton-85 (National Nuclear Laboratory) decreased in 2021

Sellafield, Cumbria

- ‘total doses’ for the representative person were 0.21mSv (or less) and decreased in 2021
- 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 2021. The contribution to ‘total dose’ from Sellafield discharges decreased in 2021
- gaseous discharges of tritium, krypton-85 and ruthenium-106, and liquid discharges of carbon-14 and strontium-90 were slightly higher, in 2021 when compared to those in 2020

This section considers the results of monitoring, by the Environment Agency, FSA, NIEA and SEPA, of 3 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 (SFL) and used to carry out nuclear fuel manufacture and other commercial activities. SFL 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 located on the Sellafield site, with 3 nuclear reactors. In 2017, Windscale was amalgamated into the Sellafield nuclear licensed site and Sellafield environmental permits.

Decommissioning activities are continuing at Windscale. Most of the radioactive wastes derive from decontamination and decommissioning operations. 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 2021, gaseous and liquid discharges were below permit limits for each of the sites (see Appendix 2, Table A2.1 and Table A2.2).

2.1 Capenhurst, Cheshire

The Capenhurst site is located near Ellesmere Port and is home to uranium enrichment plants and associated facilities. The major operators at the site are UUK, UNS and UCP. UUK operates 3 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 commissioning 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. 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 operators on the Capenhurst site each have their own permit. The UCP permit was varied in 2018 and the UNS permit was varied in 2020. These variations introduced the discharge limits for the new tails facility and revised the discharge limits for UNS

The most recent habits survey to determine the consumption and occupancy rates by members of the public was undertaken in 2021 [109].

Doses to the public

The 'total dose' from all pathways and sources of radiation was 0.17mSv in 2021 (Table 2.1), or 17% of the dose limit, and unchanged from 2020. This dose was almost entirely due to direct radiation from the Capenhurst site. The representative person was infants exposed to direct radiation close to the site and unchange from 2020. The trend in annual 'total dose' over the period 2010 to 2021 is given in Figure 1.2 and Figure 2.1. Any changes in annual 'total doses' over 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 2021 (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 0.007mSv in 2021 (down from 0.013mSv in 2020). The decrease in dose was due to lower gamma dose rates measured over the riverbank at Rivacre Brook in 2021. 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.

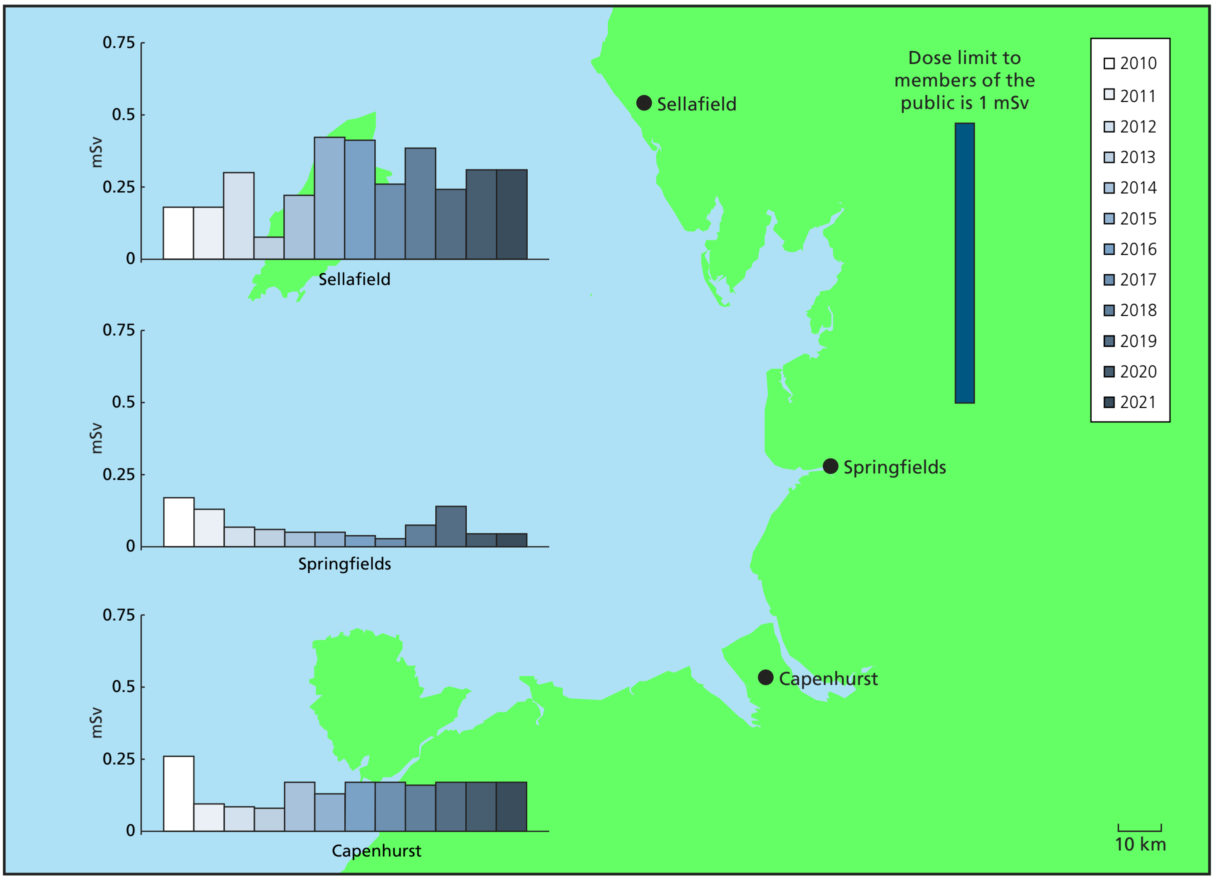


Figure 2.1 ‘Total dose’ at nuclear fuel production and reprocessing sites, 2010–2021. (Exposures at Sellafield/Whitehaven/LLWR receive a significant contribution to the dose from technologically enhanced naturally occurring radionuclides from previous non-nuclear industrial operations)

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 2021 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 2021, isotopes of uranium in silage were enhanced by small amounts (most likely due to natural variation), in comparison to those in 2020. Figure 2.2 shows the trends over time (2010 to 2021) 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.

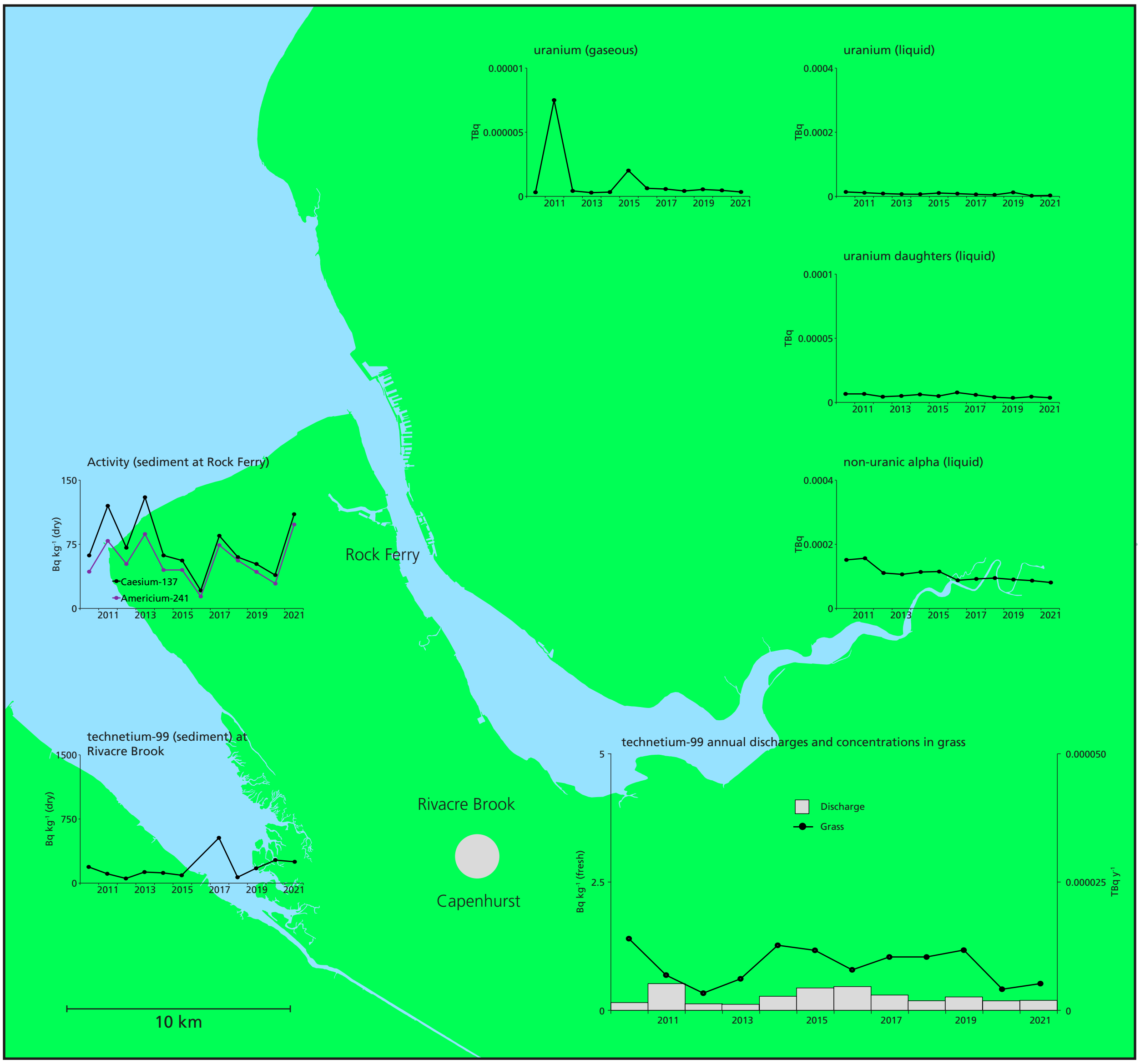


Figure 2.2 Discharges of gaseous and liquid radioactive wastes and monitoring of the environment, Capenhurst (2010–2021). (Note different scales used for discharges and activity concentrations)

Liquid waste discharges and aquatic monitoring

The permit for the UUK Capenhurst site allows liquid waste discharges to the Rivacre Brook for uranium and uranium daughters, technetium-99 and non-uranium alpha (mainly neptunium-237). Monitoring included the collection of samples of fish and shellfish from the local aquatic and downstream marine environment (for analysis of a range of radionuclides) and of freshwater and sediments for the analysis of tritium, technetium-99, gamma-emitting radionuclides, uranium, neptunium-237, and gross alpha and beta. Dose rate measurements were taken on the banks of the Rivacre Brook and surrounding area. Results for 2021 are given in Table 2.2(a) and Table 2.2(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.

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 and uranium radionuclide concentrations from this location were lower in 2021, in comparison to those in 2020, 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 2021. Measured gamma dose rates near to the discharge point were lower in 2021, in comparison to those in 2020. Downstream of the Rivacre Brook, at the location where children play, dose rates over grass were also lower in 2021.

Figure 2.2 also shows the trends over time of the releases of several other permitted radionuclides and activity concentrations in environmental samples. During the period 2010 to 2021, the overall trend was a reduction of liquid discharges over time, with most of the reductions attributed to progress in decommissioning of some older plant and equipment.

Concentrations of technetium-99 in sediment (Rivacre Brook) from liquid discharges were detectable close to the discharge point in 2021 (and slightly lower, in comparison to those in 2020). 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.

2.2 Springfields, Lancashire

The Springfields site at Salwick, near Preston, is operated by SFL under the management of Westinghouse Electric Company 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.

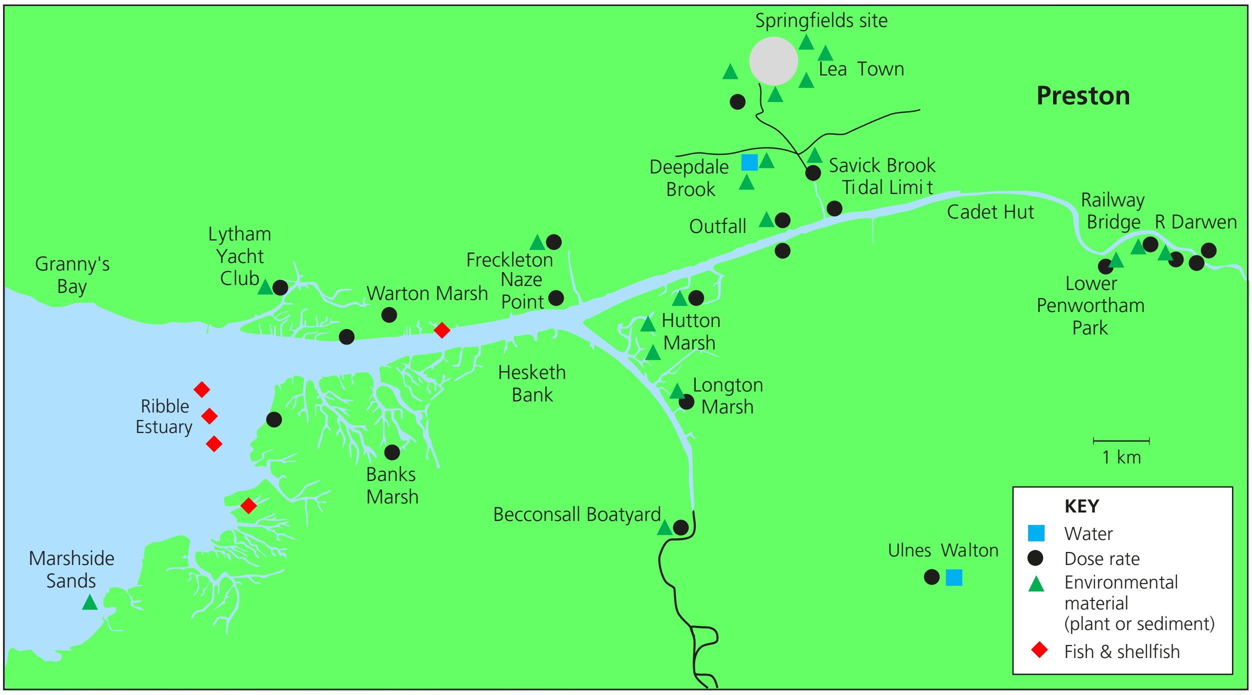


Figure 2.3 Monitoring locations at Springfields, 2021 (not including farms)

The most recent habits survey was undertaken in 2012 [110]. In 2021, based on a five-year rolling average (2017 to 2021), the habits information for houseboat dwellers was revised. 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 0.031mSv in 2021 (Table 2.1), or approximately 3% of the dose limit, down from 0.047mSv in 2020. In 2021, the representative person was adults spending time over saltmarsh (adult mushroom consumers in 2020). Most of the dose to the representative person was from external radiation over saltmarsh. This change is a due to a lower estimate of direct radiation (given in Table 1.1) and to a lesser extent, an increase of gamma dose rates over salt marsh at Banks Marsh. The annual direct radiation exposure was lower in 2021 (0.017mSv) in comparison to that in 2020 (0.047mSv).

Source specific assessments give exposures that were all less than the 'total dose' in 2021 (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 0.028mSv in 2021, or less than 3% of the dose limit for members of the public of 1mSv, and higher than in 2020 (0.024mSv). This dose is estimated using a revised (more cautious) method, by using generally higher gamma dose rates measured in the vicinity of 2 houseboat locations (at Becconsall and Freckleton) in 2021 than those previously measured beneath the houseboats at Becconsall. Gamma dose rate measurements at Becconsall were not taken directly underneath a houseboat in 2021 (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 2010 to 2021 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.

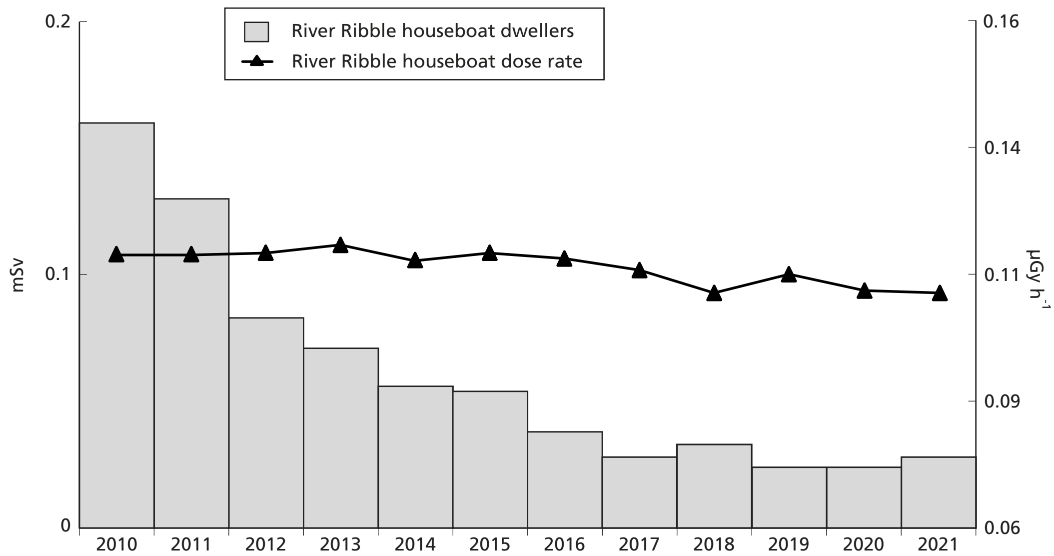


Figure 2.4 Source specific dose to houseboat occupants and dose rates at Springfields (2010–2021)

The dose for high-rate consumers of seafood was 0.015mSv in 2021, with approximately 0.014mSv from external exposure (the remainder being from consumption of fish and shellfish) and higher than that in 2020 (0.009mSv). 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 0.031mSv in 2021 (Table 2.1) and higher than that reported in 2020 (0.017mSv). 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 0.005mSv in 2021.

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 0.001mSv, and negligible in comparison with other exposure routes [111].

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.

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 2021 are given in Table 2.3(a). Uranium isotope concentrations in beetroot were similar to those in 2020. 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 (2010 to 2021) of gaseous uranium discharges and total uranium radionuclide concentrations in food (cabbage; 2010 to 2013: beetroot; 2014 to 2021). Over the period, uranium discharges have declined, with the lowest value reported from this site in 2020. Total uranium was detected in cabbage and beetroot samples during the period, but the concentrations were very low. The apparent peak of uranium in beetroot in 2017 was also low and significantly less than that found in soil samples.

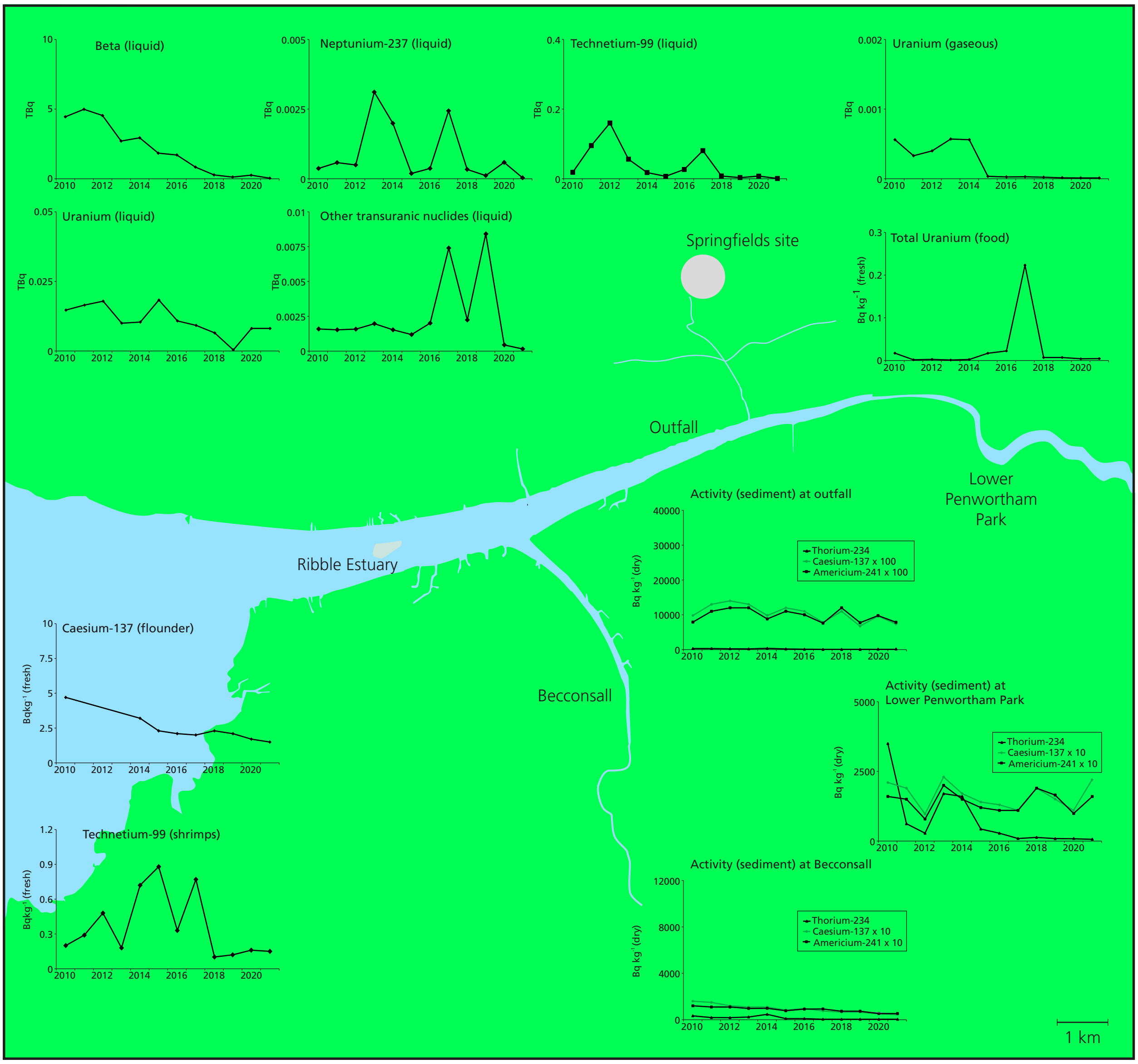


Figure 2.5 Discharges of gaseous and liquid radioactive wastes and monitoring of the environment, Springfields 2010–2021. (Note different scales used for discharges and activity concentrations)

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 2 pipelines. All discharges were slightly lower in 2021, in comparison to those in 2020. 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 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% of the annual limit) from this site in 2021. 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 2021 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 2021, thorium-234 concentrations in sediments (over the range of sampling sites) were generally similar compared to those in 2020. 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, [47]). 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 Lower Penwortham in 2021.

Caesium-137, americium-241 and plutonium radionuclides were found in biota and sediments from the Ribble Estuary in 2021. 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 (2010 to 2021) 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 2021, gamma dose rates in the estuary, including rates measured for houseboat assessments (at Becconsall), were generally higher (by small amounts) to those in 2020, 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 2021, the main operations on the Sellafield site were: fuel reprocessing at the Magnox reprocessing facility, the decommissioning and clean-up of redundant nuclear facilities and waste treatment and storage. The site also contains the Calder Hall nuclear power station and the Thermal Oxide Reprocessing Plant (THORP), which are both undergoing decommissioning.

Nuclear fuel reprocessing at THORP ceased in 2018, resulting in reduced gaseous and liquid discharges in the intervening period. THORP will continue to serve the UK until the 2070's as a storage facility for spent AGR fuel. The NDA's Magnox Operating Plan (MOP) strategy indicated that Magnox reprocessing should be completed in 2020, but as fuel still remains to be reprocessed, the decision was made to carry on with reprocessing as it is recognised as BAT for managing spent Magnox fuel. In July 2022, the Magnox reprocessing facility took its final feed of spent nuclear fuel marking the end of 58 years of Magnox reprocessing. The facility will now enter the post-operational clean-out phase. The Sellafield site also contains the Calder Hall Magnox nuclear power station, which ceased generating in 2003 and is undergoing decommissioning.

On the 1st October 2020, the environmental permit for receipt and disposal of radioactive waste was revised and re-issued to the site operator [112]. Further details of the revised permit can be found in previous RIFE reports (for example, [24]).

The gaseous discharge limits presented in Table A2.1 for the revised permit (except ruthenium-106) are the upper limits, which are in force until the completion of Magnox reprocessing and the active commissioning of HEPA filtration in the Magnox swarf storage silo (MSSS) stack as detailed in the footnotes of Table A2.1. Similarly, the upper liquid discharge limits for tritium, carbon-14 and technetium-99 are in force until the completion of Magnox reprocessing (Table A2.2), the lower limits are in force for the other radionuclides.

Sellafield Limited continued retrievals of sludge from legacy pond facilities in 2021 and continues to prepare for retrievals of intermediate level waste from legacy facilities 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 5 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 (part of the Cumbrian Coastal Community group) and review their intertidal occupancy rates. The most recent full habits survey was conducted in 2018 [113]. In 2021, some changes were found in the amounts (and mixes) of seafood species consumed and intertidal occupancy rates [114]. 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 [115] and around Barrow and the south-west Cumbrian coast in 2012 [116]. 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 [117] [118].

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 4 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 [113] and the yearly review of shellfish and fish consumption, and intertidal occupancy in 2020 [114]. Calculations are performed for 4 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 2021, the highest 'total dose' to the Cumbrian coastal community[12], near Sellafield, was assessed to have been 0.21mSv (Table 2.16), or 21% of the dose limit to members of the public, and down from 0.31mSv in 2020. As in previous years, most of this dose was due to radioactivity from sources other than those resulting from Sellafield discharges, in other words, from historical discharges of naturally occurring radionuclides from past non-nuclear industrial activity. The representative person was adults consuming crustacean shellfish at high rates who also consumed significant quantities of other seafood (fish) and a change from 2020 (adult mollusc consumers). The decrease in 'total dose' in 2021 was mostly attributed to the revision of habits information, particularly the change in the rates and a reduction in the breadth of seafood species consumed (from the revision of the habits data). 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 (0.003mSv, Table 1.1) in 2021 was considered in the 'total dose' assessments, but this made an insignificant contribution to the highest 'total dose'.

The most significant contributors to the 'total dose' in 2021 were from crustacean, fish, external exposure over sediments and other pathways (96%, 2%, 1% and 1%,

[12] 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.

respectively). The listed food groups are consumption pathways, the other pathways include mollusc consumption and direct radiation. The most important radionuclide was polonium-210 (90%) with transuranic radionuclides (including plutonium-239+240, americium-241) contributing approximately 5% of the dose.

The dose in 2021 from artificial radionuclides discharged by Sellafield (including external radiation) and from historical discharges of naturally occurring radionuclides (from past non-nuclear industrial activity) contributed 0.019mSv and 0.19mSv, respectively (values are rounded to 2 significant figures, or 3 decimal places, depending on their magnitude). In 2020, the contributions were 0.058mSv and 0.25mSv, respectively. In 2021, the contribution from external radiation was 0.002mSv (0.015mSv in 2020). 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 0.019mSv in 2021 from artificial radionuclides (including external radiation) was lower, in comparison to that in 2020. The decrease in the contribution to the 'total dose' from 2021 was mostly attributed to the revision of habits information (reduction in the consumption rates and breadth of species consumed). The contributing radionuclides in 2021 were mostly americium-241, iodine-129 and plutonium radionuclides (46%, 22%, and 8%, respectively). External exposure contributed 9% of the 'total dose' from artificial radionuclides (25% in 2020).

The contribution to the 'total dose' of 0.19mSv in 2021 from naturally occurring radionuclides (from past non-nuclear industrial activity) was lower in comparison to that in 2020 (0.25mSv). In 2021, the most contributing radionuclide was polonium-210 (~99%). The decrease in 'total dose' in 2021 was mostly attributed to the revision of habits information, particularly the lower consumption rates of seafood. In 2021, polonium-210 concentrations (above expected background) in locally caught lobsters contributed 0.18mSv to the 'total dose'. Polonium-210 concentrations (above expected natural background) in fish samples contributed 0.001mSv to the 'total dose' in 2021.

Contributions to the highest annual 'total dose' each year (2010 to 2021), 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, [47]).

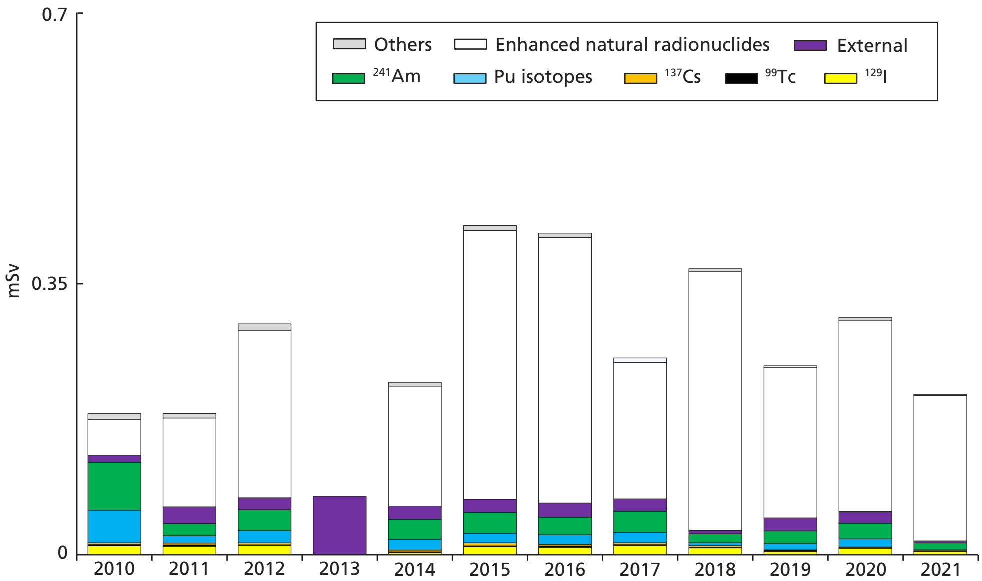


Figure 2.6 Contributions to 'total dose' from all sources at Sellafield, 2010–2021. (The highest 'total dose' in 2013 due to Sellafield discharges was to people living on houseboats near Barrow in Cumbria)

Since 2010, the larger step changes (from 2012 to 2013) were due to variations in naturally occurring radionuclides (mainly polonium-210 and lead-210) from past non-nuclear industrial activity at the former phosphate processing plant near Whitehaven. The variation in the radionuclide contributors in 2011 (from 2010) 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', from 2011 to 2012 and 2014 to 2020, was mostly due to enhanced naturally occurring radionuclides (from past non-nuclear industrial activity) and a smaller contribution from the historical discharges from Sellafield. 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 (a naturally occurring radionuclide from past non-nuclear industrial activity at the former phosphate processing plant near Whitehaven) 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 (2010 to 2021) and Figure 2.8 (2017 to 2021), 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 2010 to 2021. The pathways of exposure contributing the highest dose were mollusc, crustacean and sea fish consumers.

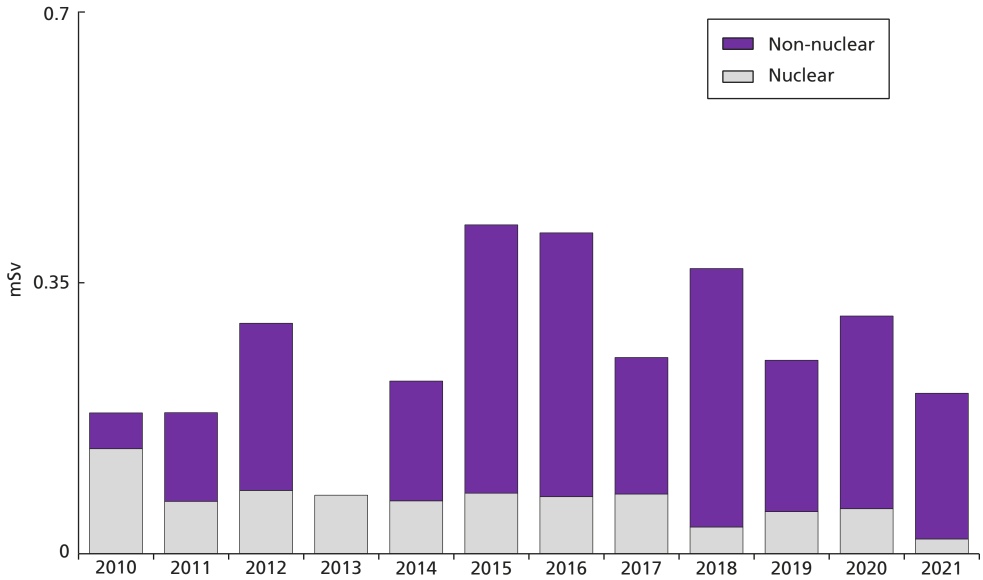


Figure 2.7 Contributions from nuclear and non-nuclear industries to 'total dose' from all sources at Sellafield, 2010–2021. (The highest 'total dose' in 2013 due to Sellafield discharges was to people living on houseboats near Barrow in Cumbria)

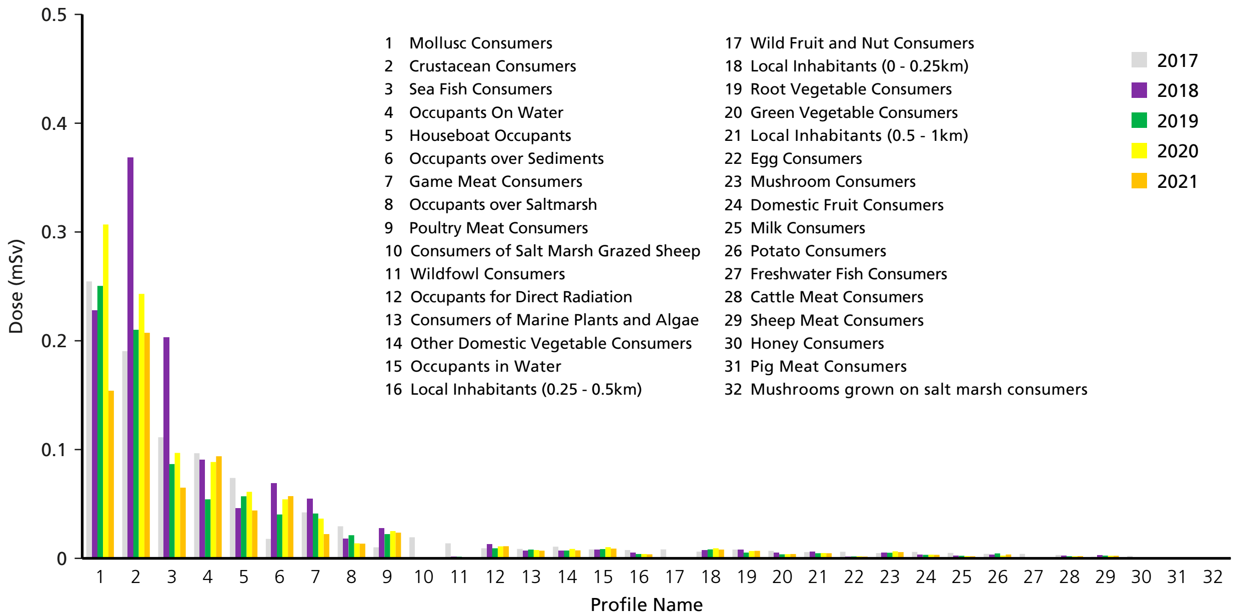


Figure 2.8 Contributions from each pathway of exposure to the 'total dose' from all sources, 2017–2021

Other age groups received less exposure than the adults 'total dose' of 0.21mSv in 2021 (10-year-old children: 0.11mSv; 1-year-old infants: 0.071mSv; prenatal children: 0.028mSv). 'Total doses' estimated for each age group may be compared with the dose for each person of approximately 2.3mSv to members of the UK population from exposure to natural radiation in the environment [29] and to the annual dose limit to members of the public of 1mSv.

‘Total dose’ from gaseous discharges and direct radiation

In 2021, the dose to the representative person receiving the highest ‘total dose’ from the pathways predominantly relating to gaseous discharges and direct radiation was 0.009mSv (Table 2.16) and down from 0.010mSv in 2020. The most exposed age group in 2021 was adults consuming root vegetables and unchanged from 2020. The decrease in the ‘total dose’ was mostly due to a lower contribution from americium-241 in root vegetables (reported at lower limit of detection (LoD)). The most significant contributors in 2021 to the ‘total dose’ for adults were from external exposure over sediments (35%), consumption of root vegetables (22%), occupancy for direct radiation (11%) and consumption of potatoes (11%) and the most important radionuclides were americium-241, carbon-14, polonium-210 (in seafood) and iodine-129 (20%, 8%, 6%, and 6%, respectively). other age groups received lower exposure than the ‘total dose’ for adults of 0.009mSv (10-year-old children: 0.006mSv, 1-year-old infants: 0.005mSv and prenatal children: <0.005mSv).

Contributions to the highest annual ‘total dose’, from gaseous discharge and direct radiation sources and by specific radionuclides, are given in Figure 2.9 over the period 2010 to 2021. Over a longer period, the trend is of declining dose (Figure 2.9, [47]) due to a general reduction in concentrations of radionuclides in food and the environment caused, in part, by reductions in discharges in this period. Over the period 2010 to 2019, ‘total doses’ were generally similar between years. The lower ‘total dose’ values after 2014 were mostly due to changes in the monitoring programme [119]. In 2018, the decrease in ‘total dose’ was mostly attributed to the revision of habits information following the full habits survey undertaken that year.

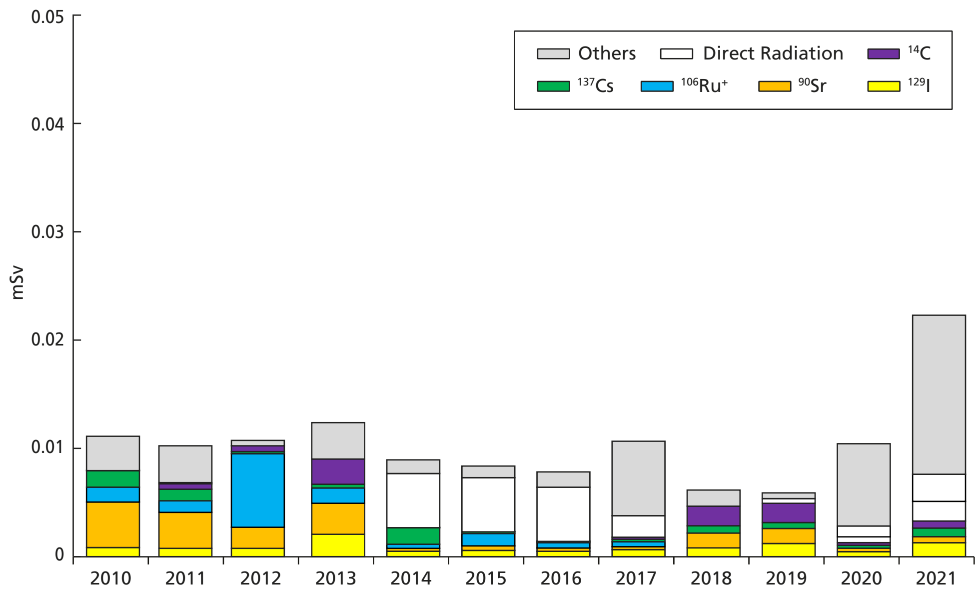


Figure 2.9 Contributions to ‘total dose’ from gaseous discharge and direct radiation sources at Sellafield, 2010–2021 (+ based on limits of detection for concentrations in foods)

'Total dose' from liquid discharges

The people receiving the highest 'total dose' from the pathways predominantly relating to liquid discharges are given in Table 2.16. Each 'total dose' is the same as that giving their maximum 'total dose' for all sources and pathways.

Source specific doses

Important source specific assessments of exposures, as a result of radioactive waste discharges from Sellafield, continued to be due to high-rate consumption of fish and shellfish and to external exposure from gamma rays over long periods. Other pathways were kept under review, particularly high-rate consumption of locally grown food (from 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 2021, 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 0.010mSv in 2021 (Table 2.16), or approximately 1% of the dose limit to members of the public and decreased from 2020 (0.011mSv). Other age groups received less exposure than the infants (1-year-old) dose of 0.011mSv in 2021 (adults: 0.009mSv; 10-year-old children: 0.008mSv; prenatal children: 0.005mSv).

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 (2021 habits survey). The second is based on a five-year rolling average using habits data gathered from 2017 to 2021. Some changes were found in the amounts (and mixes) of species consumed compared to those in the 2020 and the 2016 to 2020 rolling average. For crustaceans (crab, lobster, and other crustaceans), the total consumption rate decreased in 2021, and in the 2017 to 2021 rolling average. For fish (cod, other fish), the total consumption rate increased in 2021 and decreased in the 2017 to 2021 rolling average. For molluscs (winkles and other molluscs), the consumption rates were similar in the 2017 to 2021 rolling average and decreased in 2021 (which forms the basis for the Sellafield coastal community group (mollusc consumption)). The occupancy rate over sediments decreased in the 2021 and the 2017 to 2021 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 (for example [120]). 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) [121].

Table 2.16 summarises source specific doses to seafood consumers in 2021. The doses from artificial radionuclides to people who consume a large amount of seafood (excluding molluscan consumption) were 0.032mSv (0.063mSv in 2020) and 0.058mSv (0.062mSv in 2020) using the annual and five-year rolling average habits data, respectively. Doses to mollusc consumers, in 2021, was 0.012mSv. These doses each include a contribution due to external radiation exposure over sediments. Doses for 2021 data were lower as this dose did not include winkle consumption as included in the 2017 – 2021 habits data.

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 0.19mSv in 2021 and lower than 2020 (0.21mSv). Most of this was due to polonium-210 (95%). 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 (excluding mollusc consumption) from naturally occurring radionuclides (based on consumption rates and habits survey data in 2021) was 0.19mSv (Table 2.16). The dose to mollusc consumers (2021 data only) was 0.010mSv.

Taking artificial and enhanced natural radionuclides together, the source specific doses were 0.23mSv and 0.25mSv for the annual and five-year rolling average habits data, respectively. The dose to mollusc consumers (2021 data only) was 0.023mSv). These estimates are slightly higher than the estimate of 'total dose' from all sources of 0.21mSv. 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 2021 (Table 2.15). 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 (for example [64]). 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 2021 (Table 2.15), in comparison to those in 2020. For example, on the Dumfries and Galloway coast, the increase in dose to 0.056mSv (from 0.027mSv in 2020) was mostly due to a single americium-241 result determined using radiochemical methods in North Solway Coast Mussels in 2021 (no corresponding data was available for Kirkcudbright Scallops in 2021). All annual doses of the wider communities were well within the dose limit for members of the public of 1mSv.

The dose to a person, who typically consumes 15kg of fish per year from landings at Whitehaven is also given in Table 2.16. This consumption rate represents an average for a typical consumer of seafood from the north-east Irish Sea and the dose was less than 0.005mSv in 2021.

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 2021 are given in Table 2.9. The results of the assessment of external exposure pathways are included in Table 2.16. 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 2021, the dose was 0.043mSv, or approximately 4% of the dose limit, and down from 0.060mSv in 2020 (see Section 5.2). Other people received lower external doses in 2021. The estimated annual dose to a high-occupancy houseboat dweller in the River Ribble was 0.028mSv (see Section 2.2). The dose to a person who spends a long time over the marsh in the Ravenglass Estuary was 0.019mSv in 2021, and an increase to that in 2020 (0.018mSv, as amended in the RIFE errata). This increase in dose was due to higher occupancy over salt marsh (Appendix 1, Table X2.2).

The doses to people in 2021 were also estimated for several 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 2 different environments (at several locations) and at a distance from the Sellafield influence. The 2 different environments are i) residents that visit and use beaches, and ii) residents that visit local muddy areas or salt marsh. Typical occupancy rates [117] [118] 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 Table 2.5 to Table 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 2021, the doses to people from recreational use of beaches varied from 0.005 to 0.009mSv (Table 2.16), 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 0.008mSv. 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 0.005mSv.

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 2021, 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 0.14mSv (based on 2019 monitoring data) and 0.061mSv, respectively (Table 2.16) and both were less than 0.5% of the appropriate annual dose limit of 50mSv 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 2021, the dose (including contributions from Chernobyl and fallout from nuclear weapons testing) was estimated to be 0.009mSv, which was less than 1% of the dose limit for members of the public, and down from 0.017mSv in 2020. The decrease in dose is attributed to the removal of cerium-144 from the assessment as it was removed from the list of permitted radionuclides in sea discharges in 2020. 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 (for example [64]). 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 [113] – 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 (now UKHSA) 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 [122]. 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 most 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 2021 are summarised in Appendix 2 (Table A2.1). The permit limits gaseous discharges for gross alpha and beta activities, and 10 specified radionuclides. In addition to overall site limits, plant notification levels 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 2021. Gaseous discharges of carbon-14, strontium-90, antimony-125, iodine-129, plutonium-alpha and americium241/curium-242, decreased in 2021, however, discharges of tritium, krypton-85 and ruthenium-106 increased by small amounts, in comparison to releases in 2020.

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 2021 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 2021 are given in Table 2.4. The activity concentrations of all radionuclides around the site were low. Activity concentrations in terrestrial foodstuffs were generally similar to those in recent years. Activity concentrations of radionuclides in meat and offal (cattle and sheep) 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 carbon-14 in offal samples.

A range of foods (including fruit and vegetables) and terrestrial indicator materials was sampled in 2021 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. Strontium-90 was positively detected in a number of food samples (including milk) at low concentrations. In 2021, 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), 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.

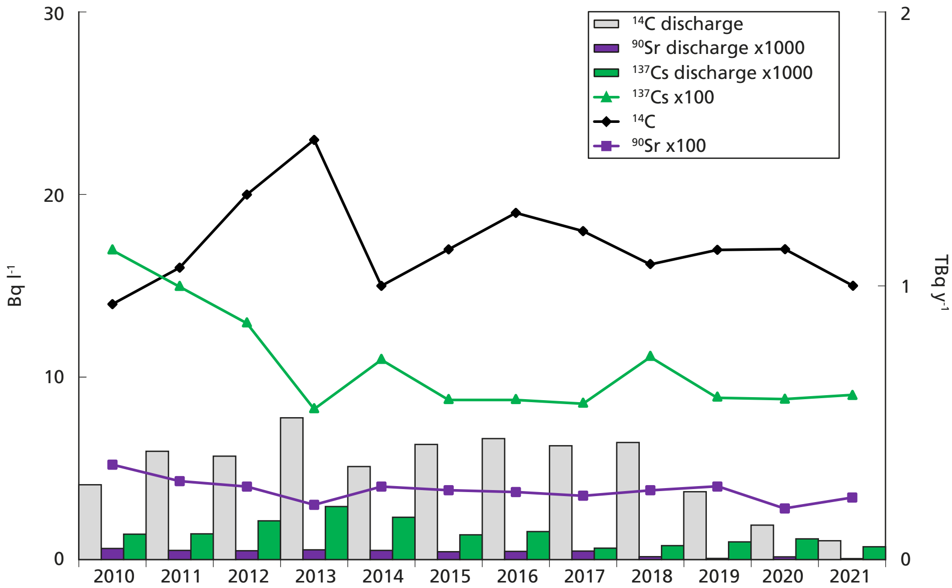


Figure 2.10 Discharges of gaseous wastes and monitoring of milk near Sellafield, 2009–2020

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 2.1km 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 [46]. Discharges from the Sellafield pipelines during 2021 are summarised in Appendix 2 (Table A2.2). In 2021, the permit sets limits on gross alpha and beta, and 12 individual radionuclides. In addition to overall site limits, plant notification levels have been set on discharges from the main contributing plants on site (Segregated Effluent Treatment Plant, Site Ion Exchange Effluent Plant (SIXEP), Enhanced Actinide Removal Plant (EARP) and THORP).

All discharges of liquid wastes from Sellafield were much less than the permit limits in 2021. Liquid discharges of carbon-14 and strontium-90 increased, by small amounts in 2021, in comparison to releases in 2020. 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 facility (planned to end in 2022), and periods of planned and unplanned reprocessing plant shutdowns that occur from year to year.

The downward trend of technetium-99 discharges from Sellafield is given in Figure 2.11 (2010 to 2021) and Figure 2.12 (1992 to 2021). Technetium-99 discharges have substantially reduced from the peak of 192TBq in 1995. Further information relating to past discharges of technetium-99 is available in earlier RIFE reports (for example [69]).

Monitoring of the marine environment

Regular monitoring of the marine environment near to Sellafield and further afield was conducted during 2021, 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 Figure 2.13 and Figure 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 15km to the north and to the south of Sellafield, from St Bees Head to Selker, and 11km offshore) and the smaller “Sellafield Offshore Area” (consisting of a rectangle, 1.8km wide by 3.6km long, situated south of the pipelines) in earlier RIFE reports (for example, 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.

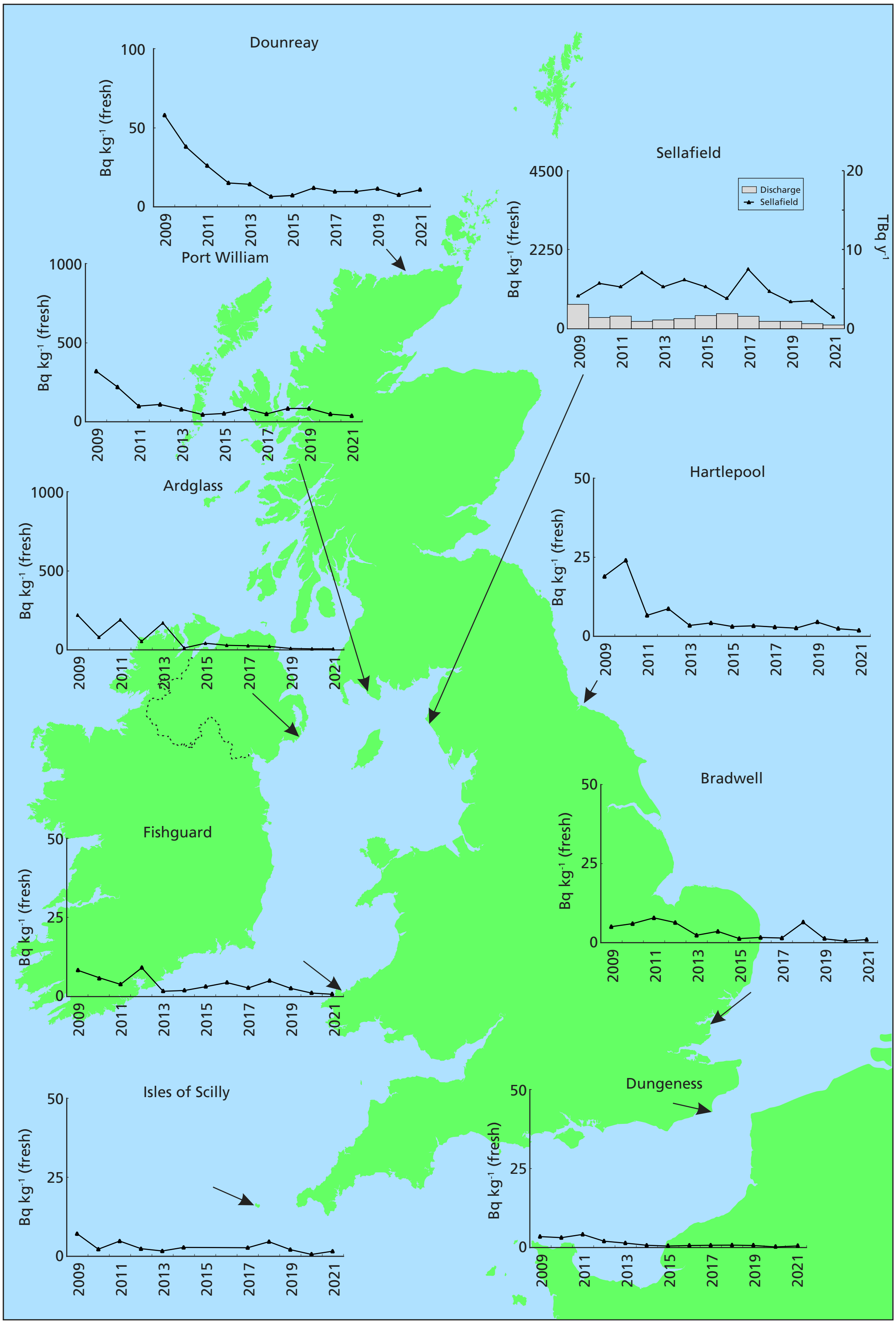


Figure 2.11 Technetium-99 in UK seaweed ('Fucus vesiculosus') from Sellafield liquid discharges between 2009–2021 (Note different scales used for Sellafield, Ardglass, Port William and Dounreay)

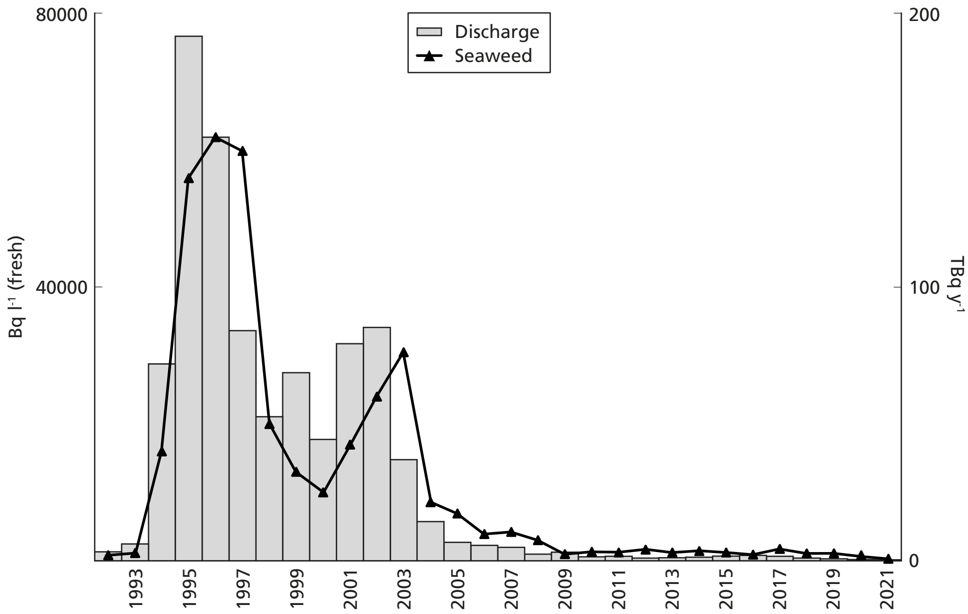


Figure 2.12 Technetium-99 in UK seaweed ('Fucus vesiculosus') from Sellafield liquid discharges between, 1992–2021

The concentrations of most radionuclides have decreased over the previous decades in response to decreases in discharges (for example Figure 2.8 to Figure 2.13, [123]). 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 Figure 2.15 to Figure 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 2021 (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 (for example Figure 2.10, [123]). For the transuranic elements (Figures 2.19 and 2.20), the trend of reductions in concentrations is not evident, unlike in earlier decades (for example Figure 2.12, [123]). 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 (Figure 2.19 and Figure 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 (slightly) higher in 2021, in comparison to those in 2020.

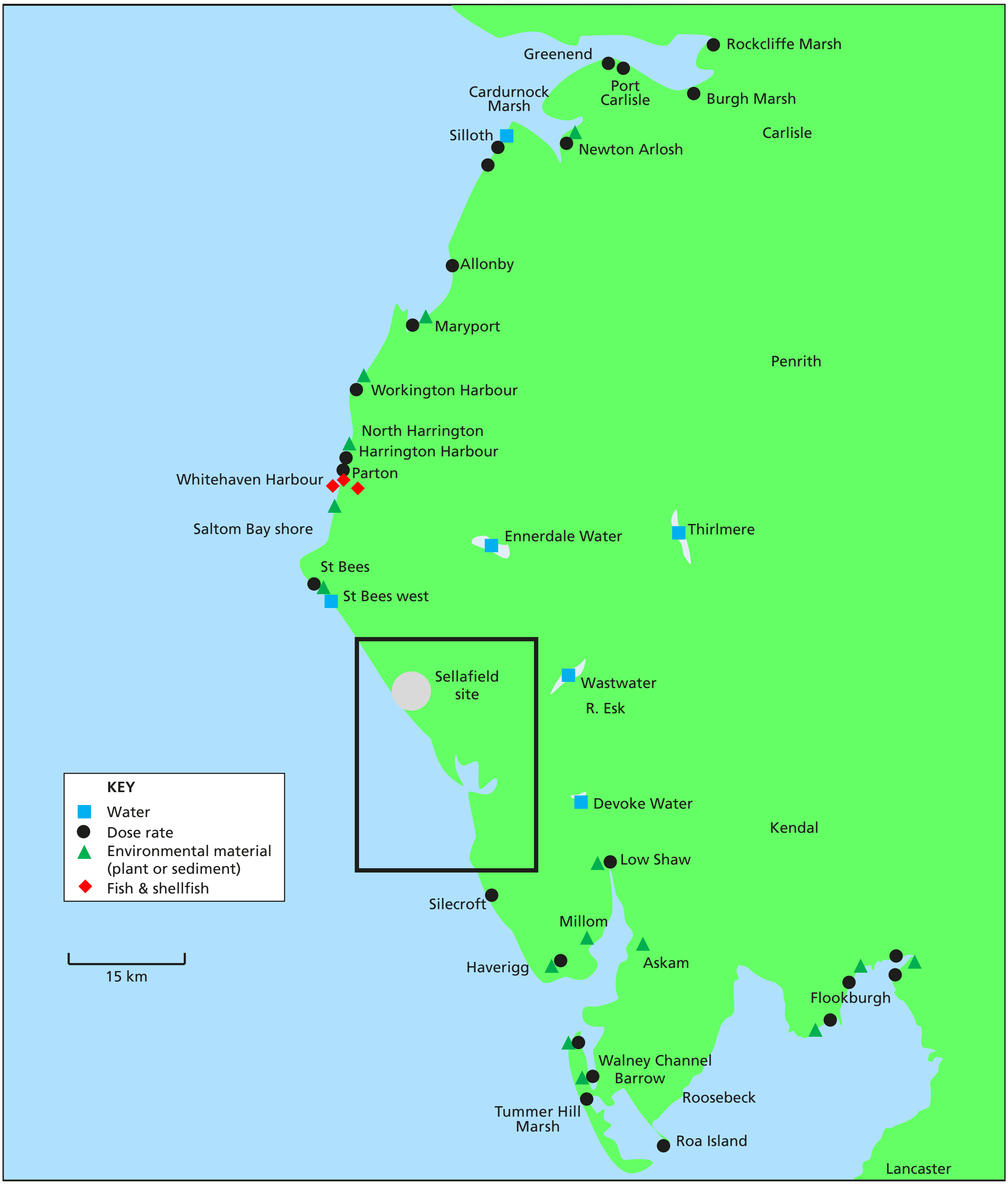


Figure 2.13 Monitoring locations in Cumbria, 2021 (not including farms)

Figure 2.14 Monitoring locations at Sellafield, 2021 (not including farms)

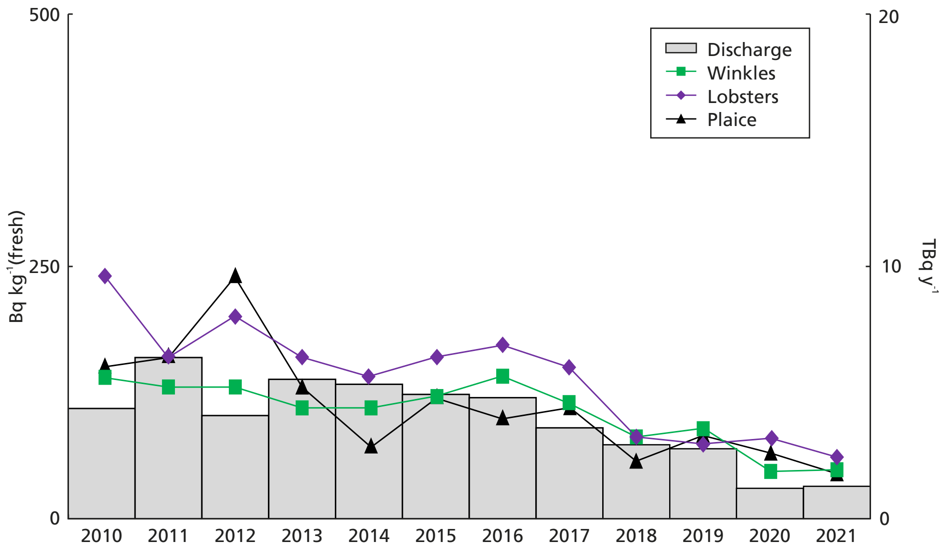


Figure 2.15 Carbon-14 liquid discharge from Sellafield and concentrations in plaice, lobsters and winkles near Sellafield, 2010–2021

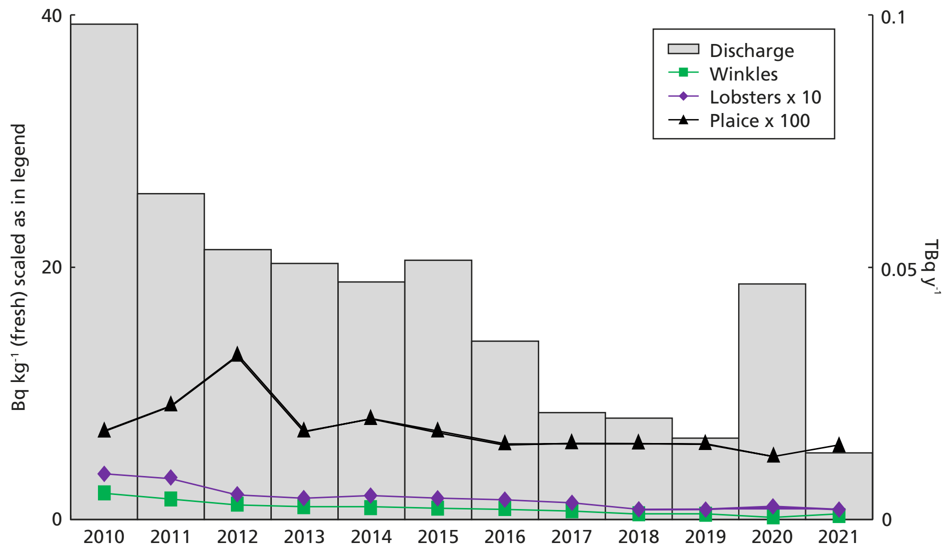


Figure 2.16 Cobalt-60 liquid discharge from Sellafield and concentrations in plaice, lobsters and winkles near Sellafield, 2010–2021

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 2021, in comparison to those in 2020. Over the longer time period, activity concentrations in fish and shellfish appear to be generally declining (with minor variations) at a slow rate (Figure 2.18). Activity concentrations in fish (and shellfish) generally reflected progressive dilution with increasing distance from Sellafield. However, the rate of decline of caesium-137 concentrations with distance was not as marked as was the case when significant reductions in discharges were achieved in earlier decades.

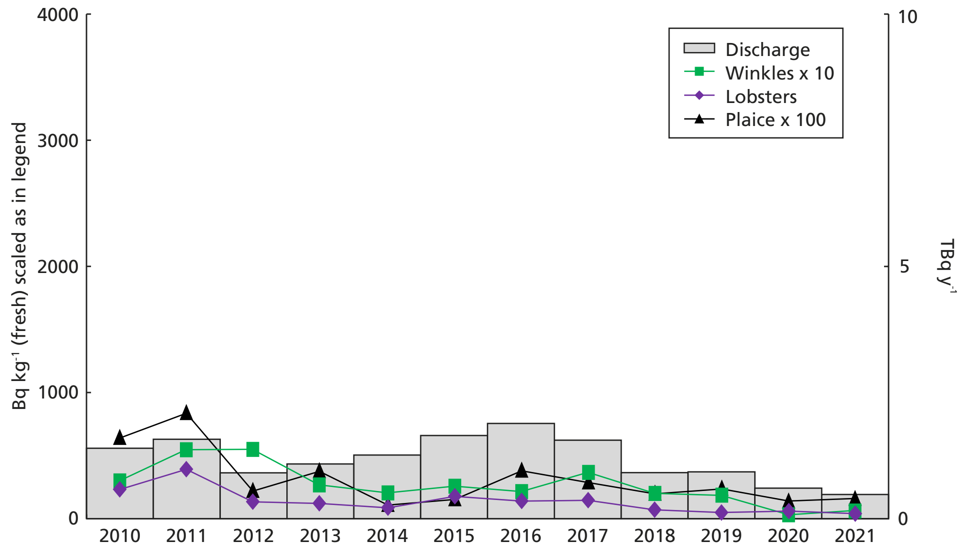


Figure 2.17 Technetium-99 liquid discharge from Sellafield and concentrations in plaice, lobsters and winkles near Sellafield, 2010–2021

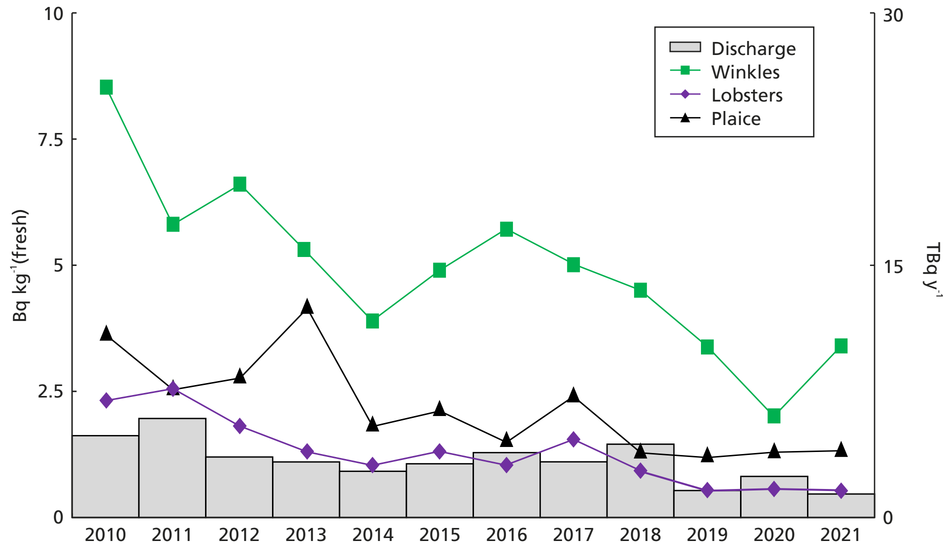


Figure 2.18 Caesium-137 liquid discharge from Sellafield and concentrations in plaice, lobsters and winkles near Sellafield, 2010–2021

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 20Bq kg^{-1} (see Appendix 1, Table X4.1), the data suggest a continued local enhancement of carbon-14 due to discharges from Sellafield. In 2021, carbon-14 is reported as the highest activity concentration in marine fish (plaice, 56Bq kg^{-1}) from Ravenglass. In 2021, tritium (and organically bound tritium (OBT)) values, across all species and locations, were reported as less than values (<25Bq kg^{-1}). Promethium-147 was detected at a very low concentrations (reported as just above the less than value) in fish and shellfish in 2021.

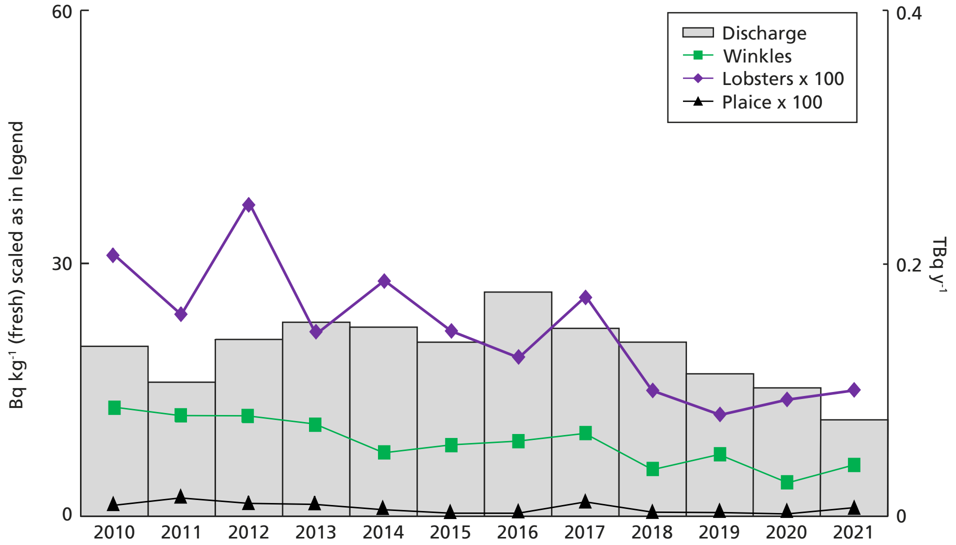


Figure 2.19 Plutonium-239+240 liquid discharge from Sellafield and concentrations in plaice, lobsters and winkles near Sellafield, 2010–2021

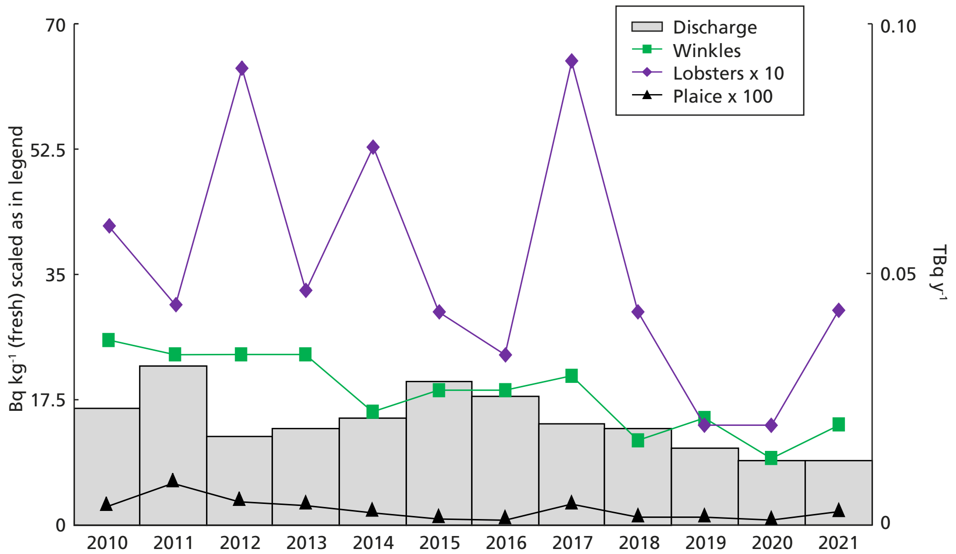


Figure 2.20 Americium-241 liquid discharge from Sellafield and concentrations in plaice, lobsters and winkles near Sellafield, 2010–2021

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 (for example, [124] [125]). The highest concentrations in the marine environment from Sellafield discharges were carbon-14, tritium and technetium-99. Comparing 2021 and 2020 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 2021 were also broadly similar (where comparisons can be made) to those in 2020.

Transuranic radionuclide data for fish and shellfish samples (chosen on the basis of potential radiological significance) in 2021 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 2021 and 2020 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 2021 (in comparison to those in 2020) at most of the north-eastern Irish Sea locations (for example winkles from Nethertown and Parton). Americium-241 concentrations in mussels (near Sellafield) were also generally similar in 2021, in comparison to those in 2020. Overall, plutonium-239+240 and americium-241 concentrations in lobsters (near Sellafield) were generally higher (with minor variations) in 2021, in comparison to those in recent years. The concentrations of plutonium-239+240 and americium-241 in winkles (Nethertown) and plaice (Sellafield coastal area) in 2020 were the lowest reported values in recent years (Figure 2.19 and Figure 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 to keep distributions of radioactivity under review. The results for 2021 are shown in Table 2.8. Radionuclides positively detected were cobalt-60, strontium-90, zirconium-95, 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 2021, 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 2020. The concentrations of long-lived radionuclides, particularly caesium-137 and the transuranic elements, largely reflect past discharges from Sellafield, which were considerably higher than in recent years. Over the last 4 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 2021, in comparison to those in 2020.

The trends over time (1992 to 2021) for activity concentrations in mud from Ravenglass and liquid discharges from Sellafield are shown in Figure 2.21 to Figure 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 2021, 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 (Figure 2.21, Figure 2.22 and Figure 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 (Figure 2.18 to Figure 2.20) and will continue to be monitored.

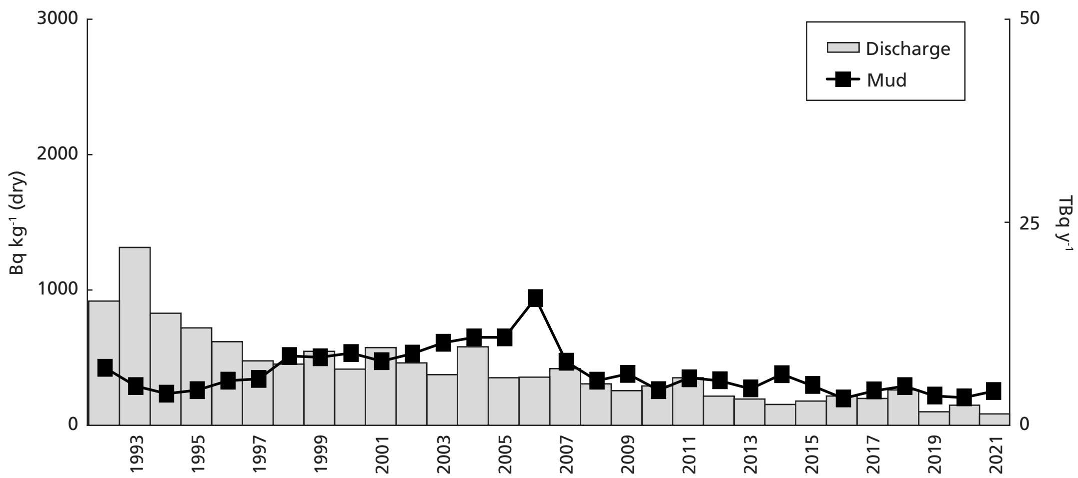


Figure 2.21 Caesium-137 liquid discharge from Sellafield and concentration in mud at Ravenglass, 1992–2021

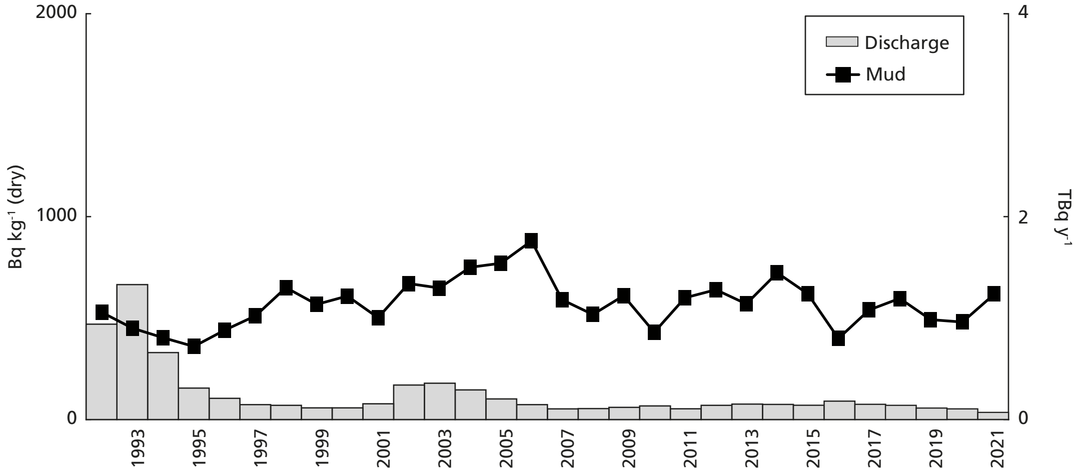


Figure 2.22 Plutonium-alpha liquid discharge from Sellafield and plutonium-239+240 concentration in mud at Ravenglass, 1992–2021

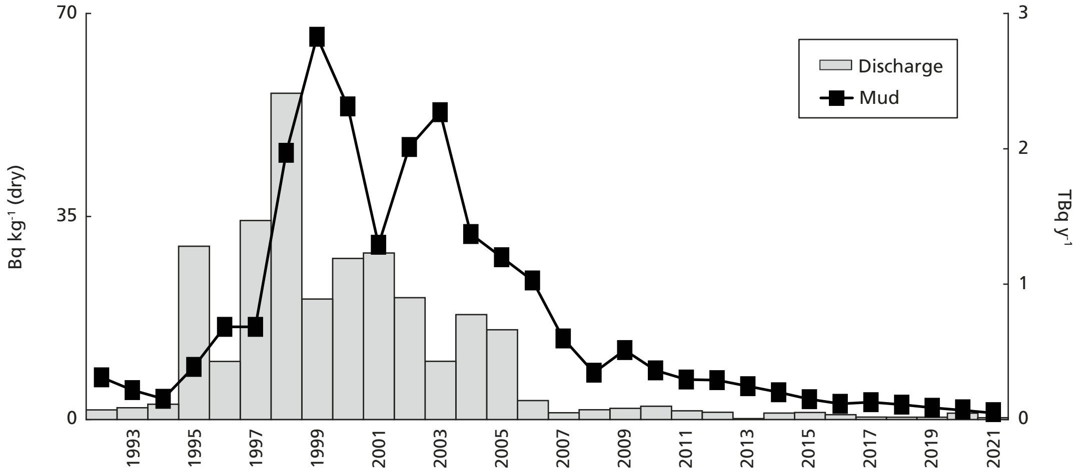


Figure 2.23 Cobalt-60 liquid discharge from Sellafield and concentration in mud at Ravenglass, 1992–2021

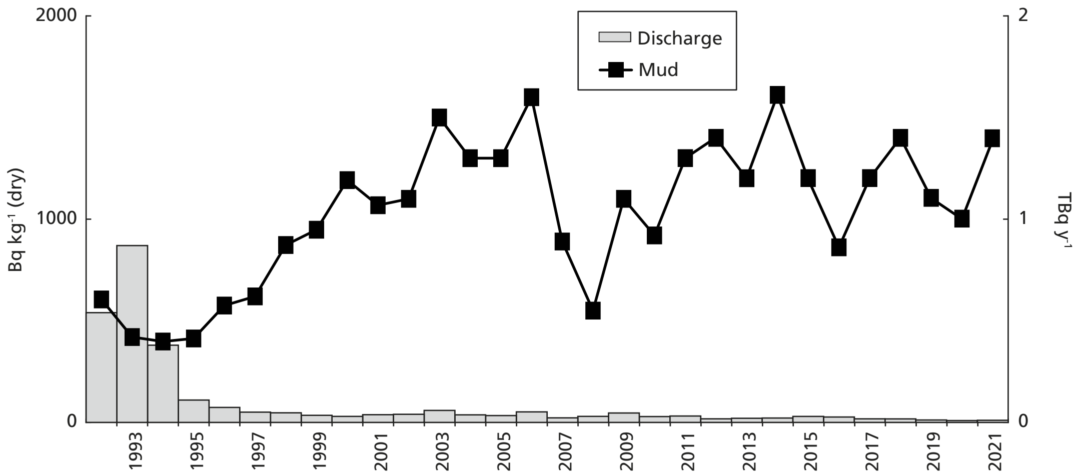


Figure 2.24 Americium-241 liquid discharge from Sellafield and concentration in mud at Ravenglass, 1992–2021

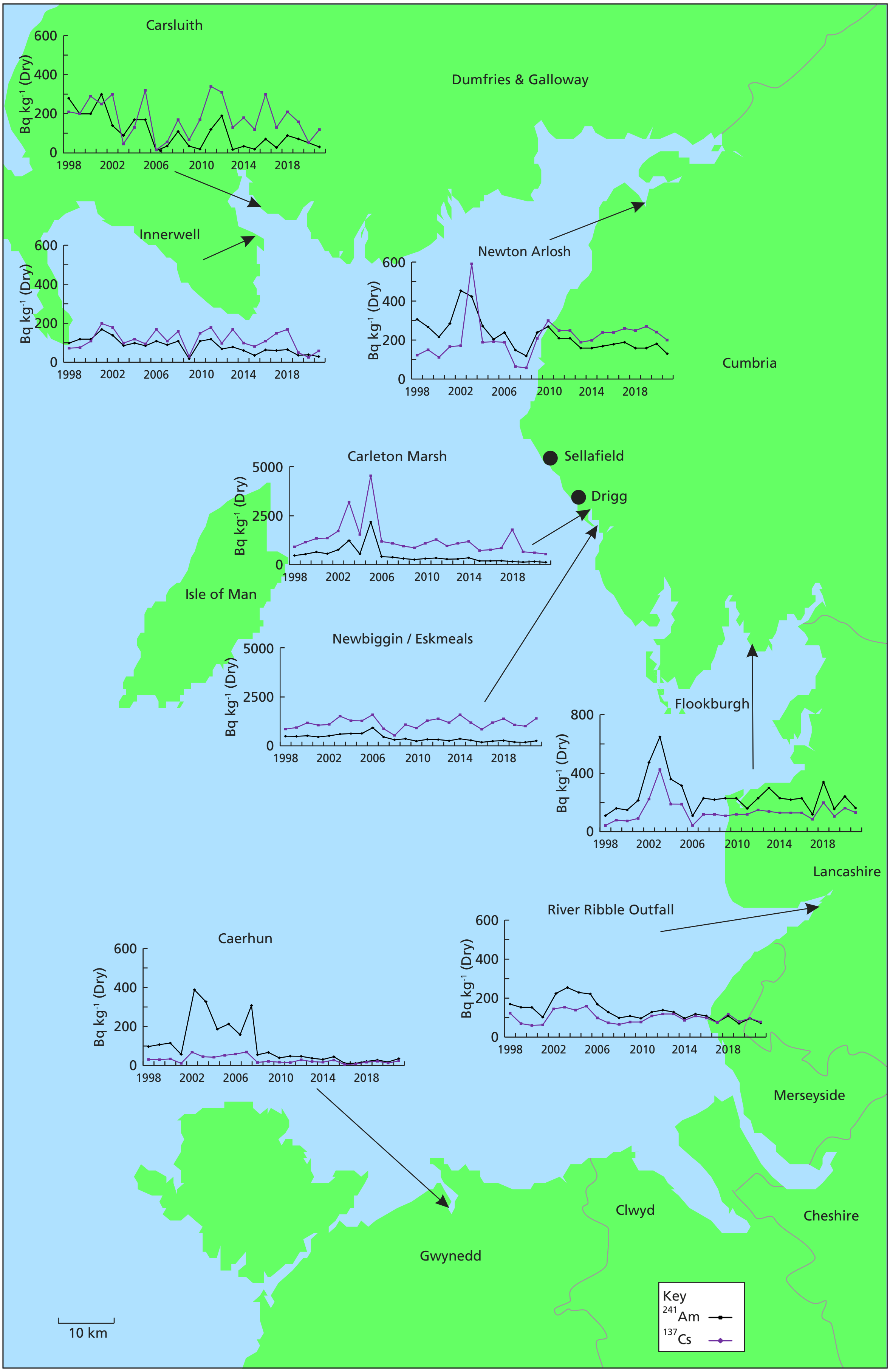


Figure 2.25 Concentrations of americium-241 and caesium-137 in coastal sediments in North West England,North Wales and South West Scotland between 1998–2021. (Note different scales used for Newbiggin and Carleton Marsh)

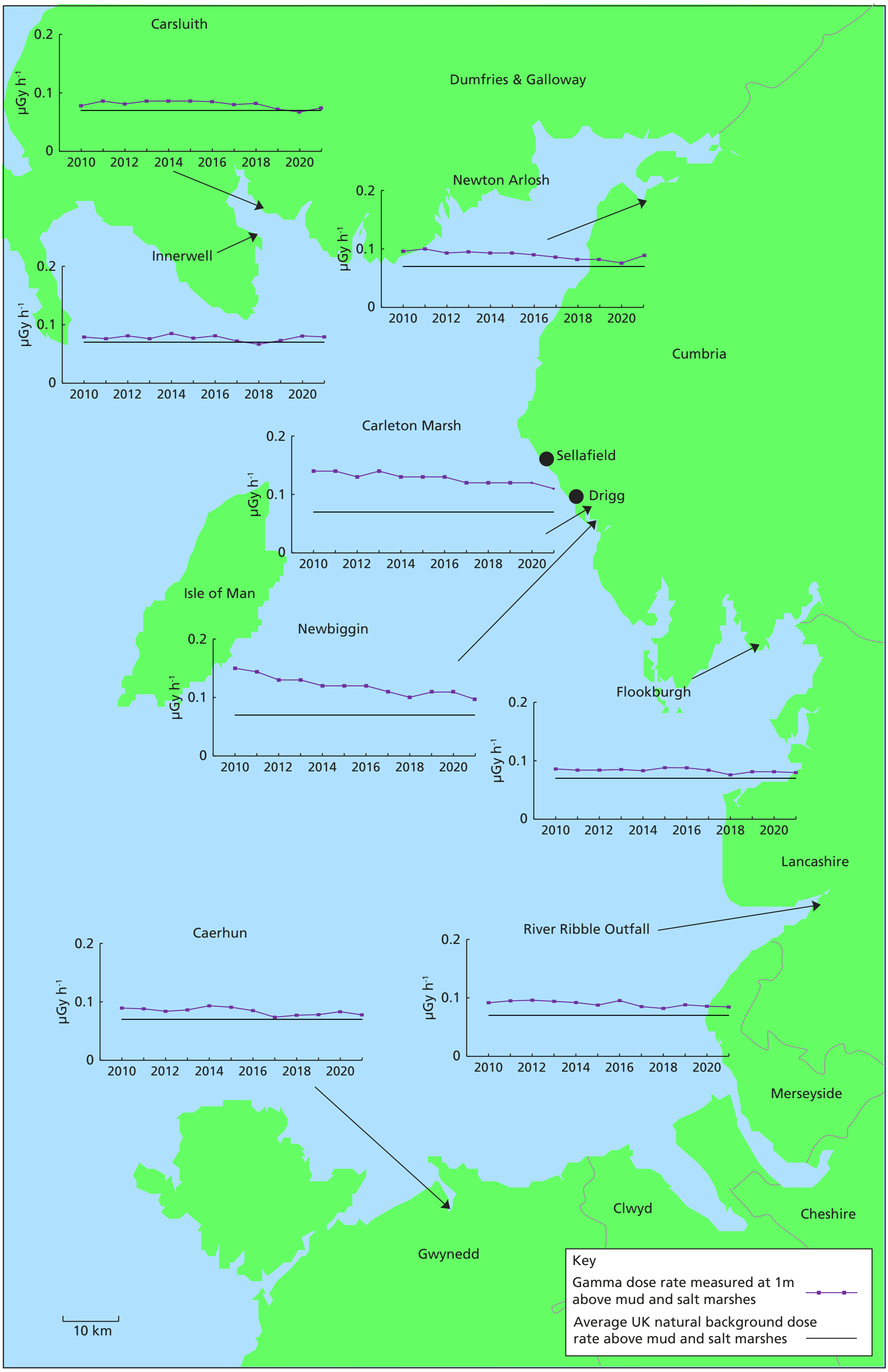


Figure 2.26 Gamma dose rates above fine coastal sediments (mud and salt marshes) in North West England, North Wales and South West Scotland between 2010–2021

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 2021 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 Carleton Marsh over the period (1998 to 2021).

Monitoring of dose rates

Dose rates are regularly monitored at many 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 1m above ground. Where comparisons can be made from similar ground types and locations, dose rates over intertidal areas throughout the Irish Sea in 2021 were generally similar to those in recent years (with small variations in comparison to those in 2020). 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 2021, 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 (2010 to 2021). 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, with generally higher dose rates 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 the last 4 decades, concentrations of radioactivity in the environment around Sellafield have declined as a result of reduced discharges. In more recent years, the values in the Esk Estuary have shown a less clear trend, with concentrations of some radionuclides fluctuating from year to year (for example, see Figure 2.22). This effect could be due to the dynamic nature of the sediment in the estuary, which is eroded and transported by tide and freshwater, periodically exposing older sediment (from depth) containing radioactivity from historical discharges. Due to annual variations 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 (for example [119]).

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 has been regularly monitored using surface contamination monitors. As in 2020, no monitoring of fishing gear was performed in 2021 due to COVID-19 restrictions that were in place during the early part of the year. Results up to 2019 are included in previous RIFE reports (for example, [20]).

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 2.10. Overall, positively detected dose rates in 2021 were generally similar to those in 2020 (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), and Tarn Bay (in comparison to those in 2020). 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 2021, no material was found using these probes in excess of the action level equivalent to 0.01mSv h^{-1}.

In 2008, the Environment Agency published a formal programme of work for the assessment of contamination by radioactive particles and objects[13] 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 [126].

[13] “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 (less than 2mm in diameter). “Objects” are larger radioactive artefacts and stones which have radioactive contamination on their surface and are larger than 2mm in size. Particles can be compared according to the hazard posed.

Beach survey work using vehicle mounted detectors, 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 2021 calendar year was completed in line with the Environment Agency's specification. A total area of 121 hectares was surveyed against a programme target of 105 hectares [127]. 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 2mm in size (for example granules, gravel, wire, pebbles, and stones) are now classified as objects. The number of radioactive finds identified was 98 in 2021, of which approximately 96% were classified as particles (less than 2mm 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 5km stretch of beach running northwest from the Sellafield site. All have been removed from the beaches. In 2021, none of the finds detected 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 2022, with the current proposal being a further 105 hectares to be surveyed.

In 2012, PHE (now UKHSA) 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 (now UKHSA) to the Environment Agency following a detailed assessment of risks in 2010 remained valid [128] [129]. 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 (now UKHSA) advice remained that no special precautionary actions were required to limit access to or use of the beaches. A report by PHE (now UKHSA) 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 [130]. 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 (now UKHSA) 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 (UKHSA) in February 2020, concluding that the risk is very low [3].

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 (now UKHSA) 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 [131] and the beach monitoring programme was temporarily extended to include 2 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 2.11 gives the results of measurements in 2021 of seaweeds from shorelines of the Cumbrian coast and further afield. Comparing 2021 and 2020 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 (2010 to 2021) and Figure 2.12 (1992 to 2021). 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 2.11) collected from sites in Cumbria were generally lower by small amounts in 2021, in comparison to those in 2020. Over the last 5 years, small variations have been found, year on year, but technetium-99 concentrations in seaweed in 2021 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 lower in 2021 compared with those in 2020. The reasons behind these variations have been described in previous RIFE reports (for example [69]).

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 [132]. The maximum potential dose was calculated to be 0.009mSv 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 [133].

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 2021, 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 (for example [64]).

The results of measurements in 2021 are given in Table 2.12. 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 2021. 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 ratio 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 both naturally occurring and artificial radioactivity into the human diet from the fishmeal pathway (that is fed to farmed fish, poultry, pigs, cows and sheep) is unlikely to be of radiological significance [134]. A detailed survey was undertaken to confirm these findings [135]. Samples, obtained from 14 fish farms in Scotland and 3 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 1Bq kg^{-1}. Annually reported RIFE results for activity concentrations in farmed salmon from the west of Scotland confirm the findings of the FSA study (for example, Table 2.5 and Table 2.7 [64]).

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 2021 are included in Table 2.13. Tritium, gross alpha and gross beta concentrations in public supplies were below the investigation levels for drinking water in the Water Supply (Water Quality) (Amendment) 2018 Regulations (retained from 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 2021, there was no evidence of tritium downstream, nor upstream of the outfall (Table 2.13). These are not drinkable waters and any low concentrations observed previously are of no radiological significance. Table 2.13 also includes the results of monitoring from Ehen Spit beach (Figure 2.13) near Sellafield where water issues from the ground at low tide. This release is not due to regulated discharges of liquid wastes but to ground water migration from the Sellafield site. The water contains high levels of salt so it will not be used as a drinking water source and therefore the only consumption would be inadvertent (incidental). Enhanced gross beta and tritium concentrations were observed in 2021 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 [136].

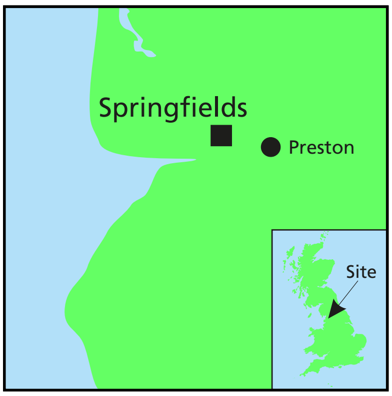
Monitoring of unusual pathways

In 1998, high caesium-137 concentrations (up to 110,000Bq kg^{-1}) were found in feral pigeons sampled in Seascale by MAFF [137]. Further background information, describing the consequences of this monitoring, and remedial measures taken by the site operator, is available in earlier RIFE reports (for example [119]). Results of the analysis of a wood pigeon sample collected in 2020 are included in Table 2.4. Unlike in 2020, wood pigeon was not sampled in 2021. In 2020, the maximum caesium-137 concentration in the muscle of wood pigeon was detected just above the less than value (0.49Bq kg^{-1}) and generally similar to those in recent years. These caesium-137 concentrations fluctuated in value prior to 2011, but elevated concentrations have not been sustained thereafter. Concentrations of artificial radionuclides were low and would add little to the exposure of local consumers. The FSA will continue to monitor this pathway.

Following 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 2021 are shown in Table 2.14. Overall, activity concentrations are generally similar to those in recent years, although plutonium-239+240 and americium-241 concentrations decreased (by small amounts) in 2021. 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 (for example [69]).

LOCATION MAPS

Capenhurst



Springfields

Sellafield

Table 2.1 Individual doses - Capenhurst and Springfields, 2021

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 inhabitants (0.5–1km)**	**0.17**	**-**	**<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	-	-	0.007	<0.005	-	-
Springfields								
Total dose' - all sources	**Adult occupants over salt marsh**	**0.031**	**-**	**-**	**0.031**	**-**	**-**	**-**
Source specific doses	Seafood consumers	0.015[c]	<0.005	-	0.014	-	-	-
	Houseboat occupants	0.028	-	-	0.028	-	-	-
	Children playing at Lower Penwortham[c]	<0.005	-	-	<0.005	<0.005	-	-
	External in intertidal areas (farmers)	0.031	-	-	0.031	-	-	-
	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, 2021

Material	Location	No. of sampling observ-ations	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}						
			^{3}H	^{99}Tc	^{137}Cs	^{234}Th	^{234}U	^{235}U	^{238}U
Marine samples									
Dab	Liverpool Bay	1	<25		0.48				
Shrimps	Wirral	1	<25	0.12	0.53				
Mussels	Liverpool Bay	1	<25		1.2				
Cockles	Dee Estuary	1	<25	1.5	0.69				
Sediment	Rivacre Brook	2[E]		250	2.3	93	210	8.5	92
Sediment	Rivacre Brook (1.5km downstream)	2[E]		44	1.4	23	26	<1.1	18
Sediment	Rossmore (3.1km downstream)	2[E]		28	1.0	22	23	<1.1	17
Sediment	Rivacre Brook (4.3km downstream)	2[E]		22	<0.39	13	18	<1.0	13
Freshwater	Rivacre Brook	2[E]	<3.9	<0.057			0.078	0.0036	0.042
Freshwater	Rivacre Brook (1.5km downstream)	2[E]	<3.6	<0.059			0.026	<0.0010	0.015
Freshwater	Rossmore (3.1km downstream)	2[E]	<3.6	<0.062			0.021	<0.00089	0.013
Freshwater	Rivacre Brook (4.3km downstream)	2[E]	<3.6	<0.065			0.021	<0.00098	0.011

Material	Location	No. of sampling observ-ations	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}							
			^{237}Np	^{238}Pu	^{239}Pu+ ^{240}Pu	^{241}Am	^{242}Cm	^{243}Cm+ ^{244}Cm	Gross alpha	Gross beta
Marine samples										
Dab	Liverpool Bay	1				<0.22				
Shrimps	Wirral	1		0.00047	0.0033	0.0072	*	*		
Mussels	Liverpool Bay	1				1.7				
Cockles	Dee Estuary	1		0.087	0.50	1.3	*	*		
Sediment	Rivacre Brook	2[E]	<4.0						370	1100
Sediment	Rivacre Brook (1.5km downstream)	2[E]	<4.0						110	600
Sediment	Rossmore (3.1km downstream)	2[E]	<4.0						120	640
Sediment	Rivacre Brook (4.3km downstream)	2[E]	<4.0						78	390
Freshwater	Rivacre Brook	2[E]	<0.061						0.096	0.46
Freshwater	Rivacre Brook (1.5km downstream)	2[E]	<0.058						<0.034	0.28
Freshwater	Rossmore (3.1km downstream)	2[E]	<0.051						<0.034	0.25
Freshwater	Rivacre Brook (4.3km downstream)	2[E]	<0.054						<0.040	0.23

Material	Location or selection[b]	No. of sampling observations	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}				
			^{3}H[d]	^{99}Tc	^{234}U	^{235}U	^{238}U
Terrestrial samples							
Milk		2	<2.9	<0.0060	<0.0013	<0.00042	<0.00042
Milk	max		<3.2	<0.0064	0.0017	<0.00046	<0.00046
Beetroot		1		<0.035	<0.00041	<0.00041	<0.00041
Silage		1		0.051	0.94	0.031	0.72
Grass/herbage	North of Ledsham	1[E]		<0.48	0.34	0.023	0.35
Grass/herbage	South of Capenhurst	1[E]		<0.71	<0.18	<0.15	0.13
Grass/herbage	East of Capenhurst	1[E]		<0.37	1.9	0.10	2.1
Grass	Dunkirk Lane (0.9km South of Site)	1[E]		<0.37	0.040	<0.0091	0.031
Soil	North of Ledsham	1[E]		3.2	25	<1.6	26
Soil	South of Capenhurst	1[E]		<3.7	18	<0.84	19
Soil	East of Capenhurst	1[E]		<0.93	21	<1.5	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, 2021

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	0.075
Dunkirk Lane	Grass and herbage	1	0.076
Near Lower Brook Farm	Grass	1	0.077
Rivacre Brook Plant outlet	Grass	1	0.079
Rivacre Brook Plant outlet	Grass and herbage	1	0.084
Rivacre Brook 1.5km downstream	Grass	2	0.076
Rossmore Road West 3.1km downstream	Grass and mud	1	0.073
Rossmore Road West 3.1km downstream	Stones	1	0.080
Rivacre Brook 4.3km downstream	Pebbles and sand	1	0.077
Rivacre Brook 4.3km downstream	Sand and stones	1	0.087
North of Ledsham	Grass and herbage	1	0.078

Table 2.3(a) Concentrations of radionuclides in food and the environment near Springfields, 2021

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
Marine samples											
Flounder	Ribble Estuary	1						1.5			
Sea Bass	Ribble Estuary	1						4.3			
Shrimps[b]	Ribble Estuary	1		34		<0.15		0.83	0.0054	0.0019	0.00073
Mussels[c]	Ribble Estuary	1						0.30	0.17	0.043	0.020
Wildfowl	Ribble Estuary	1	<11	45	<0.045		<0.95	0.50		<0.00038	<0.00038
Samphire	Marshside Sands	1				0.11		0.23			
Sediment	River Ribble outfall	4[E]						73	29	55	26
Sediment	Lea Gate	2[E]						120	28	38	25
Sediment	Lower Penwortham Park	3[E]						220	44	170	42
Sediment	River Angler Location 1	2[E]						25	14	23	15
Sediment	Penwortham road bridge - West bank	2[E]						160	41	81	39
Sediment	Lytham Yacht Club	1[E]						150	32	59	30
Sediment	Becconsall	4[E]						48	28	37	27
Sediment	Freckleton	1[E]						190	31	77	36
Sediment	Hutton Marsh	1[E]						260	37	133	42
Sediment	Longton Marsh	1[E]						300	47	200	40
Grass (washed)	Hutton Marsh	1[E]				<0.34					
Grass (unwashed)	Hutton Marsh	1[E]				<0.63					
Soil	Hutton Marsh	1[E]				24					

Material	Location	No. of sampling observ-ations	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}								
			^{234}Th	^{234}U	^{235}U	^{238}U	^{237}Np	^{238}Pu	^{239}Pu + ^{240}Pu	^{241}Am	Gross alpha
Marine samples											
Flounder	Ribble Estuary	1								<0.07	
Sea Bass	Ribble Estuary	1								<0.13	
Shrimps[b]	Ribble Estuary	1					<0.000023	0.00088	0.0048	0.0095	
Mussels[c]	Ribble Estuary	1						0.076	0.45	1.1	
Wildfowl	Ribble Estuary	1						0.00032	0.0015	0.0028	
Samphire	Marshside Sands	1								<0.20	
Sediment	River Ribble outfall	4[E]	<41	21	<1.2	23				78	360
Sediment	Lea Gate	2[E]	66	20	<1.1	22				110	570
Sediment	Lower Penwortham Park	3[E]	67	29	<1.8	30				160	740
Sediment	River Angler Location 1	2[E]	<14	16	<1.0	17				21	200
Sediment	Penwortham road bridge - West bank	2[E]	81	32	1.5	33				140	670
Sediment	Lytham Yacht Club	1[E]	55	25	1.5	27				150	530
Sediment	Becconsall	4[E]	42	20	<1.2	21				52	340
Sediment	Freckleton	1[E]	47	29	<1.7	30				170	660
Sediment	Hutton Marsh	1[E]	38	31	1.8	32				211	800
Sediment	Longton Marsh	1[E]	39	31	2.0	32				220	870

Table 2.3(a) continued

Material	Location or selection[d]	No. of sampling observations	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}					
			^{3}H	^{14}C	^{90}Sr	^{129}I	^{137}Cs	Total Cs
Terrestrial samples								
Beetroot		1	<2.0	12	<0.083	<0.019	<0.05	<0.053
Sediment	Deepdale Brook	2[E]					1.1	
Silage		1	<2.7	30	0.40	<0.030	<0.07	<0.068
Freshwater[f]	Ulnes Walton	1[E]	<3.4				<0.21	

Material	Location or selection[d]	No. of sampling observations	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}					
			^{230}Th	^{232}Th	^{234}Th	^{234}U	^{235}U	^{238}U
Terrestrial samples								
Milk		2				<0.0012	<0.00056	<0.0013
Milk	max					0.0020	<0.00071	0.0023
Beetroot		1	0.0024	0.0023		0.0023	0.00040	0.0019
Sediment	Deepdale Brook	2[E]			58	43	<1.9	42
Silage		1	0.032	0.043		0.064	0.0030	0.060
Grass	Opposite site entrance	1[E]				0.70	0.029	0.34
Grass	Opposite windmill	1[E]				0.53	0.11	0.36
Grass	Deepdale Brook	1[E]				0.42	0.021	0.37
Grass	N of Lea Town	1[E]				0.50	0.025	0.51
Soil	Opposite site entrance	1[E]				110	5.3	100
Soil	Opposite windmill	1[E]				100	5.3	95
Soil	Deepdale Brook	1[E]				120	5.9	110
Soil	N of Lea Town	1[E]				46	2.4	49
Freshwater	Deepdale Brook	4[E]				0.66	0.031	0.66
Freshwater[f]	Ulnes Walton	1[E]	<0.0017	<0.0015		0.030	<0.0016	0.026

Material	Location or selection[d]	No. of sampling observations	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}					
			^{238}Pu	^{239}Pu + ^{240}Pu	^{241}Pu	^{241}Am	Gross alpha	Gross beta
Terrestrial samples								
Beetroot		1	<0.00018	<0.00018	<0.71	0.00015		
Sediment	Deepdale Brook	2[E]					240	910
Silage		1	0.00045	0.0038	<0.39	0.0076		
Freshwater	Deepdale Brook	4[E]					0.94	0.92
Freshwater[f]	Ulnes Walton	1[E]					0.089	0.58

[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 0.00029 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 <0.0037 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, 2021

Location	Material or ground type	No. of sampling observations	$\mu Gy\ h^{-1}$
Mean gamma dose rates at 1m over substrate			
Lytham Yacht Club	Salt marsh	1	0.089
Warton Salt Marsh	Salt marsh	2	0.090
Warton Salt Marsh	Salt marsh[a]	2	0.094
Freckleton	Salt marsh	1	0.088
Naze Point	Salt marsh	2	0.096
Banks Marsh (alternative)[b]	Salt marsh	2	0.11
Banks Marsh (alternative)[b]	Salt marsh[a]	2	0.11
Becconsall Boatyard	Salt marsh	4	0.074
Longton Marsh	Salt marsh	1	0.089
Hutton Marsh	Salt marsh	1	0.11
River Ribble outfall	Mud	1	0.081
River Ribble outfall	Mud and sand	2	0.087
River Ribble outfall	Salt marsh	1	0.085
Savick Brook, confluence with Ribble	Salt marsh	2	0.087
Savick Brook, Lea Gate	Grass and salt marsh	1	0.087
Savick Brook, Lea Gate	Salt marsh	1	0.082
Penwortham road bridge	Mud and sand	2	0.079
Lower Penwortham Park	Grass	1	0.072
Lower Penwortham Park	Grass and herbage	1	0.074
Lower Penwortham Park	Grass and mud	2	0.073
River Darwen	Grass	3	0.077
River Darwen	Grass and mud	1	0.078
Riverbank Angler Location 1	Grass	2	0.074
Riverbank Angler Location 1	Grass and herbage	1	0.080
Riverbank Angler Location 1	Grass and mud	1	0.076
Ulnes Walton, BNFL area survey	Grass	3	0.070
Mean beta dose rates			$\mu Sv\ h^{-1}$
Lytham - Granny's Bay	Sand	1	0.033
Banks Marsh (alternative)[b]	Salt marsh	2	0.041
Warton Salt Marsh	Salt marsh	2	0.090

[a] 15cm above substrate
[b] As in 2020, no monitoring was undertaken at Banks Marsh in 2021 (as reported in earlier RIFE reports)

Table 2.4 Concentrations of radionuclides in terrestrial food and the environment near Sellafield, 2021

Material	Location or selection[a]	No. of sampling observations[b]	Mean radioactivity concentration (fresh)[c], Bq kg^{-1}						
			Organic ^{3}H	^{3}H	^{14}C	^{60}Co	^{90}Sr	^{99}Tc	^{106}Ru
Milk		9	<2.6	<2.5	15	<0.04	<0.034	<0.0060	<0.36
Milk	max		<3.0	<3.0	17	<0.05	0.061	<0.0062	<0.44
Apple		1	<2.5	<2.5	16	<0.02	0.10	<0.048	<0.21
Barley		1	<3.8	<3.8	91	<0.05	0.58		<0.71
Beef kidney		1	<4.8	<4.8	19	<0.07	<0.12	<0.040	<0.65
Beef liver		1	<2.3	<2.3	44	<0.03	<0.049	<0.053	<0.27
Beef muscle		1	<2.4	<2.4	46	<0.03	<0.041	<0.058	<0.27
Beetroot		1	<2.1	<2.1	3.0	<0.03	0.058	<0.048	<0.25
Cabbage		1	<2.0	<2.0	5.8	<0.06	0.037		<0.43
Carrots		1	<2.0	<2.0	11	<0.07	0.024		<0.54
Duck		2	<4.9	<4.9	41	<0.04	<0.042		<0.34
	max		<5.2	<5.2	47	<0.05	<0.044		<0.40
Eggs		1	<3.1	<3.1	40	<0.03	0.026		<0.26
Mushrooms		1	<2.1	<2.1	8.5	<0.03	0.024		<0.26
Pheasant		1	<6.4	<6.4	46	<0.06	<0.043	<0.045	<0.46
Potatoes		1	<2.0	<2.0	44	<0.07	<0.042		<0.50
Sheep muscle		2	<8.5	<8.5	32	<0.06	<0.040	<0.041	<0.47
Sheep muscle	max		10	10	33			<0.044	
Sheep offal		2	<5.1	<5.1	46	<0.03	0.058	<0.042	<0.29
Sheep offal	max		<5.5	<5.5	51	<0.04	0.083	<0.044	<0.38
Grass	Braystones	1[E]		<16	30		<0.22		<15
Grass	River Calder (upstream)	1[E]		<11	10		2.3		<8.2
Grass	River Calder (downstream)	1[E]		<11	28		2.4		<11
Soil		1	<2.2		6.7	<0.24	4.5	<0.64	<2.2
Soil	Braystones	1[E]		<9.3	9.3		<1.1		<4.5
Soil	River Calder (upstream)	1[E]		<9.1	11		<0.90		<3.4
Soil	WAMAC Access gate	1[E]		<6.4	6.9		<0.91		<4.4

Material	Location or selection[a]	No. of sampling observations[b]	Mean radioactivity concentration (fresh)[c], Bq kg^{-1}						
			^{125}Sb	^{129}I	^{131}I	^{134}Cs	^{137}Cs	Total Cs	^{234}U
Milk		9	<0.10	<0.0059	<0.0026	<0.03	<0.09	<0.09	
Milk	max		<0.11	<0.012	<0.0033	<0.05	0.15	0.13	
Apple		1	<0.05	<0.033		<0.04	0.35	0.35	
Barley		1	<0.11	<0.051		<0.03	0.33	0.33	
Beef kidney		1	<0.21			<0.07	0.53	0.53	0.0063
Beef liver		1	<0.08	<0.032		<0.03	0.38	0.38	
Beef muscle		1	<0.08	<0.018		<0.02	0.63	0.63	
Beetroot		1	<0.07	<0.023		<0.04	0.11	0.11	
Cabbage		1	<0.12	<0.027		<0.03	<0.05	<0.050	
Carrots		1	<0.14	<0.025		<0.08	0.08	0.079	0.0055
Duck		2	<0.10	<0.024		<0.06	0.10	0.098	
	max		<0.11	<0.025				0.099	
Eggs		1	<0.08	<0.031		<0.02	<0.03	<0.030	
Mushrooms		1	<0.07	<0.025		<0.03	4.3	4.3	
Pheasant		1	<0.17	<0.036		<0.08	0.15	0.15	
Potatoes		1	<0.12	<0.028		<0.06	<0.06	<0.056	0.0086
Sheep muscle		2	<0.11	<0.033		<0.06	<0.13	<0.13	
Sheep muscle	max			<0.035			0.21	0.21	
Sheep offal		2	<0.07	<0.024		<0.04	0.09	0.089	0.0043
Sheep offal	max		<0.09	<0.025		<0.05	0.11	0.11	0.0044
Grass	Braystones	1[E]	<7.7				<1.7		
Grass	River Calder (upstream)	1[E]	<5.0				4.7		
Grass	River Calder (downstream)	1[E]	<6.1				2.7		
Soil		1	<0.62	<0.030	<0.85	<0.19	21	21	
Soil	Braystones	1[E]	<2.4				53		
Soil	River Calder (upstream)	1[E]	<1.9				47		
Soil	WAMAC Access gate	1[E]	<2.5				71		

Table 2.4 continued

Material	Location or selection[a]	No. of sampling observations[b]	Mean radioactivity concentration (fresh)[c], Bq kg^{-1}					
			^{235}U	^{238}U	^{238}Pu	^{239}Pu + ^{240}Pu	^{241}Pu	^{241}Am
Milk		9			<0.000051	<0.000039	<0.19	<0.000030
Milk	max				<0.000058	<0.000046	<0.21	0.000052
Apple		1			<0.000093	0.00020	<0.52	0.00026
Barley		1			0.00032	0.0065	<0.70	0.0037
Beef kidney		1	<0.00047	0.0041	<0.00040	0.00025	<2.2	0.00013
Beef liver		1			0.000077	0.00059	<0.18	0.00065
Beef muscle		1			0.000057	0.00020	<0.51	0.00025
Beetroot		1						<0.36
Cabbage		1			<0.000076	0.000081	<0.43	0.00011
Carrots		1	0.00077	0.0054				<0.13
Duck		2			<0.000070	0.00011	<0.42	0.00020
	max				<0.00013	0.00019	<0.47	0.00031
Eggs		1			<0.000099	0.00014	<0.39	0.000072
Mushrooms		1			0.0054	0.039	0.20	0.055
Pheasant		1			0.000039	0.000065	<0.68	0.00018
Potatoes		1	<0.00052	0.0072	0.00014	0.0014	<0.48	0.0019
Sheep muscle		2			<0.000084	0.00021	<0.46	0.00040
Sheep muscle	max				0.000088	0.00029		0.00053
Sheep offal		2	<0.00050	0.0040	0.00039	0.0040	<0.61	0.0028
Sheep offal	max			0.0045	0.00043	0.0042	<0.78	0.0030
Grass	Braystones	1[E]			<0.0038	0.21	<6.2	<1.9
Grass	River Calder (upstream)	1[E]			<0.032	0.039	<0.99	<0.96
Grass	River Calder (downstream)	1[E]			<0.055	<0.22	<4.6	<1.2
Soil		1			0.038	1.0	<29	0.57
Soil	Braystones	1[E]			0.98	8.1	32	4.9
Soil	River Calder (upstream)	1[E]			<0.75	14	<15	5.2
Soil	WAMAC Access gate	1[E]			2.6	37	45	10

[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}

[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, 2021

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]	2			38		<0.06	0.013	<0.69	<0.33
Whitehaven	Cod[a]	2			29		<0.04	<0.026	<0.17	<0.20
Whitehaven	Plaice[a,b]	2	<25	<25	45		<0.06	0.019	<0.35	<0.26
Ravenglass	Plaice[a,c]	2	<25	<25	56		<0.04	0.025	<0.11	<0.11
Lancashire and Merseyside										
Morecambe Bay (Morecambe)	Flounder	2	<25	<25	52		<0.06	<0.035	<0.24	<0.28
Ribble Estuary	European Sea Bass	1					<0.06		<0.22	<0.20
Ribble Estuary	Flounder	1					<0.06		<0.21	<0.20
Liverpool Bay	Dab	1		<25			<0.08		<0.47	<0.34
Scotland										
The Minch	Herring	1[S]				<0.14	<0.10		<0.10	<0.10
The Minch	Mackerel	1[S]				<0.17	<0.10		<0.10	<0.10
Shetland	Fish meal (herring)	1[S]				<1.6	<0.14		<1.2	<0.74
Shetland	Fish oil (herring)	1[S]				<1.2	<0.11		<1.0	<0.62
Ardrossan South Bay	Mackerel	1[S]				<0.20	<0.10		<0.11	<0.11
Ardrossan South Bay	Salmon	1[S]				<0.16	<0.10		<0.10	<0.10
Inner Solway	Salmon	1[S]				<0.19	<0.10		<0.11	<0.10
Inner Solway	Trout	1[S]				<0.21	<0.10		<0.12	<0.14
Kirkcudbright	Plaice	2[S]			20	<0.16	<0.10		<0.10	<0.11
Wales										
North Anglesey	Plaice	1	<25	<25	29		<0.07		<0.23	<0.21
Northern Ireland										
North coast	Lesser spotted dogfish	4[N]					<0.11		<0.48	<0.38
Ardglass	Herring	2[N]					<0.09		<0.63	<2.4
Kilkeel	Cod	4[N]			29		<0.06		<0.26	<0.18
Kilkeel	Plaice	4[N]					<0.04		<0.11	<0.15
Kilkeel	Skates / rays	4[N]					<0.07		<1.1	<0.38
Kilkeel	Haddock	4[N]					<0.05		<0.17	<0.17
Further afield										
Norwegian Sea	Haddock	2					<0.05		<0.07	<0.10

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]	2	<0.16	<0.58	<0.14	<0.06	1.9	<0.35	180
Whitehaven	Cod[a]	2	<0.14	<0.38	<0.10	<0.05	2.2	<0.24	190
Whitehaven	Plaice[a,b]	2	1.6	<0.49	<0.13	<0.04	1.3	<0.30	160
Ravenglass	Plaice[a,c]	2	1.3	<0.35	<0.09	<0.04	1.0	<0.31	80
Lancashire and Merseyside									
Morecambe Bay (Morecambe)	Flounder	2	<0.15	<0.52	<0.13	<0.08	3.5	<0.33	
Ribble Estuary	European Sea Bass	1		<0.71	<0.14	<0.06	4.3	<0.34	
Ribble Estuary	Flounder	1		<0.52	<0.13	<0.08	1.5	<0.31	
Liverpool Bay	Dab	1		<0.71	<0.17	<0.07	0.48	<0.43	
Scotland									
The Minch	Herring	1[S]		<0.29	<0.10	<0.10	0.15	<0.22	
The Minch	Mackerel	1[S]		<0.34	<0.10	<0.10	0.28	<0.25	
Shetland	Fish meal (herring)	1[S]		<1.3	<0.36	<0.14	0.62	<0.87	
Shetland	Fish oil (herring)	1[S]		<1.1	<0.30	<0.12	<0.11	<0.66	
Ardrossan South Bay	Mackerel	1[S]		<0.29	<0.10	<0.10	0.54	<0.23	
Ardrossan South Bay	Salmon	1[S]		<0.21	<0.10	<0.10	<0.10	<0.15	
Inner Solway	Salmon	1[S]		<0.26	<0.10	<0.10	<0.10	<0.17	
Inner Solway	Trout	1[S]		<0.46	<0.14	<0.10	1.1	<0.28	
Kirkcudbright	Plaice	2[S]	<0.05	<0.45	<0.14	<0.10	<0.10	<0.31	
Wales									
North Anglesey	Plaice	1		<0.63	<0.15	<0.11	0.39	<0.36	
Northern Ireland									
North coast	Lesser spotted dogfish	4[N]		<0.98	<0.23	<0.10	0.62	<0.51	
Ardglass	Herring	2[N]		<1.1	<0.24	<0.12	0.26	<1.0	
Kilkeel	Cod	4[N]		<0.51	<0.12	<0.06	0.36	<0.31	
Kilkeel	Plaice	4[N]		<0.37	<0.10	<0.04	0.22	<0.32	
Kilkeel	Skates / rays	4[N]		<0.67	<0.15	<0.08	0.99	<0.39	
Kilkeel	Haddock	4[N]		<0.41	<0.11	<0.04	0.30	<0.27	
Further afield									
Norwegian Sea	Haddock	2		<0.43	<0.11	<0.04	0.11	<0.24	

[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 <0.92 Bq kg^{-1} and 0.038 Bq kg^{-1} respectively
[c] The concentrations of ^{129}I and ^{147}Pm were <0.92 Bq kg^{-1} and <0.075 Bq kg^{-1} respectively
[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, 2021

Location	Material	No. of sampling observations	Mean radioactivity concentration (fresh), Bq kg^{-1}							
			Organic ^{3}H	^{3}H	^{14}C	^{60}Co	^{65}Zn	^{90}Sr	^{95}Nb	^{95}Zr
Cumbria										
Parton	Crabs[a]	2			49	<0.05	<0.12	0.080	<0.19	<0.18
Parton	Lobsters[a]	2			67	<0.05	<0.12	0.033	<0.11	<0.12
Parton	Winkles[a]	2			28	0.19	<0.23	0.93	<0.38	<0.17
Whitehaven	Nephrops[a, b]	2	<25	<25	36	<0.04	<0.08	0.047	<0.08	<0.09
Whitehaven outer harbour	Mussels[a]	2			38	<0.10	<0.14	0.24	<0.08	<0.10
Nethertown	Winkles[a, c]	4	<41	<40	48	0.41	<0.21	1.2	<0.30	<0.23
Sellafield coastal area	Crabs[a,d]	2	<25	<25	62	<0.13	<0.18	0.071	<0.25	<0.22
Sellafield coastal area	Lobsters[a]	2	<25	<25	61	<0.08	<0.15	0.052	<0.14	<0.16
Ravenglass	Winkles[a]	2			42	<0.10	<0.15	0.12	<0.28	<0.14
Seascale Area	Common prawns[a]	2	<25	<25	56	<0.05	<0.11	0.034	<0.16	<0.14
Lancashire and Merseyside										
Morecambe Bay (Morecambe)	Shrimps	2	<25	<25	39	<0.06	<0.16	<0.037	<0.11	<0.14
Morecambe Bay (Morecambe)	Mussels	2	<25	<25	39	<0.06	<0.20	0.12	<0.34	<0.34
Morecambe Bay (Middleton Sands)	Cockles/Winkles	2	39	57	32	<0.09	<0.24	0.097	<0.48	<0.31
Ribble Estuary	Shrimps	1			34	<0.04	<0.10		<0.09	<0.10
Ribble Estuary	Mussels	1				<0.10	<0.20		<0.29	<0.17
Liverpool Bay	Mussels	1		<25		<0.14	<0.37		<1.7	<0.61
Dee Estuary	Cockles	1		<25		<0.08	<0.31		<0.32	<0.19
Wirral	Shrimps	1				<0.11	<0.16		<0.55	<0.22
Scotland										
Kinlochbervie	Crabs	2[S]				<0.10	<0.13		<0.10	<0.12
Lewis	Mussels	1[S]				<0.10	<0.13		<0.11	<0.13
Skye	Lobsters	1[S]				<0.10	<0.15		<0.18	<0.18
Skye	Mussels	1[S]				<0.10	<0.10		<0.12	<0.11
Islay	Crabs	1[S]				<0.10	<0.18		<0.41	<0.28
Islay	Scallops	1[S]				<0.10	<0.10		<0.10	<0.10
Kirkcudbright	Crabs[a]	2[S]			64	<0.11	<0.21	<0.10	<0.14	<0.18
Kirkcudbright	Lobsters[a]	2[S]			38	<0.10	<0.18	<0.10	<0.16	<0.18
Kirkcudbright	Winkles	2[S]				<0.13	<0.38	0.11	<0.62	<0.52
Kirkcudbright	Scallops	2[S]				<0.10	<0.10		<0.10	<0.10
Kirkcudbright	Queens	2[S]				<0.10	<0.10		<0.10	<0.10
Cutters Pool	Limpets[a]	1[S]				<0.12	<0.29		<0.37	<0.37
Cutters Pool	Winkles	1[S]				0.16	<0.25		<0.43	<0.37
Southerness	Winkles	2[S]		<5.0		<0.10	<0.24	0.26	<0.38	<0.32
North Solway coast	Mussels	2[S]		<5.0	54	<0.10	<0.26	0.25	<0.62	<0.44
Inner Solway	Shrimps	2[S]		<5.0		<0.10	<0.10	<0.10	<0.10	<0.10
Wales										
North Anglesey	Crabs	1	<25	<25	29	<0.04	<0.09		<0.10	<0.10
North Anglesey	Lobsters	1	<25	<25	31	<0.04	<0.09		<0.11	<0.12
Northern Ireland										
Ballycastle	Lobsters	2[N]				<0.06	<0.14		<0.22	<0.21
County Down	Scallops	2[N]				<0.05	<0.19		<0.29	<0.21
Kilkeel	Crabs	4[N]				<0.06	<0.20		<0.29	<0.20
Kilkeel	Lobsters	4[N]				<0.06	<0.16		<0.16	<0.17
Kilkeel	Nephrops	4[N]				<0.04	<0.15		<0.32	<0.18
Minerstown	Toothed winkles	2[N]				<0.08	<0.22		<0.28	<0.25
Minerstown	Dog whelk	1[N]				<0.11	<0.22		<0.24	<0.26
Minerstown	Winkles	1[N]				<0.06	<0.16		<0.16	<0.13
Carlingford Lough	Mussels	2[N]				<0.10	<0.32		<0.31	<0.34
Further afield										
Cromer	Crabs	2				<0.08	<0.20		<0.16	<0.26
Southern North Sea	Cockles	2				<0.05	<0.16		<0.20	<0.15

Table 2.6 continued

Location	Material	No. of sampling observations	Mean radioactivity concentration (fresh), Bq kg^{-1}							
			^{99}Tc	^{106}Ru	^{125}Sb	^{134}Cs	^{137}Cs	^{144}Ce	^{147}Pm	Gross beta
Cumbria										
Parton	Crabs[a]	2	1.3	<0.48	<0.14	<0.06	0.57	<0.35		150
Parton	Lobsters[a]	2	21	<0.44	<0.11	<0.05	0.73	<0.25		130
Parton	Winkles[a]	2	5.9	<0.56	<0.14	<0.08	2.3	<0.34		170
Whitehaven	Nephrops[a, b]	2	13	<0.32	<0.10	<0.03	1.2	<0.18	0.058	110
Whitehaven outer harbour	Mussels[a]	2	10	<0.39	<0.10	<0.04	0.93	<0.24		69
Nethertown	Winkles[a, c]	4	5.8	<0.68	<0.17	<0.07	3.4	<0.35	0.20	140
Sellafield coastal area	Crabs[a,d]	2	3.0	<0.65	<0.16	<0.08	0.50	<0.39	<0.094	95
Sellafield coastal area	Lobsters[a]	2	40	<0.83	<0.15	<0.06	0.54	<0.36		130
Ravenglass	Winkles[a]	2	4.5	<0.44	<0.11	<0.05	0.82	<0.26		96
Seascale Area	Common prawns[a]	2	0.094	<0.44	<0.11	<0.06	0.79	<0.28		62
Lancashire and Merseyside										
Morecambe Bay (Morecambe)	Shrimps	2	0.16	<0.57	<0.15	<0.08	2.0	<0.33		
Morecambe Bay (Morecambe)	Mussels	2	26	<0.54	<0.14	<0.07	0.99	<0.34		99
Morecambe Bay (Middleton Sands)	Cockles/Winkles	2	1.8	<0.57	<0.14	<0.10	1.2	<0.35		84
Ribble Estuary	Shrimps	1	<0.15	<0.40	<0.11	<0.04	0.83	<0.29		
Ribble Estuary	Mussels	1		<0.82	<0.21	<0.08	0.30	<0.39		
Liverpool Bay	Mussels	1		<1.0	<0.24	<0.11	1.2	<0.65		
Dee Estuary	Cockles	1	1.5	<0.78	<0.20	<0.15	0.69	<0.49		
Wirral	Shrimps	1	0.12	<0.59	<0.15	<0.07	0.53	<0.34		
Scotland										
Kinlochbervie	Crabs	2[S]	<0.19	<0.49	<0.16	<0.10	<0.10	<0.28		
Lewis	Mussels	1[S]		<0.48	<0.15	<0.10	<0.10	<0.30		
Skye	Lobsters	1[S]	2.9	<0.50	<0.15	<0.10	<0.10	<0.31		
Skye	Mussels	1[S]		<0.27	<0.10	<0.10	<0.10	<0.22		
Islay	Crabs	1[S]		<0.57	<0.15	<0.10	<0.10	<0.32		
Islay	Scallops	1[S]		<0.28	<0.10	<0.10	<0.10	<0.19		
Kirkcudbright	Crabs[a]	2[S]	<0.44	<0.65	<0.20	<0.11	<0.25	<0.37		
Kirkcudbright	Lobsters[a]	2[S]	17	<0.66	<0.20	<0.11	0.48	<0.37		
Kirkcudbright	Winkles	2[S]	6.3	<1.2	<0.33	<0.14	1.2	<0.60		
Kirkcudbright	Scallops	2[S]		<0.12	<0.10	<0.10	<0.10	<0.10		
Kirkcudbright	Queens	2[S]	<0.21	<0.20	<0.10	<0.10	<0.19	<0.14		
Cutters Pool	Limpets[a]	1[S]		<1.0	<0.33	<0.13	1.5	<0.61		
Cutters Pool	Winkles	1[S]		<0.92	<0.28	<0.10	1.6	<0.48		
Southerness	Winkles	2[S]	13	<0.84	<0.25	<0.11	1.2	<0.45		
North Solway coast	Mussels	2[S]	16	<0.93	<0.27	<0.11	1.6	<0.48		
Inner Solway	Shrimps	2[S]	<0.20	<0.24	<0.10	<0.10	<0.10	<0.14		
Wales										
North Anglesey	Crabs	1		<0.39	<0.10	<0.04	0.13	<0.26		
North Anglesey	Lobsters	1	11	<0.39	<0.11	<0.05	0.23	<0.28		80
Northern Ireland										
Ballycastle	Lobsters	2[N]	7.0	<0.61	<0.15	<0.10	0.12	<0.40		
County Down	Scallops	2[N]		<0.43	<0.11	<0.03	0.11	<0.25		
Kilkeel	Crabs	4[N]		<0.57	<0.15	<0.07	<0.09	<0.38		
Kilkeel	Lobsters	4[N]	6.5	<0.52	<0.13	<0.08	<0.10	<0.32		
Kilkeel	Nephrops	4[N]	1.3	<0.42	<0.10	<0.05	0.26	<0.27		
Minerstown	Toothed winkles	2[N]		<0.69	<0.18	<0.09	0.17	<0.42		
Minerstown	Dog whelk	1[N]		<0.83	<0.20	<0.06	0.19	<0.42		
Minerstown	Winkles	1[N]		<0.54	<0.14	<0.04	0.21	<0.32		
Carlingford Lough	Mussels	2[N]	2.1	<0.80	<0.20	<0.11	0.25	<0.40		
Further afield										
Cromer	Crabs	2		<0.69	<0.18	<0.12	<0.08	<0.40		
Southern North Sea	Cockles	2		<0.41	<0.11	<0.06	<0.07	<0.25		

[a] Data for natural radionuclides for some of these samples may be available in Table 6.6
[b] The concentration of ^{129}I was <0.91 Bq kg^{-1}
[c] The concentration of ^{129}I was <1.1 Bq kg^{-1}
[d] The concentration of ^{129}I was <1.0 Bq kg^{-1}
[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, 2021

Location	Material	No. of sampling observations	Mean radioactivity concentration (fresh), Bq kg^{-1}						
			^{237}Np	^{238}Pu	^{239}Pu+ ^{240}Pu	^{241}Pu	^{241}Am	^{242}Cm	^{243}Cm+ ^{244}Cm
Cumbria									
Parton	Cod	2		0.00057	0.0036	<0.21	0.0067	*	*
Parton	Crabs	2		0.023	0.14	0.69	0.71	*	*
Parton	Lobsters	2		0.019	0.11	0.56	1.4	*	*
Parton	Winkles	2		0.67	3.8	15	7.6	*	*
Whitehaven	Cod	2		0.0012	0.0064	0.24	0.012	*	*
Whitehaven	Plaice	2	0.000060	0.0015	0.0091	0.36	0.019	*	*
Whitehaven	'Nephrops'	2	0.000076	0.024	0.16	0.57	1.2	*	*
Whitehaven outer harbour	Mussels	2		0.50	3.0	12	6.6	*	*
Nethertown	Winkles	4	0.0092	1.0	6.1	27	14	*	0.028
Sellafield coastal area	Crabs	2	0.0044	0.028	0.15	0.63	0.71	*	*
Sellafield coastal area	Lobsters	2		0.026	0.15	0.71	3.0	0.0060	0.0061
Ravenglass	Plaice	2	<0.000015	0.00067	0.0041	<0.32	0.0086	*	*
Ravenglass	Winkles	2		0.26	1.5	6.2	3.6	*	*
Seascale	Prawns	2		0.014	0.087	<1.1	0.16	*	0.00057
Lancashire and Merseyside									
Morecambe Bay (Morecambe)	Flounder	2		0.00028	0.0017		0.0035	*	0.000013
Morecambe Bay (Morecambe)	Shrimps	2		0.0027	0.019		0.033	*	*
Morecambe Bay (Morecambe)	Mussels	2		0.13	0.96	3.6	2.0	*	*
Morecambe Bay (Middleton Sands)	Cockles/Winkles	2		0.16	0.90	3.5	2.5	*	*
Ribble Estuary	Flounder	1					<0.07		
Ribble Estuary	Sea Bass	1					<0.13		
Ribble Estuary	Shrimps	1	0.0000023	0.00088	0.0048		0.0095	*	*
Ribble Estuary	Mussels	1		0.076	0.45		1.1	*	0.0029

Table 2.7 continued

Location	Material	No. of sampling observations	Mean radioactivity concentration (fresh), $Bq\ kg^{-1}$						
			^{237}Np	^{238}Pu	$^{239}Pu+^{240}Pu$	^{241}Pu	^{241}Am	^{242}Cm	$^{243}Cm+^{244}Cm$
Scotland									
The Minch	Herring	1[S]		0.0018	0.0018		0.0070		
The Minch	Mackerel	1[S]		0.0028	0.0021		0.0056		
Shetland	Fish meal (herring)	1[S]		0.015	0.084		0.049		
Shetland	Fish oil (herring)	1[S]		<0.00057	0.00097		0.0072		
Kinlochbervie	Crabs	1[S]		0.025	0.19		0.21		
Lewis	Mussels	1[S]					<0.10		
Skye	Lobsters	1[S]					<0.10		
Skye	Mussels	1[S]					<0.10		
Islay	Crabs	1[S]					<0.10		
Islay	Scallops	1[S]					<0.10		
Ardrossan South Bay	Mackerel	1[S]		0.0014	0.0037		0.014		
Ardrossan South Bay	Salmon	1[S]		0.0039	0.0017		0.0074		
Kirkcudbright	Plaice	1[S]		0.00095	0.0031		0.0075		
Kirkcudbright	Scallops	1[S]					<0.10		
Kirkcudbright	Queens	1[S]		0.0067	0.051		0.067		
Kirkcudbright	Crabs	1[S]		0.27	0.82	5.0	0.37		
Kirkcudbright	Lobsters	1[S]		0.0081	0.052	0.23	0.21		
Kirkcudbright	Winkles	1[S]		0.26	1.5		2.9		
Cutters Pool	Limpets	1[S]					8.1		
Cutters Pool	Winkles	1[S]					14		
Southerness	Winkles	1[S]		0.16	0.94	11	2.1		
North Solway coast	Mussels	1[S]		0.49	3.1	11	6.2		
Annan	Shrimps	1[S]		0.0022	0.0080		0.026		
Inner Solway	Salmon	1[S]					<0.10		
Inner Solway	Shrimps	1[S]					<0.10		
Wales									
North Anglesey	Plaice	1					<0.09		
North Anglesey	Crabs	1					<0.15		
North Anglesey	Lobsters	1		0.0032	0.020	<0.56	0.21	*	0.00032
Northern Ireland									
North coast	Lesser spotted dogfish	2[N]					<0.26		
Ballycastle	Lobsters	2[N]					<0.40		
County Down	Scallops	2[N]					<0.08		
Ardglass	Herring	2[N]					<0.25		
Kilkeel	Cod	4[N]					<0.13		
Kilkeel	Plaice	4[N]					<0.17		
Kilkeel	Skates / rays	4[N]					<0.13		
Kilkeel	Haddock	4[N]					<0.12		
Kilkeel	Crabs	3[N]					<0.22		
Kilkeel	Lobsters	4[N]					<0.15		
Kilkeel	'Nephrops'	1[N]		0.00087	0.0059		0.021	*	*
Minerstown	Toothed winkles	1[N]					0.52		
Minerstown	Dog Whelk	1[N]					0.14		
Minerstown	Winkles	1[N]		0.044	0.27		0.28	*	0.00060
Carlingford Lough	Mussels	2[N]					0.19		
Further afield									
Norwegian Sea	Haddock	2					<0.11		
Cromer	Crabs	2					<0.20		
Southern North Sea	Cockles	1		0.0011	0.0094		0.0072	*	*

* Not detected by the method used
[N] Measurements labelled "N" are made on behalf of the Northern Ireland Environment Agency
[S] Measurements labelled "S" are made on behalf of the Scottish Environment Protection Agency

Table 2.8 Concentrations of radionuclides in sediment from the Cumbrian coast and further afield, 2021

Location	Material	No. of sampling observ- ations	Mean radioactivity concentration (dry), Bq kg^{-1}									
			^{54}Mn	^{60}Co	^{90}Sr	^{95}Zr	^{95}Nb	^{106}Ru	^{125}Sb	^{134}Cs	^{137}Cs	^{144}Ce
Cumbria												
Newton Arlosh	Sediment	2		<1.0		<2.3	<0.77	<7.7	<4.2	<1.1	130	<4.4
Maryport Outer Harbour	Sediment	2		<0.55		<1.2	<0.42	<3.7	<1.9	<0.49	74	<2.0
Workington Harbour	Sediment	2		<0.47		<1.1	<0.44	<3.2	<1.6	<0.46	47	<1.9
Harrington Harbour	Sediment	2		<0.52		<1.1	<0.40	<3.4	<1.8	<0.48	64	<1.9
Whitehaven Outer Harbour	Sediment	4		<0.40	<1.5	<0.73	<0.36	<2.6	<1.4	<0.36	43	<1.6
St Bees beach	Sediment	4		<0.44		<0.68	<0.28	<2.7	<1.4	<0.38	39	<1.4
Ehen spit	Sediment	4		<0.51		<0.85	<0.39	<3.2	<1.7	<0.44	84	<1.9
Sellafield beach, S of former pipeline	Sediment	4		<0.39		<0.67	<0.26	<2.4	<1.3	<0.33	36	<1.5
River Calder - downstream	Sediment	4		<0.40		<0.66	<0.31	<2.4	<1.3	<0.34	47	<1.6
River Calder - upstream	Sediment	4		<0.71		<1.1	<0.52	<3.9	<2.1	<0.62	33	<2.2
Seascale beach	Sediment	4		<0.43		<0.69	<0.28	<2.5	<1.4	<0.38	18	<1.4
Ravenglass - Carleton Marsh	Sediment	4		<0.89	23	<1.5	<0.65	<5.4	<2.8	<0.75	120	<2.9
River Mite Estuary (erosional)	Sediment	4		<1.0	38	<1.8	<0.73	<7.5	<3.9	<0.97	190	<4.0
Ravenglass - Raven Villa	Sediment	4		<0.60		<0.91	<0.45	<3.6	<2.0	<0.49	98	<2.1
Newbiggin (Eskmeals)	Sediment	4		1.7	46	<1.1	<0.50	<4.4	<2.4	<0.58	250	<2.8
Haverigg	Sediment	2		<0.45		<0.98	<0.38	<2.9	<1.5	<0.40	35	<1.6
Millom	Sediment	2		<0.48		<1.1	<0.37	<3.1	<1.7	<0.44	48	<1.9
Askam Pier	Sediment	2		<0.53		<1.0	<0.39	<3.4	<1.8	<0.49	41	<1.8
Low Shaw	Sediment	2		<0.43		<0.95	<0.27	<2.6	<1.4	<0.36	37	<1.6
Walney Channel - N of discharge point	Sediment	2		<0.46		<1.1	<0.41	<3.0	<1.6	<0.42	57	<2.0
Sand Gate Marsh	Sediment	1		<0.48		<0.68	<0.34	<3.1	<1.7	<0.45	52	<1.8
Kents Bank	Sediment	1		<0.38		<0.57	<0.35	<2.9	<1.6	<0.36	160	<2.0
Arnside	Sediment	1		<1.7		<4.9	<1.3	<13	<6.8	<1.9	230	<5.6
Lancashire												
Morecambe	Sediment	2		<0.42							29	
Half Moon Bay	Sediment	2		<0.67							91	
Red Nab Point	Sediment	1		<0.31							26	
Potts Corner	Sediment	2		<0.48							25	
Shore adjecant to Northern Outfall	Sediment	1		<0.64							48	
Sunderland Point	Sediment	1		<0.36		<0.67	<0.34	<2.5	<1.3	<0.39	42	<2.1
Conder Green	Sediment	1		<0.37		<0.70	<0.36	<2.6	<1.5	<0.40	60	<2.2
Hambleton	Sediment	1		<0.77		<1.4	<0.67	<5.4	<2.8	<0.72	170	<2.5
Skippool Creek	Sediment	1		<0.64		<1.2	<0.61	<4.5	<2.3	<0.81	130	<2.8
Fleetwood	Sediment	1		<0.47		<0.79	<0.30	<2.7	<1.5	<0.41	4.8	<1.3
Blackpool	Sediment	1		<0.34		<0.60	<0.23	<2.1	<1.1	<0.32	1.6	<1.2
Crossens Marsh	Sediment	1		<1.2		<2.4	<0.86	<9.0	<5.1	<1.2	160	<5.3
Ainsdale	Sediment	1		<0.35		<0.61	<0.23	<2.1	<1.2	<0.32	2.3	<1.2
Rock Ferry	Sediment	1		<1.7		<3.2	<1.3	<12	<6.0	<1.7	110	<4.7
Scotland												
Nigg Bay	Sediment	1[S]	<0.10	<0.10		<0.17	<0.18	<0.60	<0.20	<0.10	0.19	<0.65
Campbeltown	Sediment	1[S]	<0.10	<0.10		<0.15	<0.28	<0.59	<0.18	<0.10	4.8	<0.61
Garlieston	Sediment	1[S]	<0.10	<0.10		<0.10	<0.11	<0.48	<0.17	<0.10	12	<0.50
Innerwell	Sediment	2[S]	<0.10	<0.10		<0.25	<0.36	<0.56	<0.18	<0.10	29	<0.61
Carsluith	Sediment	1[S]	<0.10	<0.10		<0.10	<0.12	<0.73	<0.27	<0.10	31	<0.75
Skyreburn	Sediment	2[S]	<0.10	<0.10		<0.14	<0.14	<0.51	<0.17	<0.10	20	<0.55
Kirkcudbright	Sediment[a]	2[S]	<0.32	<0.28		<1.2	<1.8	<2.5	<0.77	<0.34	15	<2.1
Balcary Bay	Sediment[a]	1[S]	<0.20	0.33		<0.40	<0.74	<2.3	<0.78	<0.29	120	<1.6
Palnackie Harbour	Sediment	2[S]	<0.10	0.20		0.18	<0.22	<0.66	<0.27	<0.10	190	<0.62
Gardenburn	Sediment	2[S]	<0.10	0.21		<0.29	<0.34	<1.1	<0.44	<0.13	170	<1.1
Kippford Slipway	Sediment	2[S]	<0.10	0.32		<0.21	<0.31	<0.69	<0.26	<0.10	110	<0.66
Kippford Merse	Sediment	1[S]	<0.10	<0.10		<0.22	<0.14	<0.99	<0.47	<0.10	640	<0.92
Kirkconnell Merse	Sediment	1[S]	<0.10	0.31		<0.47	<0.65	<1.2	<0.47	<0.15	130	<1.3
Southerness	Sediment	1[S]	<0.10	<0.10		<0.10	<0.10	<0.24	<0.10	<0.10	6.3	<0.26

Table 2.8 continued

Location	Material	No. of sampling observ-ations	Mean radioactivity concentration (dry), Bq kg^{-1}									
			^{54}Mn	^{60}Co	^{90}Sr	^{95}Zr	^{95}Nb	^{106}Ru	^{125}Sb	^{134}Cs	^{137}Cs	^{144}Ce
Wales												
Rhyl	Sediment	1		<0.64		<1.4	<0.45	<4.1	<2.2	<0.81	33	<2.6
Llandudno	Sediment	1		<0.26		<0.61	<0.24	<1.7	<0.91	<0.28	1.4	<1.4
Caerhun	Sediment	1		<0.71		<1.6	<0.63	<4.6	<2.4	<0.69	35	<2.2
Llanfairfechan	Sediment	1		<0.57		<1.4	<0.53	<3.7	<2.0	<0.72	22	<2.4
Northern Ireland												
Carrichue	Sandy mud	2^{N}	<0.34	<0.19		<1.2	<0.97	<1.9	<0.47	<0.21	1.7	<2.1
Portrush	Sand	2^{N}	<0.19	<0.13		<0.89	<1.3	<1.3	<0.33	<0.16	0.32	<2.1
Oldmill Bay	Clay	1^{N}	<0.26	<0.25		<0.95	<0.78	<2.4	<0.62	<0.15	7.5	<2.3
Oldmill Bay	Sandy mud	1^{N}	<0.50	<0.21		<0.89	<1.8	<2.1	<0.58	<0.16	7.8	<1.6
Ballymacormick	Sandy mud	2^{N}	<0.28	<0.20		<1.5	<0.92	<2.0	<0.53	<0.21	10	<2.0
Strangford Lough - Nicky's Point	Mud	2^{N}	<0.38	<0.21		<1.3	<1.5	<2.1	<0.53	<0.32	8.8	<2.0
Dundrum Bay	Sandy mud	1^{N}	<0.34	<0.17		<1.6	<2.7	<1.9	<0.48	<0.29	3.4	<2.5
Dundrum Bay	Mud	1^{N}	<0.43	<0.24		<2.7	<3.2	<2.4	<0.51	<0.16	2.9	<1.4
Carlingford Lough	Mud	2^{N}	<0.67	<0.32		<7.3	<57	<3.7	<0.86	<0.35	32	<4.1

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	<2.8	<2.0				200	470	1100
Maryport Outer Harbour	Sediment	2	<1.6	<0.83				200	410	870
Workington Harbour	Sediment	2	<1.3	<0.81				100	400	960
Harrington Harbour	Sediment	2	<1.4	<0.83				82	350	760
Whitehaven Outer Harbour	Sediment	4	<1.1	<0.70	11	71	250	75	270	640
St Bees beach	Sediment	4	<1.2	<0.63				120	180	500
Ehen spit	Sediment	4	<1.3	<0.84				82	300	1100
Sellafield beach, S of former pipeline	Sediment	4	<1.0	<0.65				97	200	540
River Calder - downstream	Sediment	4	<0.99	<0.73				83	240	680
River Calder - upstream	Sediment	4	<1.9	<0.97					350	1600
Seascale beach	Sediment	4	<1.2	<0.65				100	190	570
Ravenglass - Carleton Marsh	Sediment	4	<2.0	<1.3	43	260	920	540	990	1200
River Mite Estuary (erosional)	Sediment	4	<2.7	<1.8	64	390	1300	750	1300	1400
Ravenglass - Raven Villa	Sediment	4	<1.4	<0.94				440	710	1200
Newbiggin (Eskmeals)	Sediment	4	<2.1	<1.3	99	620	2100	1400	1800	1300
Haverigg	Sediment	2	<1.2	<0.72				170	370	760
Millom	Sediment	2	<1.3	<0.81				150	310	820
Askam Pier	Sediment	2	<1.5	<0.76				120	300	680
Low Shaw	Sediment	2	<1.1	<0.70				89	230	720
Walney Channel - N of discharge point	Sediment	2	<1.2	<0.82				160	390	790
Sand Gate Marsh	Sediment	1	<1.3	<0.80				61	190	730
Kents Bank	Sediment	1	<0.98	<0.92				130	220	900
Arnside	Sediment	1	<5.0	<2.3				200	660	1000

Table 2.8 continued

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
Lancashire											
Morecambe	Sediment	2					42				
Half Moon Bay	Sediment	2			8.3	54	140				
Red Nab Point	Sediment	1					33				
Potts Corner	Sediment	2					34				
Shore adjecant to Northern Outfall	Sediment	1					83				
Sunderland Point	Sediment	1	<0.91	<1.1			66			280	810
Conder Green	Sediment	1	<0.96	<1.1			89			430	960
Hambleton	Sediment	1	<2.2	<1.1			190			500	1200
Skippool Creek	Sediment	1	<1.7	<1.2			170			400	1200
Fleetwood	Sediment	1	<1.3	<0.56			11			79	400
Blackpool	Sediment	1	<0.90	<0.54			3.8			<69	210
Crossens Marsh	Sediment	1	<2.9	<2.4			150			470	1300
Ainsdale	Sediment	1	<0.90	<0.56			2.6			<94	360
Rock Ferry	Sediment	1	<4.8	<2.1			98			450	1200
Scotland											
Nigg Bay	Sediment	1[S]	<0.18	1.1			<0.33				
Campbeltown	Sediment	1[S]	<0.16	<0.29			1.0				
Garlieston	Sediment	1[S]	<0.13	0.60	2.3	13	20				
Innerwell	Sediment	2[S]	<0.15	1.2	5.3	33	58				
Carsluith	Sediment	1[S]	<0.12	1.3	11	59	120			180	1100
Skyreburn	Sediment	2[S]	<0.16	<0.52	2.5	18	29				
Kirkcudbright	Sediment[a]	2[S]	<0.51	<2.2			29				
Balcary Bay	Sediment[a]	1[S]	<0.31	<0.67			280				
Palnackie Harbour	Sediment	2[S]	<0.40	0.77	28	170	330				
Gardenburn	Sediment	2[S]	<0.19	<0.79	28	170	360				
Kippford Slipway	Sediment	2[S]	<0.35	1.4	18	110	180				
Kippford Merse	Sediment	1[S]	<0.15	1.6	1.1	15	13			410	2400
Kirkconnell Merse	Sediment	1[S]	0.70	0.76	20	130	280				
Southerness	Sediment	1[S]	<0.10	0.52	1.4	11	19				
Wales											
Rhyl	Sediment	1	<1.8	<1.1			30			390	1200
Llandudno	Sediment	1	<0.64	<0.67						110	500
Caerhun	Sediment	1	<2.0	<0.91			23			260	940
Llanfairfechan	Sediment	1	<1.6	<0.96			19			290	750
Northern Ireland											
Carrichue	Sandy mud	2[N]	<0.78	<0.85	0.054	0.44	0.86	*	*		
Portrush	Sand	2[N]	<0.43	<0.46			1.1				
Oldmill Bay	Clay	1[N]	<0.80	<1.3			8.6				
Oldmill Bay	Sandy mud	1[N]	<0.67	<1.1			8.3				
Ballymacormick	Sandy mud	2[N]	<0.63	<0.95			13				
Strangford Lough - Nicky's Point	Mud	2[N]	<0.90	<1.2			3.6				
Dundrum Bay	Sandy mud	1[N]	<0.55	<1.5			2.5				
Dundrum Bay	Mud	1[N]	<0.77	<1.0			1.9				
Carlingford Lough	Mud	2[N]	<1.0	<1.4	1.6	11	8.7	*	*		

* Not detected by the method used

S Measurements labelled "S" are made on behalf of the Scottish Environment Protection Agency

N Measurements labelled "N" are made on behalf of the Northern Ireland Environment Agency. All other measurements are made on behalf of the Environment Agency

a Data for natural radionuclides for some of these samples may be available in Table 6.6

Table 2.9 Gamma radiation dose rates over areas of the Cumbrian coast and further afield, 2021

Location	Ground type	No. of sampling observations	Mean gamma dose rate in air at 1m, $\mu Gy\ h^{-1}$
Cumbria, Rockcliffe-Harrington			
Rockcliffe Marsh	Salt marsh	2	0.074
Burgh Marsh	Salt marsh	2	0.072
Port Carlisle 1	Mud	1	0.078
Port Carlisle 1	Mud and sand	1	0.081
Port Carlisle 2	Salt marsh	2	0.079
Newton Arlosh	Salt marsh	2	0.089
Silloth harbour	Sand	1	0.082
Silloth harbour	Sand and stones	1	0.087
Allonby	Sand	2	0.078
Maryport harbour	Sand	2	0.081
Workington harbour	Pebbles	1	0.10
Workington harbour	Shingle	1	0.10
Harrington harbour	Pebbles and sand	1	0.094
Harrington harbour	Sand and stones	1	0.092
Cumbria, Whitehaven-Drigg			
Whitehaven - outer harbour	Sand	3	0.083
Whitehaven - outer harbour	Sand and stones	1	0.087
St Bees	Sand	4	0.068
Nethertown beach	Pebbles	1	0.12
Nethertown beach	Shingle	3	0.12
Ehen spit	Pebbles and sand	3	0.10
Ehen spit	Sand	1	0.10
Braystones	Grass	1	0.081
Braystones beach	Pebbles	2	0.10
Braystones beach	Pebbles and sand	1	0.10
WAMAC Access gate	Grass	1	0.097
Sellafield dunes	Grass	4	0.089
North of former pipeline on foreshore	Sand	4	0.072
South of former pipeline on foreshore	Pebbles and sand	1	0.10
South of former pipeline on foreshore	Sand	3	0.069
River Calder downstream of site	Grass and pebbles	2	0.089
River Calder downstream of site	Grass and sand	1	0.085
River Calder downstream of site	Grass and stones	1	0.093
River Calder upstream of site	Grass	1	0.098
Seascale beach	Pebbles and sand	1	0.082
Seascale beach	Sand	3	0.069
Cumbria, Ravenglass-Askam			
Ravenglass - Carleton Marsh	Salt marsh	4	0.11
Ravenglass - River Mite estuary (erosional)	Salt marsh	4	0.11
Ravenglass - Raven Villa	Salt marsh	4	0.11
Ravenglass - boat area	Pebbles and sand	3	0.097
Ravenglass - boat area	Pebbles and stones	1	0.098
Ravenglass - ford	Sand	3	0.082
Ravenglass - ford	Sand and stones	1	0.087
Muncaster Bridge	Grass	1	0.090
Muncaster Bridge	Salt marsh	3	0.10
Ravenglass - salmon garth	Sand	1	0.095
Ravenglass - salmon garth	Sand and stones	3	0.10
Ravenglass - Eskmeals Nature Reserve	Salt marsh	4	0.095
Newbiggin/Eskmeals Bridge	Salt marsh	4	0.097
Newbiggin/Eskmeals viaduct	Salt marsh	4	0.10
Tarn Bay	Sand	3	0.066
Tarn Bay	Sand and stones	1	0.091
Silecroft	Pebbles	1	0.11
Silecroft	Shingle	1	0.11

Table 2.9 continued

Location	Ground type	No. of sampling observations	Mean gamma dose rate in air at 1m, $\mu Gy\ h^{-1}$
Haverigg	Pebbles and sand	1	0.087
Haverigg	Sand	1	0.079
Millom	Mud and sand	1	0.089
Millom	Sand and stones	1	0.090
Low Shaw	Salt marsh	2	0.074
Askam	Sand	4	0.063
Askam Pier	Mud and sand	4	0.072
Cumbria, Walney-Arnside			
Walney Channel, N of discharge point	Mud and sand	4	0.077
Tummer Hill Marsh	Salt marsh	2	0.096
Roa Island	Mud and sand	1	0.084
Roa Island	Pebbles and rock	1	0.075
Sand Gate Marsh	Salt marsh	2	0.082
Kents Bank 2	Salt marsh	2	0.080
Arnside 2	Salt marsh	2	0.080
Lancashire and Merseyside			
Morecambe Central beach	Sand	2	0.069
Half Moon Bay	Sand	2	0.074
Pipeline (Heysham)	Sand and stones	1	0.069
Red Nab Point	Sand and stones	1	0.076
Middleton Sands	Sand	2	0.068
Sunderland Point	Mud and sand	1	0.082
Sunderland Point	Sand	1	0.085
Colloway Marsh	Salt marsh	1	0.096
Lancaster	Grass	2	0.070
Aldcliffe Marsh	Salt marsh	2	0.079
Conder Green	Salt marsh	2	0.077
Pilling Marsh	Salt marsh	2	0.083
Knott End	Sand	2	0.071
Height o’ th’ hill - River Wyre	Salt marsh	2	0.089
Hambleton	Salt marsh	2	0.092
Skippool Creek	Salt marsh	2	0.087
Skippool Creek (mud)	Salt marsh	2	0.088
Fleetwood shore 1	Sand	2	0.068
Fleetwood shore 2	Salt marsh	2	0.097
Blackpool	Sand	2	0.061
Crossens Marsh	Salt marsh	2	0.082
Ainsdale	Sand	2	0.058
Rock Ferry	Mud and sand	2	0.080
West Kirby	Sand	2	0.064
Scotland			
Piltanton Burn	Sediment	2[S]	0.061
Garlieston	Sediment	2[S]	0.068
Innerwell	Sediment	2[S]	0.079
Bladnoch	Sediment	3[S]	0.071
Carsluith	Sediment	2[S]	0.074
Skyreburn Bay (Water of Fleet)	Sediment	2[S]	0.073
Kirkcudbright	Salt marsh	2[S]	0.059
Cutters Pool	Sediment	4[S]	0.077
Balcary Bay	Salt marsh	2[S]	0.079
Gardenburn	Sediment	1[S]	0.068
Palnackie Harbour	Sediment	2[S]	0.066
Kippford - Slipway	Sediment	2[S]	0.090
Kippford - Merse	Salt marsh	1[S]	0.080
Kippford - Merse	Sediment	1[S]	0.069
Kirkconnell Marsh	Sediment	1[S]	0.058
Southerness	Sediment	2[S]	0.062

Table 2.9 continued

Location	Ground type	No. of sampling observations	Mean gamma dose rate in air at 1m, $\mu Gy\ h^{-1}$
Wales			
Flint 1	Mud	2	0.083
Flint 2	Salt marsh	2	0.084
Rhyl	Salt marsh	2	0.079
Llandudno	Shingle	1	0.077
Llandudno	Sediment	1	0.090
Caerhun	Salt marsh	2	0.078
Llanfairfechan	Sand and shells	2	0.073
Northern Ireland			
Lisahally	Mud	1[N]	0.055
Donnybrewer	Shingle	1[N]	0.047
Carrichue	Mud	1[N]	0.064
Bellerena	Mud	1[N]	0.054
Benone	Sand	1[N]	0.052
Castlerock	Sand	1[N]	0.055
Portstewart	Sand	1[N]	0.053
Cushendun	Sand	1[N]	0.056
Cushendall	Sand and stones	1[N]	0.057
Red Bay	Sand	1[N]	0.055
Carnlough	Sand	1[N]	0.053
Glenarm	Sand	1[N]	0.057
Half Way House	Sand	1[N]	0.052
Ballygally	Sand	1[N]	0.054
Drains Bay	Sand	1[N]	0.052
Larne	Sand	1[N]	0.055
Whitehead	Sand	1[N]	0.056
Carrickfergus	Sand	1[N]	0.053
Jordanstown	Sand	1[N]	0.053
Helen's Bay	Sand	1[N]	0.055
Groomsport	Sand	1[N]	0.058
Millisle	Sand	1[N]	0.071
Ballywalter	Sand	1[N]	0.065
Ballyhalbert	Sand	1[N]	0.065
Cloghy	Sand	1[N]	0.062
Portaferry	Shingle and stones	1[N]	0.083
Kircubbin	Sand	1[N]	0.081
Greyabbey	Sand	1[N]	0.081
Ards Maltings	Mud	1[N]	0.078
Island Hill	Mud	1[N]	0.069
Nicky's Point	Mud	1[N]	0.077
Strangford	Shingle and stones	1[N]	0.094
Kilclief	Sand	1[N]	0.062
Ardglass	Mud	1[N]	0.083
Killough	Mud	1[N]	0.074
Ringmore Point	Sand	1[N]	0.066
Tyrella	Sand	1[N]	0.070
Dundrum	Sand	1[N]	0.081
Newcastle	Sand	1[N]	0.096
Annalong	Sand	1[N]	0.098
Cranfield Bay	Sand	1[N]	0.076
Mill Bay	Sand	1[N]	0.097
Greencastle	Sand	1[N]	0.076
Rostrevor	Sand	1[N]	0.10
Narrow Water	Mud	1[N]	0.082

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

Table 2.10 Beta radiation dose rates over intertidal areas of the Cumbrian coast, 2021

Location	Ground type	No. of sampling observations	Mean beta dose rate in tissue, $mSv\ h^{-1}$
Whitehaven - outer harbour	Sand	3	0.096
Whitehaven - outer harbour	Sand and stones	1	0.19
St Bees	Sand	4	0.093
Sellafield beach, N of discharge point	Sand	4	0.13
Ravenglass - Raven Villa	Salt marsh	4	0.15
Tarn Bay	Sand	3	0.13
Tarn Bay	Sand and stones	1	0.11

Table 2.11 Concentrations of radionuclides in aquatic plants from the Cumbrian coast and further afield, 2021

Location	Material	No. of sampling observ-ations	Mean radioactivity concentration (fresh), $Bq\ kg^{-1}$								
			^{60}Co	^{65}Zn	^{90}Sr	^{95}Zr	^{95}Nb	^{99}Tc	^{106}Ru	^{110m}Ag	^{125}Sb
Cumbria											
Silloth	Seaweed	2	<0.78			<1.1	<0.52	50	<4.7	<0.76	<2.7
Harrington Harbour	Seaweed	2	<0.67			<0.94	<0.48	65	<4.3	<0.66	<2.6
St Bees[a]	Seaweed	2	<0.88		<0.30	<1.1	<0.58	180	<5.5	<0.87	<3.0
Sellafield[b]	Seaweed	2	<0.50		<0.54	<0.66	<0.33	340	<3.1	<0.48	<1.8
Ravenglass	Samphire	1[F]	<0.09	<0.21		<0.38	<0.15	0.51	<0.77	<0.13	<0.19
Ravenglass[c]	Seaweed	2	<0.78		<0.95	<1.0	<0.52	46	<4.8	<0.76	<2.8
Lancashire											
Half Moon Bay[d]	Seaweed	2	<0.70			<0.84	<0.45	85	<4.0	<0.64	<2.3
Marshside Sands	Samphire	1[F]	<0.03	<0.14		<0.08	<0.13	0.11	<0.28	<0.04	<0.07
Scotland											
Lerwick	Fucus vesiculosus	1[S]	<0.10	<0.10		<0.10	<0.10	2.6	<0.26	<0.10	<0.10
Kinlochbervie	Fucus vesiculosus	2[S]	<0.10	<0.21		<0.23	<0.25	9.8	<0.68	<0.10	<0.19
Lewis	Fucus vesiculosus	1[S]	<0.10	<0.16		<0.16	<0.16	20	<0.43	<0.10	<0.13
Islay	Fucus vesiculosus	1[S]	<0.10	<0.12		<0.12	<0.11	20	<0.32	<0.10	<0.10
Campbeltown	Fucus vesiculosus	1[S]	<0.10	<0.23		<0.23	<0.22	15	<0.68	<0.10	<0.20
Nigg Bay Aberdeen	Fucus vesiculosus	1[S]	<0.10	<0.13		<0.11	<0.10	5.3	<0.35	<0.10	<0.11
Port William	Fucus vesiculosus	4[S]	<0.10	<0.21		<0.25	<0.29	36	<0.64	<0.11	<0.18
Garlieston	Fucus vesiculosus	4[S]	<0.10	<0.19		<0.20	<0.24	36	<0.54	<0.12	<0.16
Auchencairn	Fucus vesiculosus	4[S]	<0.10	<0.20		<0.23	<0.27	62	<0.58	<0.13	<0.16
Wales											
Cemaes Bay	Seaweed	2	<0.75			<0.90	<0.48	9.9	<4.3	<0.69	<2.4
Porthmadog	Seaweed	2	<0.63			<0.83	<0.44	0.52	<4.0	<0.66	<2.3
Lavernock Point	Seaweed	2	<0.75			<0.98	<0.50	<0.32	<4.7	<0.76	<2.8
Fishguard	Seaweed	2	<0.42			<0.78	<0.27	<0.99	<2.6	<0.45	<1.4
Northern Ireland											
Portrush	Fucus species	4[N]	<0.05	<0.21		<0.17	<0.19		<0.39	<0.06	<0.10
Strangford Lough (Island Hill)[e]	Rhodymenia species	4[N]	<0.09	<0.25		<0.30	<0.31	0.24	<0.73	<0.11	<0.18
Ardglass	Ascophyllum nodosum	1[N]	<0.07	<0.31		<0.18	<0.15		<0.57	<0.09	<0.14
Ardglass	Fucus vesiculosus	3[N]	<0.04	<0.15		<0.28	<0.41	6.7	<0.40	<0.06	<0.09
Carlingford Lough	Ascophyllum nodosum	1[N]	<0.04	<0.18		<0.25	<0.13		<0.35	<0.05	<0.08
Carlingford Lough	Fucus species	3[N]	<0.05	0.17		<0.24	<0.24	11	<0.41	<0.06	<0.10
Isles of Scilly	Seaweed	1	<0.51			<0.69	<0.37	1.6	<3.1	<0.54	<2.0

Table 2.11 continued

Location	Material	No. of sampling observ-ations	Mean radioactivity concentration (fresh), $Bq\ kg^{-1}$							
			^{129}I	^{134}Cs	^{137}Cs	^{144}Ce	^{155}Eu	^{238}Pu	$^{239}Pu + ^{240}Pu$	^{241}Am
Cumbria										
Silloth	Seaweed	2	<0.71	<0.71	2.9	<2.0				3.1
Harrington Harbour	Seaweed	2	<0.86	<0.64	1.2	<2.1				<0.73
St Bees[a]	Seaweed	2	<1.0	<0.79	<1.4	<2.4		0.90	4.8	<2.9
Sellafield[b]	Seaweed	2	<1.4	<0.46	1.5	<1.8		0.64	3.2	3.0
Ravenglass	Samphire	1[F]		<0.05	1.3	<0.38	<0.27			6.9
Ravenglass[c]	Seaweed	2	<0.92	<0.72	5.4	<2.1		2.4	14	19
Lancashire										
Half Moon Bay[d]	Seaweed	2	<0.77	<0.62	3.0	<1.9				2.9
Marshside Sands	Samphire	1[F]		<0.02	0.23	<0.20	<0.09			<0.20
Scotland										
Lerwick	Fucus vesiculosus	1[S]		<0.10	<0.10	<0.19	<0.10			<0.11
Kinlochbervie	Fucus vesiculosus	2[S]		<0.10	0.21	<0.41	<0.16			<0.12
Lewis	Fucus vesiculosus	1[S]		<0.10	0.17	<0.38	<0.19			<0.20
Islay	Fucus vesiculosus	1[S]		<0.10	0.12	<0.26	<0.14			<0.15
Campbeltown	Fucus vesiculosus	1[S]		<0.10	0.21	<0.42	<0.17			0.22
Nigg Bay Aberdeen	Fucus vesiculosus	1[S]		<0.10	<0.10	<0.22	<0.10			<0.10
Port William	Fucus vesiculosus	4[S]		<0.10	0.29	<0.39	<0.16			<0.37
Garlieston	Fucus vesiculosus	4[S]		<0.10	6.9	<0.36	<0.16			15
Auchencairn	Fucus vesiculosus	4[S]		<0.10	1.8	<0.35	<0.16			3.4
Wales										
Cemaes Bay	Seaweed	2		<0.63	<0.52	<2.0				<0.63
Porthmadog	Seaweed	2		<0.60	<0.79	<1.8				<0.61
Lavernock Point	Seaweed	2		<0.69	<0.58	<2.3	<1.1			<0.78
Fishguard	Seaweed	2		<0.38	<0.28	<0.99				<0.27
Northern Ireland										
Portrush	Fucus species	4[N]		<0.03	<0.05	<0.23	<0.10			<0.13
Strangford Lough (Island Hill)[e]	Rhodymenia species	4[N]		<0.09	0.53	<0.49	<0.26	0.0073	0.44	0.88
Ardglass	Ascophyllum nodosum	1[N]		<0.05	0.18	<0.34	<0.15			<0.17
Ardglass	Fucus vesiculosus	3[N]		<0.06	0.23	<0.21	<0.14			<0.18
Carlingford Lough	Ascophyllum nodosum	1[N]		<0.02	0.16	<0.23	<0.16			<0.11
Carlingford Lough	Fucus species	3[N]		<0.03	0.23	<0.25	<0.16			<0.19
Isles of Scilly	Seaweed	1		<0.46	<0.39	<1.8	<0.85			<0.62

[a] The concentrations of ^{14}C was 29 $Bq\ kg^{-1}$
[b] The concentrations of ^{14}C was 62 $Bq\ kg^{-1}$
[c] The concentrations of ^{14}C was 8.1 $Bq\ kg^{-1}$
[d] The concentrations of ^{35}S was 8.5 $Bq\ kg^{-1}$
[e] The concentrations of ^{242}Cm and $^{243+244}Cm$ were not detected by the method used
[F] Measurements labelled "F" are made on behalf of the Food Standards Agency
[N] Measurements labelled "N" are made on behalf of the Northern Ireland Environment Agency
[S] Measurements labelled "S" are made on behalf of the Scottish Environment Protection Agency
All other measurements are made on behalf of the Environment Agency

Table 2.12 Concentrations of radionuclides in terrestrial food and the environment near Ravenglass, 2021

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		4		<2.2	14	<0.04	<0.017	<0.05	<0.07	<0.0054	<0.32	<0.09	<0.0038	<0.04
Milk	max					<0.05	<0.021	<0.06			<0.35	<0.10		
Beef kidney		1		<2.6	47	<0.02	<0.080	<0.11	<0.10	<0.041	<0.21	<0.06	<0.052	<0.03
Beef liver		1		<4.9	14	<0.06	<0.029	<0.14	<0.15	<0.051	<0.47	<0.12	<0.024	<0.07
Beef muscle		1		<3.0	47	<0.07	<0.050	<0.28	<0.16	<0.039	<0.54	<0.13	<0.018	<0.09
Blackberries		1	<2.0	<2.0	17	<0.02	0.090	<0.03	<0.05		<0.21	<0.06	<0.029	<0.02
Sheep muscle		2		<5.6	59	<0.06	<0.054	<0.17	<0.18	<0.041	<0.50	<0.13	<0.023	<0.04
Sheep muscle	max			<8.5	62		0.057	<0.24	<0.24	<0.043	<0.51		<0.028	<0.05
Sheep offal		2		<8.5	49	<0.02	<0.045	<0.06	<0.05	<0.046	<0.22	<0.06	<0.022	<0.03
Sheep offal	max			13	66		<0.049	<0.09		<0.048			<0.024	

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		4	<0.06		<0.30				<0.000052	<0.000047	<0.19	0.000021
Milk	max		0.10		<0.44							
Beef kidney		1	0.15	0.15	<0.18	0.0045	<0.00040	0.0033	<0.00013	0.00018	<0.73	0.0022
Beef liver		1	0.09	0.088	<0.32				0.00052	0.0031	<0.20	0.0047
Beef muscle		1	0.18	0.18	<0.64				0.000033	0.000023	<0.18	0.000074
Blackberries		1	<0.04	<0.042	<0.18				<0.00010	0.00024	<0.58	0.00027
Sheep muscle		2	1.5	1.5	<0.53				<0.000031	0.000094	<0.19	0.00018
Sheep muscle	max		1.7	1.7	<0.74				<0.000048	0.00013		0.00023
Sheep offal		2	0.53	0.53	<0.19				0.000055	0.00042	<0.29	0.00050
Sheep offal	max		0.56	0.56					0.000064	0.00048	<0.38	0.00052

Table 2.13 Concentrations of radionuclides in surface waters from West Cumbria, 2021

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	72	<0.36	<0.033	<0.14	<0.35	<0.29	<0.00060	0.0039	<2.4	7.3
River Ehen (100m downstream of sewer outfall)	4	5.1	<0.32	<0.085		<0.29	<0.24	<0.00026	<0.00054	<0.23	1.4
River Calder (downstream)	4	<3.7	<0.32	<0.093	<0.056	<0.33	<0.27	<0.00032	<0.0015	<0.017	0.27
River Calder (upstream)	4	<3.5	<0.27	<0.015	<0.042	<0.28	<0.23	<0.00033	<0.0012	<0.020	0.055
River Ehen (upstream of site and tidal confluence)	4	<3.6	<0.33	<0.013		<0.32	<0.26	<0.00032	<0.00023	<0.017	0.070
Wast Water	1	<3.9	<0.20				<0.18			<0.021	0.024
Ennerdale Water	1	<4.0	<0.11			<0.13	<0.10			<0.014	0.027
Sellafield Tarn	1	4.3		<0.015	<0.047		<0.26	<0.0022	<0.0078		
Devoke Water	1	<4.2	<0.08			<0.09	<0.07			<0.015	0.041
Thirlmere	1	<4.0	<0.32				<0.28			<0.019	0.019

Table 2.14 Concentrations of radionuclides in road drain sediments from Whitehaven and Seascale, 2021

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	<1.6	<0.55	<1.5	100	3.1	22	29
Seascale SS 233	1	<1.4	<0.76	<1.4	150	2.8	20	24
Seascale SS 209	1	<0.55	<0.74	<0.51	7.2	0.80	4.6	5.7
Seascale SS 232	1	<0.50	<0.71	<0.50	16	1.7	12	12
Seascale SS 231	1	<1.1	<0.61	<1.1	20	5.0	30	39
Whitehaven SS 201	1	<2.9	<0.52	<3.2	18	<0.16	1.0	<2.2

Table 2.15 Doses from artificial radionuclides in the Irish Sea, 2008-2021

Group	Exposure, mSv per year						
	2008	2009	2010	2011	2012	2013	2014
Northern Ireland	0.017	0.012	0.010	0.010	0.011	0.010	0.009
Dumfries and Galloway	0.047	0.047	0.040	0.040	0.046	0.044	0.045
Whitehaven	0.009	0.011	0.010	0.010	0.013	0.010	0.012
Sellafield (5 year average consumption)	0.23	0.20	0.18	0.15	0.14	0.12	0.089
Morecambe Bay	0.042	0.041	0.046	0.034	0.034	0.036	0.032
North Wales	0.018	0.015	0.013	0.014	0.014	0.013	0.018

Group	Exposure, mSv per year						
	2015	2016	2017	2018	2019	2020	2021
Northern Ireland	0.009	0.011	0.010	0.011	0.010	0.009	0.007
Dumfries and Galloway	0.038	0.044	0.035	0.029	0.031	0.027	0.056
Whitehaven	0.017	0.016	0.017	0.018	0.014	0.013	0.012
Sellafield (5 year average consumption)	0.084	0.083	0.085	0.072	0.064	0.062	0.058
Morecambe Bay	0.031	0.024	0.026	0.015	0.024	0.015	0.019
North Wales	0.014	0.015	0.014	0.014	0.012	0.010	0.010

Table 2.16 Individual radiation exposures, Sellafield, 2021

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 crustacean consumers	**0.21**	**0.016**	**0.18**	**-**	**<0.005**	**-**	**<0.005**	**<0.005**
'Total dose' - maximum effect of gaseous release and direct radiation sources								
Adult root vegetable consumers	**0.009**	**<0.005**	**<0.005**	**<0.005**	**<0.005**	**-**	**<0.005**	**<0.005**
'Total dose' - maximum effect of liquid release source								
Adult crustacean consumers	**0.21**	**0.016**	**0.18**	**-**	**<0.005**	**-**	**<0.005**	**<0.005**
Source specific doses								
Seafood consumers								
Local seafood consumers (habits averaged 2017-21)	0.25[f]	0.039	0.19	-	0.019	-	-	-
Local seafood consumers (habits for 2021)	0.23[g]	0.017	0.19	-	0.015	-	-	-
Local mollusc consumers (habits for 2021)	0.023[l]	0.012	0.010	-	-	-	-	-
Whitehaven seafood consumers	0.012	0.012	-	-	-	-	-	-
Dumfries and Galloway seafood and wildfowl consumers	0.056	0.047	-	-	0.008	-	-	-
Morecambe Bay seafood consumers	0.019	0.005	-	-	0.014	-	-	-
Northern Ireland seafood consumers	0.007	0.007	-	-	<0.005	-	-	-
North Wales seafood consumers	0.010	0.006	-	-	<0.005	-	-	-
Other groups								
Ravenglass Estuary, marsh users	0.019	-	-	-	0.015	<0.005	-	-
Bait diggers and shellfish collectors[h]	0.061	-	-	-	0.061	-	-	-
Ribble Estuary houseboats	0.028	-	-	-	0.028	-	-	-
Barrow Houseboats[k]	0.043	-	-	-	0.043	-	-	-
Local infant consumers of locally grown food at Ravenglass	0.009[i]	-	-	0.009	-	-	-	-
Local infant consumers of locally grown food at LLWR near Drigg	0.007[i]	-	-	0.007	-	-	-	-
Infant inhabitants and consumers of locally grown food	0.010	-	-	0.010	-	-	<0.005	-
Groups with average consumption or exposure								
Average seafood consumer in Cumbria	<0.005	<0.005	-	-	-	-	-	-
Average consumer of locally grown food[j]	<0.005	-	-	<0.005	-	-	-	-
Typical visitor to Cumbria	<0.005	<0.005	<0.005	-	<0.005	-	-	-

Table 2.16 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 beaches								
Dumfries and Galloway	0.005	-	-	-	0.005	-	-	-
North Cumbria	0.008	-	-	-	0.008	-	-	-
Sellafield	0.009	-	-	-	0.009	-	-	-
Lancashire	0.006	-	-	-	0.006	-	-	-
North Wales	0.006	-	-	-	0.006	-	-	-
Recreational user of mud/saltmarsh areas								
Dumfries and Galloway	<0.005	-	-	-	<0.005	-	-	-
North Cumbria	<0.005	-	-	-	<0.005	-	-	-
Sellafield	0.008	-	-	-	0.008	-	-	-
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 occuring 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 0.019 mSv

f The dose due to nuclear industry discharges was 0.058 mSv

g The dose due to nuclear industry discharges was 0.032 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

k Exposures at Barrow are largely due to discharges from the Sellafield site

l The dose due to nuclear industry discharges was 0.012 mSv

3. Nuclear power stations

Highlights

- ‘total doses’ for the representative person were equal or less than 3% of the dose limit for all sites assessed

Operating sites

Hartlepool, County Durham

- ‘total dose’ for the representative person was 0.012mSv and decreased in 2021
- liquid discharges of tritium and sulphur-35 decreased in 2021

Heysham, Lancashire

- ‘total dose’ for the representative person was 0.015mSv and increased in 2021
- gaseous discharges of carbon-14 from Heysham 1, and carbon-14 and argon-41 from Heysham 2 decreased in 2021
- liquid discharges of tritium from Heysham 1, and tritium and sulphur-35 from Heysham 2 decreased in 2021

Hinkley Point, Somerset

- ‘total dose’ for the representative person was 0.030mSv and increased in 2021
- liquid discharges of tritium increased from Hinkley B in 2021

Hunterston, North Ayrshire

- ‘total dose’ for the representative person was 0.006mSv and increased in 2021
- gaseous discharges of carbon-14 and sulphur-35 from Hunterston B increased in 2021
- liquid discharges of tritium from Hunterston B increased in 2021

Sizewell, Suffolk

- ‘total dose’ for the representative person was 0.016mSv and decreased in 2021

Torness, East Lothian

- ‘total dose’ for the representative person was 0.005mSv and decreased in 2021

Decommissioning sites

Berkeley, Gloucestershire and Oldbury, South Gloucestershire

- ‘total dose’ for the representative person was 0.013mSv and increased in 2021

Bradwell, Essex

- ‘total dose’ for the representative person was less than 0.005mSv and unchanged in 2021

Chapelcross, Dumfries and Galloway

- ‘total dose’ for the representative person was 0.018mSv and unchanged in 2021
- gaseous discharges of “all other radionuclides” decreased in 2021

Dungeness, Kent

- ‘total dose’ for the representative person was 0.012mSv and unchanged in 2021

Trawsfynydd, Gwynedd

- ‘total dose’ for the representative person was 0.010mSv and decreased in 2021

Wylfa, Isle of Anglesey

- ‘total dose’ for the representative person was 0.005mSv and decreased in 2021

This section considers the results of environment and food monitoring, under the responsibility of the Environment Agency, FSA, FSS, NRW and SEPA, undertaken near nuclear power stations (both operating stations and decommissioning sites). There are a total of 19 nuclear power stations (which may contain more than 1 reactor and reactor type) at 14 locations, 9 in England (Berkeley, Oldbury, Bradwell, Calder Hall, Dungeness, Hartlepool, Heysham, Hinkley Point and Sizewell), 3 in Scotland (Chapelcross, Hunterston and Torness) and 2 in Wales (Trawsfynydd and Wylfa).

Eleven of the 19 nuclear power stations are older, first generation, 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). Its remit is to secure the decommissioning and clean-up of the UK’s civil public sector nuclear licensed sites. All Magnox stations are now in the process of decommissioning.

All of the first-generation nuclear reactors are now fuel free. In March 2022, the NDA published its annual business plan (2022 to 2025) and a new strategy. The plan summarises the programme of work at each of the sites [138].

In 2013, Magnox Limited managed 10 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 10 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 2021 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. In June 2021, EDF decided to move Dungeness B into defueling phase following an extended outage since September 2018. In June 2021, the UK government and EDF signed an agreement to transfer control of the AGR power stations to the NDA after cessation of generation and defueling of the reactors.

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 2021, gaseous and liquid discharges were below regulated limits for each of the power stations (see Appendix 2, Table A2.1 and Table A2.2). Solid waste transfers in 2021 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). Hartlepool, Heysham, Hinkley Point, Hunterston, Sizewell and Torness sites are included under operating power stations (Section 3.1). Berkeley, Bradwell, Chapelcross, Dungeness, Hinkley Point, Hunterston, Oldbury, Trawsfynydd, and Wylfa sites are included under decommissioning power stations (Section 3.2). Nuclear sites that have both operating and decommissioning power plants (Hinkley Point, Hunterston and Sizewell) are considered under operating sites because, for the purposes of environmental monitoring, as the effects from both sites contribute to the same area.

3.1 Operating sites

3.1.1 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 March 2024. The most recent habits survey was undertaken in 2014 [139].

Doses to the public

The 'total dose' from all pathways and sources of radiation was 0.012mSv in 2021 (Table 3.1), which was approximately 1% of the dose limit, and down from 0.017mSv in 2020. The decrease in 'total dose' was mainly attributed to lower gamma dose rates measured over sand in 2021, in comparison to that in 2020. The representative person was adults living near to the site and a change from 2020 (adults spending time over sand). The trend in 'total dose' over the period 2010 to 2021 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 2021 (Table 3.1). The estimated dose was 0.005mSv and up from less than 0.005mSv in 2020. The small increase in dose was mostly due to higher carbon-14 concentrations in milk in 2021. The dose to a local fish and shellfish consumer (including external radiation but excluding naturally occurring radionuclides) was 0.010mSv in 2021, and down from 0.017mSv in 2020. The reason for the decrease in dose was the same as that contributing to the maximum 'total dose'.

As in recent years, a source specific assessment was not undertaken to determine the exposure from naturally occurring radionuclides in 2021, as a consequence of reported polonium-210 concentrations in mollusc samples. Prior to 2019, winkle samples collected from South Gare (inside the Tees Estuary entrance) also 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 naturally occurring radionuclides in molluscs. As in recent years, due to limited availability, a winkle sample was not collected from Paddy's Hole in 2021. 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 2021.

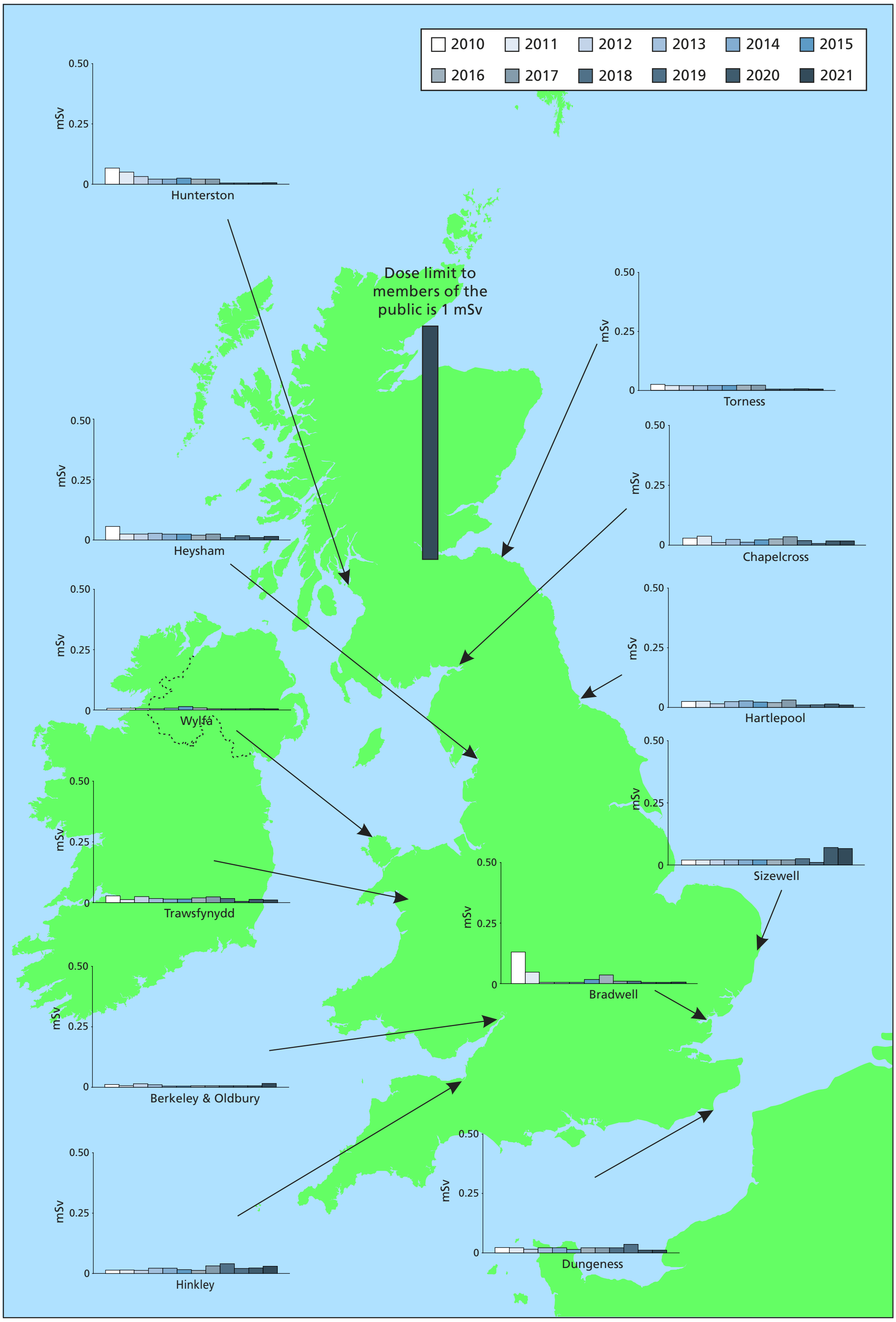


Figure 3.1 'Total dose' at nuclear power stations, 2010–2021. (Small doses less than or equal to 0.005 mSv are recorded as being 0.005 mSv)

Gaseous discharges and terrestrial monitoring

Gaseous radioactive waste is discharged via stacks to the local environment. Analyses of tritium, carbon-14, sulphur-35 and gamma-emitting radionuclides were carried out in milk and crop samples. Samples of freshwater were also taken from boreholes. Data for 2021 are given in Table 3.2(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 potato) in 2021. Carbon-14 was also detected in locally produced milk at concentrations slightly above 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 Water Supply (Water Quality) (Amendment) 2018 Regulations (retained from 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. Aqueous discharges of tritium and sulphur-35 decreased in 2021, in comparison to those in 2020, and are dominated by liquid discharges arising from the bypass gas plant, which is only in operation while the reactor is at power. The discharges of these radioisotopes are therefore dependent on, and closely correlated to, reactor power output. In the latter part of 2021, there was a double reactor outage which reduced discharges significantly and accounts for the reduction in the 2021 figures. Also of note is that sulphur-35 discharges closely follow the increase and decrease of Carbonyl Sulphide (COS) injections into the reactors, which are on a downwards trajectory. Injection of COS into both reactors is used to mitigate carbon deposition on fuel and reactor component surfaces and thereby improve nuclear safety levels and extend plant life. Results of the aquatic monitoring programme conducted in 2021 are shown in Table 3.2(a) and Table 3.2(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 2021, in comparison to those in recent years.

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, [69]). Technetium-99 concentrations in seaweed are less than 1% of the equivalent concentrations near Sellafield.

As in recent years, apart from 2020, iodine-131 was positively detected in seaweed samples collected around the mouth of the River Tees Estuary in 2021. Detectable concentrations of caesium-137 were mainly due to disposals from Sellafield and fallout from nuclear weapons testing. However, caesium-137 concentrations in sediment have remained low for several years (Figure 3.2). Overall, gamma dose rates over intertidal sediment in 2021 were lower (where comparisons can be made from similar ground types and locations), to those observed in 2020.

In 2021, the reported polonium-210 and lead-210 concentrations in winkles from South Gare are values expected due to naturally occurring sources (given in Appendix 1, Table X4.1). As in recent years, a winkle sample could not be collected from the estuary entrance near Paddy's Hole in 2021.

3.1.2 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 2 separate nuclear power stations, Heysham 1 and Heysham 2, each powered by twin 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 2024 and 2028, respectively. Disposals of radioactive waste from both stations are permitted via separate and adjacent outfalls to Morecambe Bay and via stacks. However, in RIFE, both stations are considered together for purposes of environmental monitoring, because the effects from both sites contribute to the same area.

The most recent habits survey was conducted in 2016 [140].

Doses to the public

The 'total dose' from all pathways and sources of radiation was 0.015mSv in 2021 (Table 3.1) or less than 2% of the dose limit for members of the public, and up from 0.010mSv in 2020. As in recent years, the representative person was adults spending time over sediments. The apparent increase in 'total dose' in 2021 was mostly due to higher gamma dose rates measured over different substrates (particularly at Red Nab point), in comparison to those in 2020.

The trend in 'total dose' over the period 2010 to 2021 is given in Figure 3.1. In 2010, the higher 'total dose' was attributed to higher gamma dose rates measured over beaches); thereafter (2011 to 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.

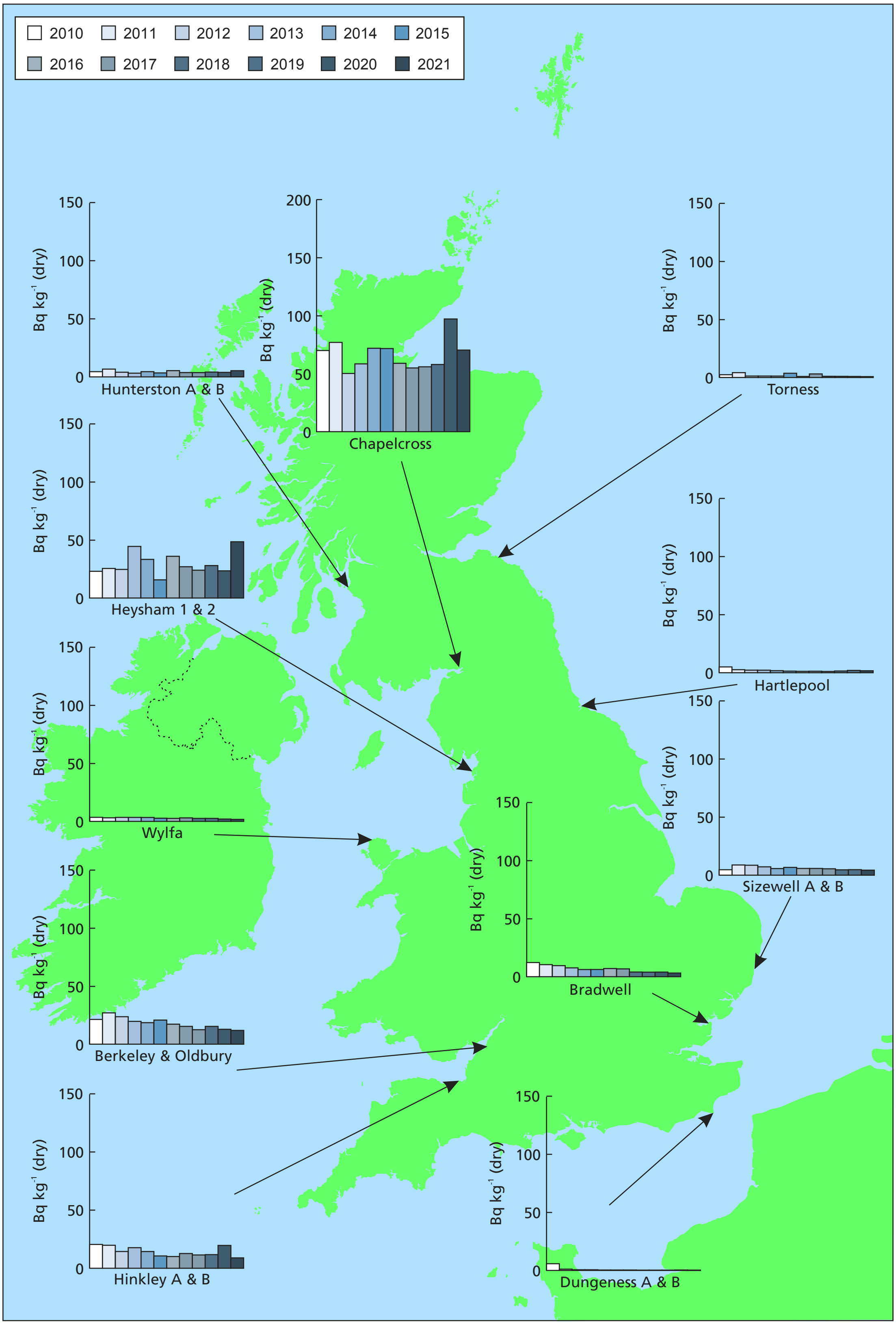


Figure 3.2 Caesium-137 concentration in marine sediments near nuclear power stations between 2010–2021

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 2021 (Table 3.1). The estimated dose for terrestrial food consumption was 0.006mSv and up from 0.005mSv in 2020. The estimated dose to the turf cutters was less than 0.005mSv in 2021 and down from 0.005mSv in 2020. The small increase in dose for the terrestrial food consumption was mostly attributed to a higher maximum concentration of carbon-14 in milk measured in 2021. The reason for the small decrease in dose from turf cutting in 2021 was because lower gamma dose rates were measured over saltmarsh, in comparison to those in 2020. 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 0.019mSv in 2021, which was less than 2% of the dose limit for members of the public of 1mSv (Table 3.1). The dose in 2020 was 0.015mSv. The reason for the increase in dose was the same as that contributing to the maximum 'total dose'.

Gaseous discharges and terrestrial monitoring

Both stations discharge gaseous radioactive waste via stacks to the atmosphere. Gaseous discharges of carbon-14 from Heysham 1, and discharges of carbon-14 and argon-41 from Heysham 2 decreased in 2021, in comparison to those in 2020. The monitoring programme for determining the effects of gaseous disposals was similar to that for other power stations. Data for 2021 are given in Table 3.3(a). The effects of gaseous disposals from the site were not easily detectable in foodstuffs in 2021. As in 2020, the carbon-14 concentrations in milk were above the default value used to represent background in 2021. Tritium, gross alpha and gross beta concentrations in freshwater were below the investigation levels for drinking water in the Water Supply (Water Quality) (Amendment) 2018 Regulations (retained from the European Directive 2013/51).

Liquid waste discharges and aquatic monitoring

Regulated discharges of radioactive liquid effluent are made via outfalls into Morecambe Bay. Liquid discharges of tritium and sulphur-35 decreased from Heysham 2 in 2021, in comparison to releases in 2020. When COS injection commenced at Heysham 2 in 2016 it was predicted that there would be an increase in sulphur-35 levels. This was discussed with the Environment Agency at the time and a BAT case was produced. There has been an increasing trend in sulphur-35 discharges since COS injection commenced, but the rate of increase has been lower than was originally predicted. The rate of change increased following the Unit 8 statutory outage in 2020 but did not reach the levels predicted. Levels have recently decreased following Unit 8 off-load depressurised refuelling; further work is on-going to understand the change.

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 2021 are given in Table 3.3(a) and Table 3.3(b). In general, activity concentrations in 2021 were similar (in comparison to those in 2020) and the effect of liquid disposals from Heysham was difficult to detect above the Sellafield background. Unlike in recent years, tritium was not positively detected in mussels. Plutonium radionuclides and americium-241 concentrations in mussels were slightly lower in 2021, in comparison to those in 2020. Concentrations of technetium-99 in marine samples originating from Sellafield discharges were similar to those in recent years. As in 2020, strontium-90 was detected at low concentrations (reported as just above, or close to, the less than value) in food samples collected in 2021. Overall, gamma dose rates were higher in 2021 (in comparison to 2020) including those measured at Half Moon Bay (sand) and Red Nab point (sand and stones).

3.1.3 Hinkley Point, Somerset

The Hinkley Point Power Station sites are situated on the Somerset coast, west of the River Parrett estuary. There are 2 separate stations, A and B, that include twin Magnox reactors and twin 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. In November 2020, EDF Energy announced that Hinkley Point B will end generation in July 2022. In RIFE, a single environmental monitoring programme covers the effects of the 2 power stations, because the effects from both sites contribute to the same area. The most recent habits survey was conducted in 2017 [141].

The construction of the two new generation EPR™ reactors continues at Hinkley Point C. In November 2021, ONR provided NNB GenCo (HPC) with consent to commence bulk mechanical, electrical, and heating, ventilation and air conditioning (HVAC) installation in the unit 1 nuclear island. Summary details of earlier environmental permits issued (by the Environment Agency), the pre-construction safety case (published by the ONR), the planning consents granted and other approvals, are available in earlier RIFE reports (for example [69]). Hinkley Point C is now expected to begin electricity generation in June 2027. Latest information can be found at: https://www.gov.uk/government/collections/hinkley-point.

Doses to the public

In 2021, the 'total dose' from all pathways and sources of radiation was 0.030mSv (Table 3.1), or 3% of the dose limit, and up from 0.023mSv in 2020. The representative person was adults spending time over sediments, a change from 2020 (prenatal children of adults spending time over sediments). The increase in 'total dose' was mostly because higher gamma dose rates were measured on mud substrates at Stolford, from one year to the next.

The trend in 'total dose' over the period 2010 to 2021 is given in Figure 3.1. The large 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 2021 (Table 3.1). The dose to this consumer of locally grown food was 0.005mSv in 2021 and unchanged from 2020. The dose to the local fisherman was 0.018mSv in 2021, or less than 2% of the dose limit for members of the public of 1mSv. The reason for the increase in dose from 0.014mSv (in 2020) was the same as that contributing to the maximum 'total dose'. This dose estimate also includes the effects of discharges (historical) of tritium from the former GE Healthcare Limited plant at Cardiff and uses an increased dose coefficient (see Appendix 1, Annex 3.4). The estimated dose for a houseboat occupant was 0.022mSv in 2021 and up from 0.020mSv in 2020. The main reason for the small increase was mostly due to a higher gamma dose rate measured over mud and sand at Blue Anchor Bay in comparison to 2020. 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.

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 2021 are given in Table 3.4(a). Activity concentrations of tritium and gamma-emitting radionuclides (including caesium-137) in all terrestrial materials are reported as less than values. Unlike in 2020, sulphur-35 was positively detected in food samples (blackberries and honey) in 2021. As in 2020, the carbon-14 concentrations in locally produced milk were higher than typical values from natural background. Carbon-14 was detected in blackberries (as in previous years) above the expected background value in 2021. Tritium, gross alpha and gross beta concentrations in reservoir water were below the investigation levels for drinking water in the Water Supply (Water Quality) (Amendment) 2018 Regulations (retained from the European Directive 2013/51).

Liquid waste discharges and aquatic monitoring

Regulated discharges of radioactive liquid effluent from both power stations are made via separate outfalls into the Bristol Channel. Discharges of tritium increased from Hinkley B in 2021, in comparison to 2020. The tritium produced by the reactors is proportional to reactor power. During 2020 the reactors were shut down for outage for longer resulting is less tritium being discharged than in 2021. The gaseous tritium reacts with oxygen in the reactor to form tritiated water, the majority of which is removed by the desiccant dryers and discharged to sea via the aqueous route, due to the lower dose to the public per discharge. Analyses of seafood and marine indicator materials and measurements of external radiation were conducted over intertidal areas. The environmental results for 2021 are given in Table 3.4(a) and Table 3.4(b). Overall, activity concentrations observed in seafood and other materials from the Bristol Channel were generally similar to those in recent years. As in 2020, tritium was not positively detected in shrimps in 2021. 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 2021 were generally higher (where comparisons can be made for similar ground types and locations), in comparison to those observed in 2020.

3.1.4 Hunterston, North Ayrshire

Hunterston Power Station is located on the Ayrshire coast near West Kilbride and consists of 2 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 2 major 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.

Most 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 several 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 and is currently undergoing modifications in order to process radioactively contaminated acid wastes. Processing of the legacy higher activity waste, present at the Hunterston A site has begun and will be processed through either SILWE or WILWREP, with the current plans being to make 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, referenced as Reactors 3 and 4. The life of the station has been extended twice, and the current end of generation is set for early January 2022. Reactor 3 had its final run in 2021 and permanently shut down in November 2021. Reactor 4 was operational for most of 2021 except for approximately four months when it was awaiting permission from ONR to restart for its final run.

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 [142].

Doses to the public

The 'total dose' from all pathways and sources of radiation was 0.006mSv in 2021 (Table 3.1), which was less than 1% of the dose limit, and slightly up from 0.005mSv in 2020. The small increase in dose was mostly due to the concentration of plutonium-239+240 measured in molluscs. The representative person was adults consuming molluscs and a change from that in 2020 (prenatal children of occupants over sediments). The trend in 'total dose' over the period 2010 to 2021 is given in Figure 3.1.

Source specific assessments for a high-rate consumer of locally grown food, and of local seafood, give exposures that were higher than the 'total dose' in 2021 (Table 3.1). The estimated dose for seafood consumption was 0.011mSv in 2021, and up from that in 2019 (0.010mSv). The reason for the small increase in dose is the same as that contributing to the maximum 'total dose'.

The estimated dose to a terrestrial food consumer was 0.008mSv in 2021, which was less than 1% of the dose limit for members of the public of 1mSv. The reason for the decrease in dose from 0.013mSv (in 2020) was mostly due to a decrease of the concentrations of carbon-14 measured in milk in 2021.

Gaseous discharges and terrestrial monitoring

Gaseous discharges are made via separate discharge points from the Hunterston A and Hunterston B stations. Since both reactors were at power for much of the year, discharges of carbon-14 and sulphur-35 from Hunterston B increased in 2021, in comparison to those in 2020. 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 2021 are given in Table 3.5(a) and Table 3.5(c). The concentrations of radionuclides in air, milk, crops and fruit were generally low and similar to those in previous years (where comparisons can be made). Sulphur-35 was positively detected in grass at 5 different locations and in soil at 2 of those locations. As in 2020, europium-155 was positively detected in soil and also in grass in 2021. Tritium, gross alpha and gross beta concentrations in freshwater were below the investigation levels for drinking water in the Water Supply (Water Quality) (Amendment) 2018 Regulations (retained from the European Directive 2013/51).

All activity concentrations in air at locations near to the site (Table 3.5(c)) were reported as less than values. Due to COVID-19 restrictions, the number of observations at Fairlie and West Kilbride remained similar to 2020. Sample collections from Low Ballees restarted in 2021 after stopping in 2020. Solid waste transfers in 2021 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. Since both reactors were at power for much of the year, discharges of carbon-14 and sulphur-35 from Hunterston B increased in 2021, in comparison to those in 2020.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 2021 are shown in Table 3.5(a) and Table 3.5(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 2021 but and were generally similar to those reported in recent years. Unlike in recent years, all cobalt-60 concentrations in sediments were reported as less than value in 2021. As in 2020, the plutonium-239+240 concentration in the scallop sample was significantly higher than those observed in previous years, but of low radiological significance. Gamma dose rates were generally similar in 2021, in comparison to those in 2020. Measurements of the beta dose rates over sand are reported as less than values in 2021. Caesium-137 concentrations in sediment have remained low over the last decade (Figure 3.2).

3.1.5 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 Sizewell B power station began operation in 1995 and whilst the end of power generation is currently scheduled for 2035, the site operator is investigating extending operations to 2055 and potentially longer. The most recent habits survey was conducted in 2015 [143]. With effect from September 2021, the permit for Sizewell B was varied to increase the annual permitted limit of carbon-14 to the atmosphere. The variation returned the limit from 500GBq to the original authorisation limit of 600GBq, due to changing plant behaviour. Further information on the variation, public consultation and our decision can be found at https://consult.environment-agency.gov.uk/nuclear/consultation-on-the-variation-of-permit-xb3538dh-t/ and in Appendix 2 (Table A2.1).

In 2020, NNB GenCo (SZC) applied to the ONR for a nuclear site license for Sizewell C, the Environment Agency for a radioactive substances activities permit and the Planning Inspectorate for a Development Consent Order (DCO) for Sizewell C where EDF Energy have proposed construction of 2 EPR™ reactors. Examination of the DCO application concluded in October 2021. In July 2022, the Secretary of State for the Department of Business, Energy and Industrial Strategy announced that the Sizewell C project had been granted its DCO. The latest information can be found at: https://www.gov.uk/guidance/sizewell-nuclear-regulation.

Doses to the public

The ‘total dose’ from all pathways and sources of radiation was 0.016mSv in 2021 (Table 3.1) or less than 2% of the dose limit, and down from 0.017mSv in 2020. 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 2020) was mostly attributed to a slightly lower estimate of direct radiation in 2021 (Table 1.1). The trend in ‘total dose’ over the period 2010 to 2021 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 5 or 6), following the closure of the Magnox reactors at Sizewell A in 2006 (Figure 4.1, [47]).

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, gave exposures that were less than the 'total dose' in 2021 (Table 3.1). A source specific assessment for a high-rate consumer of fish and shellfish and of external exposure for houseboat occupancy gave an exposure that was less than 0.005mSv in 2021, and similar to that in 2020 (Table 3.1). The estimated dose to a high-rate consumer of locally grown foodstuffs was less than 0.005mSv in 2021, and down from 0.005mSv in 2020. The increase was mainly due to a small decrease of carbon-14 in milk in 2021, in comparison to 2020.

Gaseous discharges and terrestrial monitoring

Gaseous wastes are discharged via separate stacks to the local environment. The results of the terrestrial monitoring in 2021 are shown in Table 3.6(a). Gamma-ray spectrometry and radiochemical analysis of tritium and sulphur-35 in milk and crops generally showed very low concentrations of artificial radionuclides near the power stations in 2021. In 2021, carbon-14 concentrations in locally produced milk were just above the default value used to represent background level. As in recent years, sulphur-35 was positively detected at a very low concentration in barley. Tritium concentrations in local freshwater were reported as less than values in 2021. Tritium, gross alpha and gross beta concentrations in surface water were below the investigation levels for drinking water in the Water Supply (Water Quality) (Amendment) 2018 Regulations (retained from 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. The project to drain the fuel storage pond at Sizewell A was completed in 2019. This has resulted in a significant reduction in liquid effluent generation at Sizewell A. Small volumes of effluent were discharged by the foul sewer route via the sewage treatment works that is shared with Sizewell B. This route is monitored at quarterly intervals for tritium and caesium-137 for reassurance purposes. In the aquatic programme, analysis of seafood, sediment, and seawater, and measurements of gamma dose rates were conducted in intertidal areas. Data for 2021 are given in Table 3.6(a) and Table 3.6(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. Unlike in recent years, tritium was positively detected in a sample of fish (herring), but concentrations of strontium-90 observed in sediment samples were all reported as less than values. Caesium-137 concentrations in sediment have remained low over the last decade and are generally decreasing over 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 2020.

3.1.6 Torness, East Lothian

Torness Power Station is located near Dunbar on the east coast of Scotland. The station is powered by twin AGRs and began operation at the end of 1987. In 2021 EDF announced that the expected end of generation date for Torness to be 2028. Previously the stated date had been 2030 plus or minus 2 years. EDF keep operational dates under constant review which has allowed them to provide the additional clarity on lifetime expectations.

SEPA has continued the determination of the application submitted by EDF to cover the receipt and management of debris found in fuel transport flask. The process is expected to be completed during 2022.

Discharges because of COS injected to reduce carbon build up on fuel continued to be stable during the year. There has been a change to the process used to refuel the reactors such that the reactors are taken offload and depressurised. This has had an impact on the profile of discharges notably carbon 14, sulphur 35 and tritium. There is has been no significant impact to the magnitude of the annual discharges.

The gaseous and liquid discharges from the site are given in Appendix 2.

The most recent habits survey, to determine the consumption and occupancy rates by members of the public, was undertaken in 2016 [144].

Doses to the public

In 2021, the ‘total dose’ from all pathways and sources of radiation was 0.005mSv (Table 3.1), or 0.5% of the dose limit, and decreased from 0.006mSv in 2020. As in 2020, the representative person was prenatal children of local inhabitants consuming wild fruits and nuts. The trend in ‘total dose’ over the period 2010 to 2021 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 terrestrial food gave an exposure that was higher than the total dose at 0.008mSv in 2021 (Table 3.1) and up from 2020 (0.006mSv). The increase in dose was mostly due to a higher less than value for strontium-90 measured in milk used in the dose assessment. The estimated dose to a high consumer of local fish and shellfish was less than 0.005mSv in 2021, or less than

0.5% of the dose limit for members of the public of 1mSv, and unchanged from that in 2020.

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 3 locations was undertaken to investigate the inhalation pathway. The results of terrestrial food and air monitoring in 2021 are given in Table 3.7(a) and Table 3.7(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. Caesium-137 was positively detected in goose, green beans, lamb and soil but at low concentrations. Americium-241 concentrations in all terrestrial food and soil samples (measured by gamma–ray spectrometry) were reported as less than values in 2021. The tritium, gross alpha and gross beta concentrations in freshwater were well below the investigation levels for drinking water in the Water Supply (Water Quality) (Amendment) 2018 Regulations (retained from the European Directive 2013/51). Measured concentrations of radioactivity in air, at locations near to the site, were all reported as less than values in 2021 (Table 3.7(c)). Solid waste transfers in 2021 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 (and to a lesser extent, tritium) decreased in 2021, in comparison to those releases in 2020 (due to general operational variability between years). Seafood, seaweed, sediment, and seawater samples were collected in 2021. Measurements were also made of gamma dose rates over intertidal areas, supported by analyses of sediment, and a beta dose rate on fishing gear.

The results of the aquatic monitoring in 2021 are shown in Table 3.7(a) and Table 3.7(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 was detected in environmental indicator samples at low concentrations. This activation product was likely to have originated from the station. Technetium-99 concentrations in marine samples were similar to those in 2020. 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. A measurement of the contact beta dose rate on fishermen’s pots was reported as less than values in 2021.

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 twin 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. With effect from 1 May 2021, there was a variation in the site permit. The permit variation increased the annual permitted limit of tritium to the atmosphere (from 20GBq to 1TBq) to progress with some decommissioning operations. Further details can be found in Appendix 2 (Table A2.1).

Oldbury Power Station is located on the south bank of the River Severn close to the village of Oldbury-on-Severn and has 2 Magnox reactors. Electricity generation started in 1967 and ceased in 2012. De-fuelling was completed in 2016 and the site is now prioritising the retrieval, treatment and storage 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 [145].

Doses to the public

In 2021, the 'total dose' from all pathways and sources of radiation was 0.013mSv (Table 3.1), or approximately 1% of the dose limit, and up from less than 0.005mSv in 2020. The representative person was infants living near to the site and a change from that in 2020 (adults spending time over sediments). The increase in 'total dose' was mostly attributed to direct radiation from the Berkeley site in 2021. The trend in the 'total dose' over the period 2010 to 2021 is given in Figure 3.1. Any longer-term variations in 'total doses' over time are attributable to changes in the contribution from direct radiation.

As in 2020, 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, gave exposures that were also less than 0.005mSv in 2021 (Table 3.1). The dose to a consumer of fish and shellfish includes external gamma radiation and a component due to the tritium historically discharged from the former GE Healthcare Limited plant at Cardiff. This latter component is a result of the higher dose coefficient for OBT (see Appendix 1). The estimated dose for houseboat dwellers was 0.025mSv in 2021, and an increase from 2020 (0.011mSv). The reason for the increase in estimated dose for houseboat dwellers (from 0.011mSv in 2020) was because the gamma dose rate over mud recorded at Sharpness was higher in 2021, in comparison to those in 2020. 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 categories of ground type and houseboat location (as identified in the habits survey [145]).

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 2021 are given in Table 3.8(a). Unlike in 2020, sulphur-35 was detected positively in terrestrial food samples (apples) in 2021. Carbon-14 concentrations in milk were higher than those reported in 2020 and slightly above 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 Water Supply (Water Quality) (Amendment) 2018 Regulations (retained from 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 the ONR as fuel free in 2016. There are therefore no further sources of caesium-137 on site, and discharges will continue to decrease for this radionuclide.

Analyses of seafood and marine indicator materials as well as measurements of external radiation were conducted over muddy intertidal areas. Data for 2021 are given in Table 3.8(a) and Table 3.8(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 between 2010 to 2021 (Figure 3.2). As in recent years, the tritium concentrations in fish and seawater were reported as less than values in 2021. In earlier decades, concentrations of tritium in seafood have been relatively high and were likely to be mainly due to historical discharges from the former 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 observed in recent years (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. At the end of 2018, Bradwell became the UK's first Magnox site to reach the interim end-stage of passive Care and Maintenance, following an accelerated decommissioning programme. In 2017, Magnox Limited applied to the Environment Agency to vary its environmental permit. The revised permit, effective from the 1st of 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. In January 2021, the Environment Agency commenced a public consultation on the GDA of the HPR-1000 reactor design proposed for Bradwell B. In February 2022, the Environment Agency confirmed this design was suitable for use in the United Kingdom.

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 to 2017) are described in earlier RIFE reports (for example [47]).

The most recent habits survey was undertaken in 2015 [146].

Doses to the public

The 'total dose' from all pathways and sources of radiation was 0.006mSv in 2021 (Table 3.1), or less than 1% of the dose limit for members of the public of 1mSv, and up from less than 0.005mSv 2020. The representative person was prenatal children of adults living near to the site and a change from 2020 (adults living in a houseboat). The increase in 'total dose' was mostly attributed to direct radiation from the site in 2021.The trend in 'total dose' over the period 2010 to 2021 is given in Figure 3.1. Any significant variations in 'total dose' over time were attributed to changes in the estimate of direct radiation.

As in 2020, the source specific assessment for a high-rate consumer of fish and shellfish gave an exposure that was less than 0.005mSv in 2021. The dose to a high-rate consumer of local grown foods was 0.006mSv in 2021 and up from less than 0.005mSv in 2020. The small increase in dose was mostly due to higher carbon-14 concentrations measured in milk samples collected in 2021.

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 freshwater are also taken from a coastal ditch. Data for 2021 are given in Table 3.9(a). Activity concentrations were low in terrestrial samples. Carbon-14 was detected in locally produced milk at concentrations higher than the expected background concentration. Unlike in 2020, tritium was positively detected in the grass sample (lucerne), but not in any freshwater samples collected in 2021. Unlike in recent years, strontium-90 was not positively detected in the coastal ditch freshwater sample collected near the turbine hall. The gross beta activities (and gross alpha in 2021) in water from the coastal ditch were lower than those reported in recent years but continued to be enhanced above background concentrations, and in excess of the investigation levels for drinking water in the Water Supply (Water Quality) (Amendment) 2018 Regulations (retained from the European Directive 2013/51). 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 2021. 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 2021 are given in Table 3.9(a) and Table 3.9(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 has been an overall decline in caesium-137 concentrations in sediments over the last decade (Figure 3.2). The caesium-137 concentrations observed in sediment samples collected in 2021 were similar to those reported in 2020 and were amongst the lowest reported values in recent years. Gamma dose rates on beaches were difficult to distinguish from natural background and were generally similar to those in recent years.

3.2.3 Chapelcross, Dumfries and Galloway

Chapelcross was Scotland's first commercial nuclear power station. It has 4 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 [147]. In 2017, a separate habits survey was also conducted to determine the consumption and occupancy rates by members of the public on the Dumfries and Galloway coast [115]. 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). Due to restrictions resulting from the Covid pandemic the 2020 habit survey associated with the Chapelcross site was postponed and is currently planned for 2022.

Doses to the public

The 'total dose' from all pathways and sources of radiation was 0.018mSv in 2021 (Table 3.1), which was less than 2% of the dose limit, and unchanged from 2020. As in recent years, the representative person was infants consuming locally produced milk at high rates. The trend in 'total dose' over the period 2010 to 2021 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, gave exposures that were less than the 'total dose' in 2021 (Table 3.1). The dose for the terrestrial food consumer was estimated to be 0.015mSv in 2021, up from 0.013mSv in 2020. The small increase in dose was mostly due to higher reported less than values for americium-241 in potatoes in 2021. The dose for the seafood and wildfowl consumer was 0.006mSv in 2021, slightly decreased from 0.007mSv in 2020 due to lower gamma dose rates measured over saltmarsh (near the main pipeline and at Dornoch Brow Merse). The dose for the high-rate consumer of crustacean was less than 0.005mSv, unchanged from 2020.

Doses from the presence 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.

Gaseous discharges and terrestrial monitoring

Gaseous radioactive waste is discharged via stacks to the local environment. Discharges of "all other radionuclides" decreased in 2021, in comparison to releases in 2020. 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 2 locations were also monitored to investigate the inhalation pathway. The results of terrestrial food and air monitoring in 2021 are given in Table 3.10(a) and Table 3.10(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, and grass samples were all reported as less than values.

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 freshwater samples were well below the investigation levels for drinking water in the Water Supply (Water Quality) (Amendment) 2018 Regulations (retained from the European Directive 2013/51). Activity concentrations in air samples at locations near to the site (Table 3.10(c)) are reported as less than values (or close to the less than value). Solid waste transfers in 2021 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 2021 (most reported as <1% of the annual limit). Samples of seawater and seaweed ('Fucus vesiculosus'), as environmental indicators, were collected in addition to shrimps, fish, sediments and measurement of gamma dose rates. Data for 2021 are given in Table 3.10(a) and Table 3.10(b). Concentrations of artificial radionuclides in marine materials in the Chapelcross vicinity are mostly due to the effects of Sellafield discharges and are consistent with values expected at this distance from Sellafield. Concentrations of most radionuclides remained similar to those detected in recent years. Low concentrations of cobalt-60 and europium-155 were positively detected (reported as just above the less than value) in sediment samples.

As in previous years, concentrations of caesium-137, plutonium radionuclides and americium-241 were enhanced in sediment samples taken close to the pipeline in 2021. The average concentration of caesium-137 in sediments analysed in 2021 was slightly lower than in 2020, which was the highest since 2010 (97Bq kg^{-1}) and is known to be largely due to Sellafield discharges (Figure 3.2). In 2021, gamma dose rates over intertidal sediment were lower, in comparison to those in 2020 (where comparisons can be made). As in 2020, measurements of the contact beta dose rate on fishing nets and sediment are reported as less than values in 2021.

Between 1992 and 2009, several 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 2021 (as for the interim years). The relining of the pipeline and grouting at strategic points, which was undertaken between 2009 and 2010, has reduced the potential for particles to be released.

3.2.4 Dungeness, Kent

The Dungeness power stations are located on the south Kent coast between Folkestone and Rye. There are 2 separate A and B nuclear power stations on neighbouring sites: station A was powered by twin Magnox reactors and station B has twin 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. In June 2021, EDF Energy Nuclear Generation Limited decided to move Dungeness B nuclear power station into the defueling phase with immediate effect, following over two years of outage to deal with a range of technical issues. The most recent habits survey was conducted in 2019 [148].

Doses to the public

In 2021, the 'total dose' from all pathways and sources of radiation was 0.012mSv (Table 3.1), which was approximately 1% of the dose limit of 1mSv, and was unchanged from 2020. As in recent years, this was almost entirely due to direct radiation from the site. The representative person was adults living near the site. The trend in 'total dose' over the period 2010 to 2021 is given in Figure 3.1. 'Total doses' ranged between 0.012 and 0.037mSv 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 0.63mSv, following the shutdown of the Magnox reactors in 2006 (Figure 4.1, [47]).

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 2021 (Table 3.1). The dose to a high-rate consumer of locally grown foods was estimated to be less than 0.005mSv and unchanged from 2020. The dose to a local seafood consumer was estimated to be

0.008mSv in 2021, generally similar to the dose in 2020 (0.007mSv). As in recent years, the estimation of dose for a houseboat occupant (from external exposure) was not required in 2021 (consistent with information identified in the habits survey).

Gaseous discharges and terrestrial monitoring

Gaseous wastes are discharged via separate stacks to the local environment. 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 2021 are given in Table 3.11(a). Activity concentrations in many terrestrial foods are reported as less than values (or close to the less than value). As in recent years, sulphur-35 was not positively detected in local terrestrial food samples in 2021. In 2021, tritium concentrations in all terrestrial food were reported as less than values. Tritium, gross alpha and gross beta concentrations in freshwater were below the investigation levels for drinking water in the Water Supply (Water Quality) (Amendment) 2018 Regulations (retained from 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. Dungeness B has been in double reactor outage since the second half of 2018 until it entered the defueling phase in June 2021. The draining of fuel ponds at Dungeness A was completed in 2019 and this removed the main source of aqueous waste discharges on site. Marine monitoring included gamma dose rate measurements, and analysis of seafood and sediments. The results of monitoring for 2021 are given in Table 3.11(a) and Table 3.11(b). The caesium-137 concentrations in seafood are attributable to discharges from the stations, 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 molluscs (scallop sample collected in 2021) were typical of values expected at sites remote from Sellafield. All tritium results in seafood were reported as less than values in 2021. 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 (<5.8Bq kg^{-1}). Gamma dose rates were generally difficult to distinguish from the natural background.

3.2.5 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. As part of NDA's site-specific approach to decommissioning, Trawsfynydd was selected as the lead location, where the reactors will be dismantled without achieving an interim site state [71]. The most recent habits survey was undertaken in 2018 [149].

Doses to the public

The 'total dose' from all pathways and sources of radiation was 0.010mSv in 2021 (Table 3.1), which was 1% of the dose limit, and down from 0.012mSv in 2020. The representative person in 2021 was adults exposed to external radiation over lake sediments and unchanged from 2020. The decrease in 'total dose' was mostly attributed to direct radiation from the site in 2021. The trend in 'total dose' over the period 2010 to 2021 is given in Figure 3.1.

The dose to an angler (who consumes large quantities of fish and spends long periods of time in the location being assessed) was 0.008mSv in 2021 (Table 3.1), which was less than 1% of the dose limit for members of the public of 1mSv and unchanged from 2020. 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 0.040mSv, or 4% of the dose limit. The dose in 2020 was slightly lower (0.039mSv).

Gaseous discharges and terrestrial monitoring

The results of the terrestrial programme, for local food (including milk) and grass samples in 2021, are shown in Table 3.12(a). Results from surveys, providing activity concentrations in sheep samples, are available in earlier RIFE reports (for example [64]). Concentrations of activity in all terrestrial samples were low. Tritium concentrations in all milk samples were reported as less than values. Carbon-14 concentrations in milk were generally similar in 2021 (in comparison to those in recent years) and just above those values used to represent background concentrations. Measured activities for caesium-137 were reported as less than values (or close to the less than value) in 2021. 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 2021, 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 2021.

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 were also analysed in 2021. 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 2021 are given in Table 3.12(a) and Table 3.12(b). The majority of activity concentrations in fish and sediments result from historical discharges. As in recent years, only rainbow trout samples were collected in 2021. 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 [46]. As in previous years, caesium-137 concentrations in water samples are reported as less than values in 2021. 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 higher than those in 2020 at all sampling locations except the pipeline. In 2021, the highest caesium-137 concentration was in a sediment sample collected 1.5km Southeast of the power station of (300Bq kg^{-1}) and was higher than in 2020 (230Bq kg^{-1} collected near the main discharge pipeline). Americium-241 were 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 in 2021 were generally similar to those in recent years. Strontium-90 and transuranic concentrations in fish continued to be very low in 2021 and it is the effects of caesium-137 that dominate the external radiation pathways.

In the lake itself, there remains clear evidence for the effects of liquid discharges from the power station (caesium-137, and other radionuclide, concentrations in sediments). However, gamma dose rates measured on the shoreline (where anglers fish) were difficult to distinguish from background dose rates in 2021 and were generally similar (where comparison could be made) to those in 2020. 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.

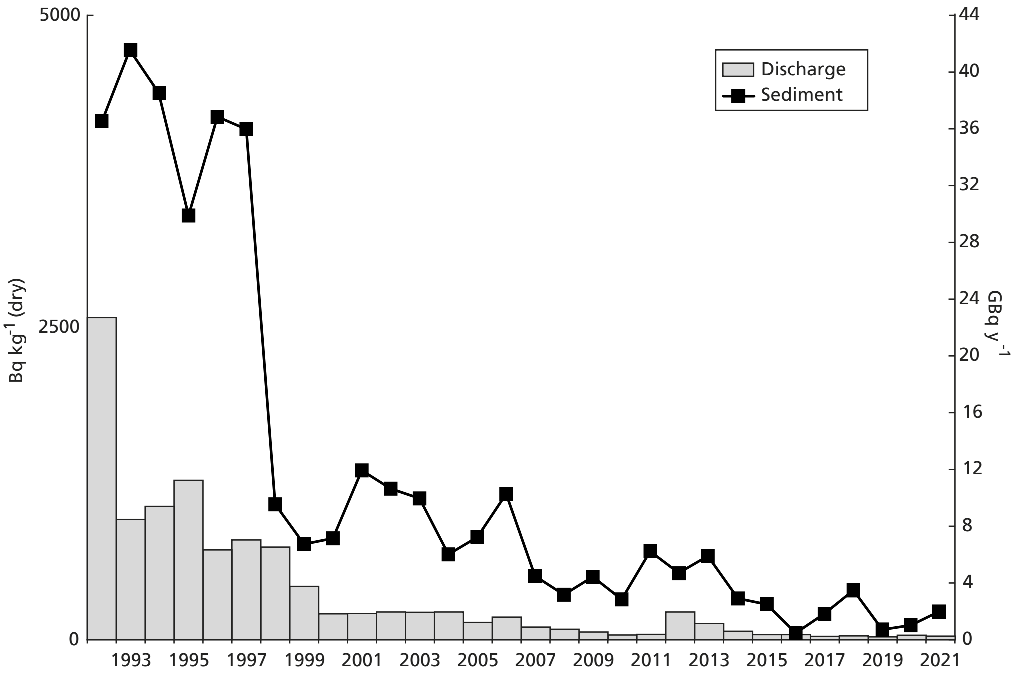


Figure 3.3 Caesium-137 liquid discharge from Trawsfynydd and concentration in sediment in Trawsfynydd lake, 1992–2021

3.2.6 Wylfa, Isle of Anglesey

Wylfa Power Station is located on the north coast of Anglesey and has 2 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-fueling operations were completed in 2019 [150]. This milestone marked the end of de-fueling 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 [151].

Doses to the public

The ‘total dose’ from all pathways and sources of radiation was 0.005mSv in 2021 (Table 3.1), which was 0.5% of the dose limit, and down from 0.006mSv in 2020. In 2021, the representative person was infants (1-year old) living near the site and a change from 2020 (adults spending time over sediments). The trend in ‘total dose’ over the period 2010 to 2021 is given in Figure 3.1. ‘Total doses’ remained broadly similar, from year to year, and were generally very low.

Source specific assessments for a high-rate consumer of locally grown foods, and for a high-rate consumer of fish and shellfish (including external radiation) gave exposure levels that were higher than the ‘total dose’ (Table 3.1). The dose to a high-rate consumer of fish and shellfish (including external radiation) was 0.007mSv in 2021. The main reason for a small decrease in dose from 0.008mSv (in 2020) was because of generally lower gamma dose rates measured over listed substrates in 2021 (at both Cemaes Bay and Cemlyn Bay West). The dose to a high-rate consumer of locally grown foods was 0.006mSv in 2021 and up from less than 0.005mSv in 2020. The main reason for the increase in dose was because of higher concentrations of carbon-14 in milk samples collected in 2021.

Gaseous discharges and terrestrial monitoring

In 2021, discharges of tritium and carbon-14 increased, however were similar to those in 2020. The focus of the terrestrial sampling was for the analyses of tritium, carbon-14 and sulphur-35 in milk and crops. Data for 2021 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 grass samples. The maximum carbon-14 concentration in locally produced milk increased in 2021, in comparison to that in 2020, to a concentration just above the expected background concentration.

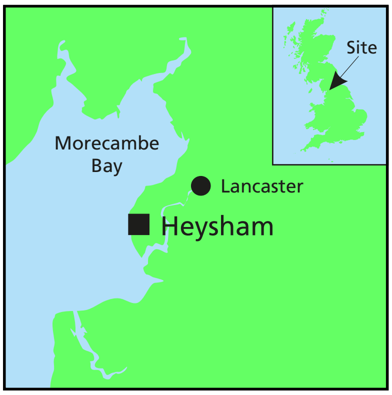
Liquid waste discharges and aquatic monitoring

The aquatic monitoring programme consists of sampling of fish and shellfish, and the measurement of gamma dose rates. Samples of sediment, seawater and seaweed are analysed as environmental indicator materials. The results of the programme in 2021 are given in Table 3.13(a) and Table 3.13(b). The data for artificial radionuclides related to the Irish Sea continue to reflect the distant effects of Sellafield discharges. The activity concentrations in 2021 were similar to those in recent years. The reported concentration of technetium-99 in seaweed in 2021 (due to the distant effects of discharges to sea from Sellafield) was the lowest observed in recent years. Caesium-137 concentrations in sediment have remained low over the last decade

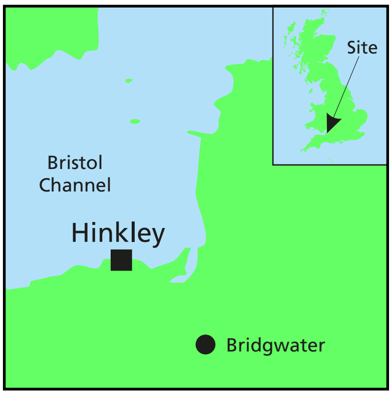
(Figure 3.2). Overall, gamma dose rates in 2021 were generally lower than those in 2020.

LOCATION MAPS – OPERATING SITES

Hartlepool

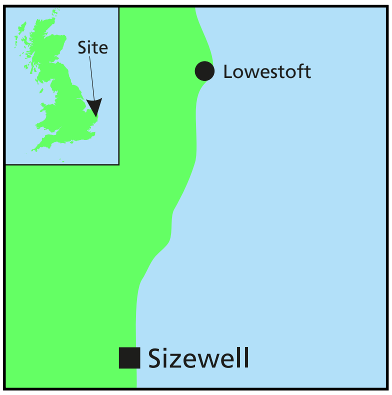


Heysham

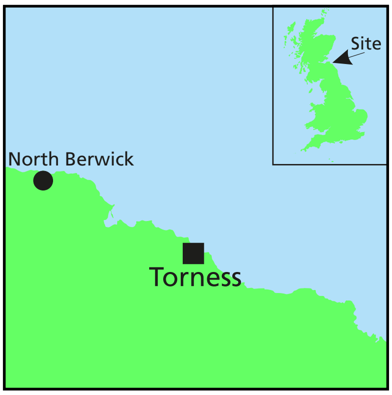


Hinkley Point

Hunterston

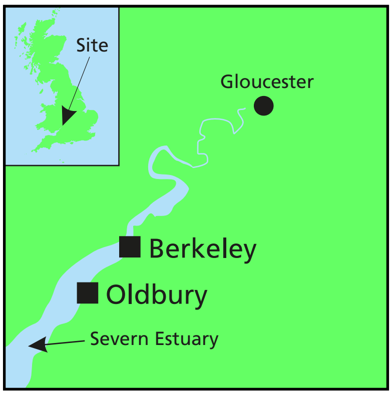


Sizewell

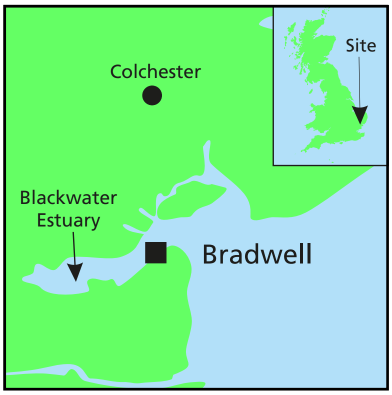


Torness

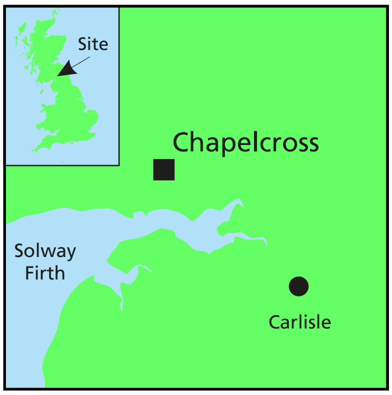
LOCATION MAPS – DECOMMISSIONING SITES



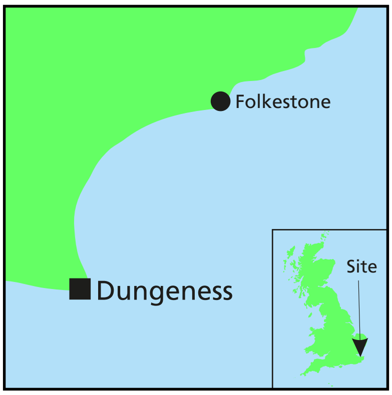
Berkeley



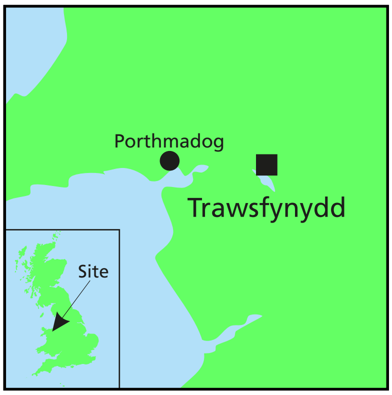
Bradwell



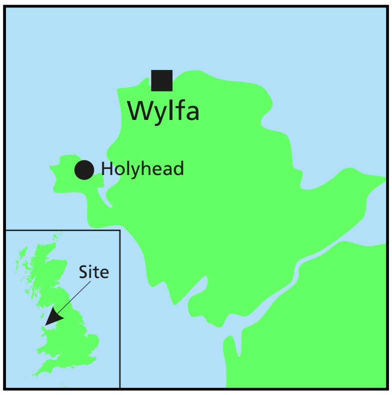
Chapelcross



Dungeness



Trawsfynydd



Wylfa

Table 3.1 Individual doses - nuclear power stations, 2021

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
Operating sites							
Hartlepool							
'Total dose' - all sources	**Local adult inhabitants (0-0.25km)**	**0.012**	**<0.005**	**-**	**0.005**	**<0.005**	**0.006**
Source specific doses	Seafood consumers[c]	0.010	<0.005	-	0.007	-	-
	Infant inhabitants and consumers of locally grown food	0.005	-	0.005	-	<0.005	-
Heysham							
'Total dose' - all sources	Adult occupants over sediment	0.015	<0.005	<0.005	0.015	<0.005	<0.005
Source specific doses	Seafood consumers	0.019	0.005	-	0.014	-	-
	Turf cutters	<0.005	-	-	<0.005	-	-
	Infant inhabitants and consumers of locally grown food	0.006	-	0.005	-	<0.005	-
Hinkley Point							
'Total dose' - all sources	**Adult occupants over sediment**	**0.030**	**<0.005**	**<0.005**	**0.030**	**-**	**-**
Source specific doses	Seafood consumers	0.018	<0.005	-	0.017	-	-
	Infant inhabitants and consumers of locally grown food	<0.005	-	<0.005	-	<0.005	-
Hunterston							
'Total dose' - all sources	**Adult mollusc consumers**	**0.006**	**0.006**	**-**	**<0.005**	**-**	**-**
Source specific doses	Seafood consumers	0.011	0.009	-	0.005	-	-
	Infant inhabitants and consumers of locally grown food	0.008	-	0.006	-	<0.005	-
Sizewell							
'Total dose' - all sources	**Local adult inhabitants (0-0.25km)**	**0.016**	**<0.005**	**<0.005**	**<0.005**	**<0.005**	**0.015**
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	-
Torness							
'Total dose' - all sources	**Prenatal children of wild fruit and nut consumers**	**0.005**	**<0.005**	**0.005**	**<0.005**	**-**	**-**
Source specific doses	Seafood consumers	<0.005	<0.005	-	<0.005	-	-
	Infant inhabitants and consumers of locally grown food	0.008	-	0.008	-	<0.005	-
Decommissioning sites							
Berkeley & Oldbury							
'Total dose' - all sources	**Infant local inhabitants (0-0.25km)**	**0.013**	**-**	**<0.005**	**-**	**<0.005**	**0.013**
Source specific doses	Seafood consumers	<0.005	<0.005	-	<0.005	-	-
	Houseboat occupants	0.025	-	-	0.025	-	-
	Infant inhabitants and consumers of locally grown food	<0.005	-	<0.005	-	<0.005	-
Bradwell							
'Total dose' - all sources	**Prenatal children of local inhabitants (0-0.25km)**	**0.006**	**-**	**<0.005**	**-**	**<0.005**	**0.006**
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	-
Chapelcross							
'Total dose' - all sources	**Infant milk consumers**	**0.018**	**<0.005**	**0.018**	**<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	0.015	-	0.015	-	<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
Dungeness							
'Total dose' - all sources	**Local adult inhabitants (0.25-0.5km)**	**0.012**	**<0.005**	**<0.005**	**<0.005**	**<0.005**	**0.010**
Source specific doses	Seafood consumers	0.008	<0.005	-	0.006	-	-
	Infant inhabitants and consumers of locally grown food	<0.005	-	<0.005	-	<0.005	-
Trawsfynydd							
'Total dose' - all sources	**Adult occupants over sediment**	**0.010**	**<0.005**	**-**	**0.007**	**<0.005**	**<0.005**
Source specific doses	Anglers	0.008	<0.005	-	0.007	-	-
	Infant inhabitants and consumers of locally grown food	0.040	-	0.040	-	<0.005	-
Wylfa							
'Total dose' - all sources	**Local adult inhabitants (0.25-0.5km)**	**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	0.006	-	0.006	-	<0.005	-

[a] The 'total dose' is the dose which accounts for all sources including gaseous and liquid discharges and direct radiation. The 'total dose' for the representative person with the highest dose is presented. Other dose values are presented for specific sources, either liquid discharges or gaseous discharges, and their associated pathways. They serve as a check on the validity of the 'total dose' assessment. The representative person is an adult unless otherwise stated. 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 Hartlepool nuclear power station, 2021

Material	Location	No. of sampling observ-ations	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}							
			Organic ^{3}H	^{3}H	^{14}C	^{60}Co	^{99}Tc	^{131}I	^{137}Cs	^{210}Pb
Marine samples										
Plaice	Pipeline	1	<25	<25	19	<0.09		<1.2	0.13	
Crabs	Pipeline	1	<25	<25	26	<0.05		<0.16	<0.05	
Winkles	South Gare	2	<25	<25	29	<0.08		<0.70	<0.13	1.9
Seaweed	Pilot Station	2[E]				<0.97	1.9	7.9	<0.67	
Sediment	Old Town Basin	2[E]				<0.49			0.72	
Sediment	Seaton Carew	2[E]				<0.30			<0.23	
Sediment	Paddy's Hole	2[E]				<0.42			0.91	
Sediment	North Gare	2[E]				<0.34			<0.25	
Sediment	Greatham Creek	2[E]				<0.46			2.2	
Sediment	Redcar Sands	2[E]				<0.37			<0.26	
Sea coal	Old Town Basin	2[E]				<0.47			1.2	
Sea coal	Carr House Sands	2[E]				<0.46			<0.86	
Seawater[b]	North Gare	2[E]		<4.3		<0.30			<0.23	

Material	Location	No. of sampling observ-ations	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}							
			^{210}Po	^{238}Pu	^{239}Pu+ ^{240}Pu	^{241}Am	^{242}Cm	^{243}Cm+ ^{244}Cm	Gross alpha	Gross beta
Marine samples										
Plaice	Pipeline	1				<0.06				
Crabs	Pipeline	1				<0.11				
Winkles	South Gare	2	9.7	0.0039	0.028	0.012	*	*		
Seaweed	Pilot Station	2[E]				<0.73				
Sediment	Old Town Basin	2[E]				<0.61				
Sediment	Seaton Carew	2[E]				<0.38				
Sediment	Paddy's Hole	2[E]				<0.66				
Sediment	North Gare	2[E]				<0.39				
Sediment	Greatham Creek	2[E]				<0.71				
Sediment	Redcar Sands	2[E]				<0.40				
Sea coal	Old Town Basin	2[E]				<0.55				
Sea coal	Carr House Sands	2[E]				<0.65				
Seawater[b]	North Gare	2[E]				<0.34			<3.2	14

Material	Location or selection[c]	No. of sampling observ-ations[d]	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}							
			^{3}H	^{14}C	^{35}S	^{60}Co	^{131}I	^{137}Cs	Gross alpha	Gross beta
Terrestrial samples										
Milk		2	<2.8	20	<0.25	<0.05	<1.6	<0.04		
Milk	max		<3.5	21	<0.28		<2.2	<0.05		
Potatoes		1	<2.0	38	0.40	<0.03	<0.05	<0.05		
Wheat		1	<3.2	110	2.1	<0.05	<0.07	<0.05		
Grass	0.8km NW of site	2[E]	<16	24	2.9	<1.2		<0.88		
Grass	0.6km NE of site	2[E]	<20	<17	3.9	<1.5		<1.1		
Freshwater	Boreholes, Dalton Piercy	2[E]	<4.1		<0.21	<0.36		<0.31	<0.065	0.15

* 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 <0.39 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 3.2(b) Monitoring of radiation dose rates near Hartlepool nuclear power station, 2021

Location	Ground type	No. of sampling observations	$\mu Gy\ h^{-1}$
Mean gamma dose rates at 1m over substrate			
Fish Sands	Pebbles and sand	1	0.067
Fish Sands	Sand	1	0.060
Old Town Basin	Sand and sea coal	2	0.068
Carr House	Sand and sea coal	2	0.062
Seaton Carew	Sand	1	0.059
Seaton Carew	Sand and stones	1	0.057
North Gare	Sand	1	0.066
North Gare	Sand and stones	1	0.056
Paddy's Hole	Sand and stones	2	0.16
Greatham Creek nature reserve	Mud and sand	2	0.083
Redcar Sands	Sand	2	0.061

Table 3.3(a) Concentrations of radionuclides in food and the environment near Heysham nuclear power stations, 2021

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									
Flounder	Morecambe	2	<25	<25	52	<0.06	<0.035	<0.15	3.5
Shrimps	Morecambe	2	<25	<25	39	<0.06	<0.037	0.16	2.0
Cockles/Winkles[b]	Middleton Sands	2	39	57	32	<0.09	0.097	1.8	1.2
Mussels[c]	Morecambe	2	<25	<25	39	<0.06	0.12	26	0.99
Wildfowl	Morecambe	1				<0.07			0.30
Seaweed[d]	Half Moon Bay	2[E]				<0.70		85	3.0
Sediment	Half Moon Bay	2[E]				<0.66			91
Sediment	Potts' Corner	2[E]				<0.48			25
Sediment	Morecambe central beach	2[E]				<0.42			29
Sediment	Red Nab Point	1[E]				<0.31			26
Sediment	Shore adjacent to Northern Outfall	1[E]				<0.64			48
Seawater[e]	Shore adjacent to Northern Outfall	2[E]		9.5		<0.31			<0.26

Material	Location	No. of sampling observ-ations	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}						
			^{238}Pu	^{239}Pu + ^{240}Pu	^{241}Pu	^{241}Am	^{242}Cm	^{243}Cm + ^{244}Cm	Gross alpha
Marine samples									
Flounder	Morecambe	2	0.00028	0.0017		0.0035	*	0.000013	
Shrimps	Morecambe	2	0.0027	0.019		0.033	*	*	
Cockles/Winkles[b]	Middleton Sands	2	0.16	0.90	3.5	2.5	*	*	
Mussels[c]	Morecambe	2	0.13	0.96	3.6	2.0	*	*	
Wildfowl	Morecambe	1				<0.06			
Seaweed[d]	Half Moon Bay	2[E]				2.9			
Sediment	Half Moon Bay	2[E]	8.3	54		140			
Sediment	Potts' Corner	2[E]				34			
Sediment	Morecambe central beach	2[E]				42			
Sediment	Red Nab Point	1[E]				33			
Sediment	Shore adjacent to Northern Outfall	1[E]				83			
Seawater[e]	Shore adjacent to Northern Outfall	2[E]				<0.29			<1.9

Material	Location or selection[f]	No. of sampling observ-ations[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	<3.0	18	<0.30	<0.05	<0.05		
Milk	max		<3.3	22			<0.06		
Beetroot		1	<2.0	20	0.40	<0.05	<0.04		
Silage		1	<2.4	72	1.9	<0.07	<0.05		
Grass	Half Moon Bay, recreation ground	2[E]	<14	18	3.6	<1.0	<0.80		
Grass	Overton	2[E]	<8.0	16	2.6	<1.2	<0.91		
Freshwater	Damas Gill reservoir	2[E]	<3.4	3.1	<0.33	<0.30	<0.25	<0.016	0.045
Freshwater	Lower Halton Weir	2[E]	<3.4	<5.2	<0.32	<0.22	<0.20	<0.014	0.091

* 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 10 Bq kg^{-1}

c The concentration of ^{210}Po was 32 Bq kg^{-1}

d The concentrations of ^{35}S was <8.5 Bq kg^{-1}

e The concentrations of ^{35}S was <1.1 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 3.3(b) Monitoring of radiation dose rates near Heysham nuclear power stations, 2021

Location	Ground type	No. of sampling observations	μGy h^{-1}
Mean gamma dose rates at 1m over substrate			
Sand Gate Marsh	Salt marsh	2	0.082
Arnside 2	Salt marsh	2	0.080
Morecambe central beach	Sand	2	0.069
Half Moon Bay	Sand	2	0.074
Pipeline	Sand and stones	1	0.069
Red Nab point	Sand and stones	1	0.076
Middleton Sands	Sand	2	0.068
Sunderland Point	Mud and sand	1	0.082
Sunderland Point	Sand	1	0.085
Colloway Marsh	Salt marsh	1	0.096
Lancaster	Grass	2	0.070
Aldcliffe Marsh	Salt marsh	2	0.079
Conder Green	Salt marsh	2	0.077

Table 3.4(a) Concentrations of radionuclides in food and the environment near Hinkley Point nuclear power stations, 2021

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									
Grey Mullet	Stolford	1	<25	<25	24	<0.06			0.16
Shrimps	Stolford	1	<25	<25	22	<0.05			0.11
Limpets	Stolford	1	<25	<25	17	<0.07			<0.06
European Oyster	Stolford	1	<25	<25	7.3	<0.05			<0.04
Seaweed	Pipeline	2[E]				<0.99		<0.57	<0.72
Sediment	Pipeline	2[E]				<0.53	<0.77		3.7
Sediment	Stolford	2[E]				<0.62	<0.77		10
Sediment	Steart Flats	2[E]				<0.57	<1.1		8.0
Sediment	River Parrett	1[E]				<0.51	<0.89		15
Sediment	River Parrett Central 2	2[E]				<0.59	<0.81		6.6
Sediment	Weston-Super-Mare	2[E]				<0.42	<1.2		<1.5
Sediment	Burnham-On-Sea	2[E]				<0.34	<0.69		0.55
Sediment	Kilve	2[E]				<0.64	<0.84		<6.2
Sediment	Helwell Bay	1[E]				<0.51	<0.65		1.4
Sediment	Blue Anchor Bay	2[E]				<0.40	<0.83		<0.86
Seawater	Pipeline	1[E]		<3.7		<0.24	<0.031		<0.18

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									
Grey Mullet	Stolford	1			<0.05				
Shrimps	Stolford	1	0.000019	0.00034	0.00040	*	*		
Limpets	Stolford	1			<0.20				
European Oyster	Stolford	1			<0.08				
Seaweed	Pipeline	2[E]			<0.86				
Sediment	Pipeline	2[E]			<0.72				
Sediment	Stolford	2[E]			<0.80				
Sediment	Steart Flats	2[E]			<0.78				
Sediment	River Parrett	1[E]			<0.90				
Sediment	River Parrett Central 2	2[E]			<0.85				
Sediment	Weston-Super-Mare	2[E]			<0.56				
Sediment	Burnham-On-Sea	2[E]			<0.45				
Sediment	Kilve	2[E]			<0.74				
Sediment	Helwell Bay	1[E]			<0.76				
Sediment	Blue Anchor Bay	2[E]			<0.55				
Seawater	Pipeline	1[E]			<0.24			<2.1	13

Material	Location or selection[b]	No. of sampling observations[c]	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}						
			^{3}H	^{14}C	^{35}S	^{60}Co	^{137}Cs	Gross alpha	Gross beta
Terrestrial samples									
Milk		2	<2.4	19	<0.33	<0.05	<0.05		
Milk	max		<2.7		<0.40	<0.06			
Blackberries		1	<2.0	21	0.30	<0.06	<0.06		
Honey		1	<4.9	100	0.40	<0.04	<0.04		
Wheat		1	<3.3	76	<0.20	<0.05	<0.04		
Grass	Gunter's Grove	2[E]	<8.2	18		<2.0	<1.5		
Grass	Wall Common	2[E]	<10	24		<1.5	<1.1		
Freshwater	Durleigh Reservoir	2[E]	<4.0		<0.11	<0.27	<0.22	<0.024	0.14
Freshwater	Ashford Reservoir	2[E]	<3.7		<0.12	<0.27	<0.22	<0.019	0.077

* 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 3.4(b) Monitoring of radiation dose rates near Hinkley Point nuclear power stations, 2021

Location	Ground type	No. of sampling observations	$\mu Gy\ h^{-1}$
Mean gamma dose rates at 1m over substrate			
Weston-super-Mare	Sand	1	0.063
Weston-super-Mare	Sand and mud	1	0.066
Burnham-on-Sea	Sand	2	0.060
River Parrett	Mud	1	0.083
River Parrett Bridgwater Central 2	Mud	2	0.080
Steart Flats	Mud	2	0.072
Stolford	Mud	1	0.089
Stolford	Mud and rock	1	0.085
Hinkley Point	Mud and rock	2	0.088
Kilve	Mud and rock	1	0.073
Kilve	Sand and rock	1	0.097
Helwell Bay	Mud and rock	1	0.092
Blue Anchor Bay	Mud and sand	1	0.085
Blue Anchor Bay	Pebbles and shingle	1	0.075

Table 3.5(a) Concentrations of radionuclides in food and the environment near Hunterston nuclear power stations, 2021

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	1			<0.10	<0.10	<0.13	
Hake	Millport	1			<0.10	<0.10	<0.10	
Crabs	Millport	2			<0.10	<0.10	<0.10	0.40
Nephrops	Millport	2			<0.10	<0.10	<0.32	
Lobsters	Largs	1			<0.10	<0.10	<0.10	25
Squat lobsters	Largs	2			<0.10	<0.10	<0.18	1.0
Scallops	Largs	2			<0.10	<0.10	<0.10	
Oysters	Hunterston	1			<0.10	<0.10	<0.10	
Fucus vesiculosus	N of pipeline	2			<0.10	<0.14	<0.23	
Fucus vesiculosus	S of pipeline	2			<0.10	<0.10	<0.17	
Sediment	Largs	1			<0.10	<0.10	<0.11	
Sediment	Millport	1			<0.10	<0.10	<0.10	
Sediment	Gull's Walk	1			<0.10	<0.10	<0.10	
Sediment	Ardneil Bay	1			<0.10	<0.10	<0.10	
Sediment	Fairlie	1			<0.16	<0.16	<0.38	
Sediment	Pipeline	1			<0.10	<0.10	<0.10	
Sediment	Ardrossan North Bay	1			<0.10	<0.10	<0.10	
Sediment	Ardrossan South Bay	1			<0.10	<0.10	<0.10	
Seawater	Pipeline	2	210	<0.61	<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	1	<0.10	0.78	<0.15			<0.16
Hake	Millport	1	<0.10	0.61	<0.10			<0.10
Crabs	Millport	2	<0.10	<0.15	<0.10	0.011	0.065	0.029
Nephrops	Millport	2	<0.12	0.29	<0.17			<0.11
Lobsters	Largs	1	<0.10	0.35	<0.10			0.40
Squat lobsters	Largs	2	<0.10	<0.11	<0.12	0.0085	0.050	0.046
Scallops	Largs	2	<0.10	<0.10	<0.10	0.12	0.68	0.18
Oysters	Hunterston	1	<0.10	<0.10	<0.10			<0.10
Fucus vesiculosus	N of pipeline	2	<0.11	0.54	<0.14			<0.49
Fucus vesiculosus	S of pipeline	2	<0.10	0.23	<0.10			<0.10
Sediment	Largs	1	<0.10	4.0	0.24			0.25
Sediment	Millport	1	<0.10	2.7	<0.14			0.39
Sediment	Gull's Walk	1	<0.10	9.9	<0.27			0.92
Sediment	Ardneil Bay	1	<0.10	1.9	<0.18			<0.19
Sediment	Fairlie	1	<0.25	8.9	<0.46			<0.30
Sediment	Pipeline	1	<0.10	2.9	<0.19			0.53
Sediment	Ardrossan North Bay	1	<0.11	3.3	<0.23			<0.32
Sediment	Ardrossan South Bay	1	<0.10	2.0	<0.20			0.54
Seawater	Pipeline	2	<0.10	<0.10	<0.10			<0.10

Table 3.5(a) continued

Material	Selection[b]	No. of sampling observ-ations[c]	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}									
			^{3}H	^{14}C	^{35}S	^{90}Sr	^{95}Nb	^{137}Cs	^{155}Eu	^{241}Am	Gross alpha	Gross beta
Terrestrial Samples												
Milk		2	<5.0	<15	<0.56	<0.10	<0.08	<0.06		<0.05		
Milk	max				<0.60		<0.09	<0.07				
Beef		1	<5.0	22	<0.50	<0.10	<0.15	0.41		<0.10		
Blackberries		1	11	18	<0.50	0.34	<0.11	0.20		<0.06		
Broccoli		1	<5.0	<15	<0.50	<0.10	<0.05	<0.05		<0.05		
Cabbage		1	<5.0	<15	<0.50	<0.10	<0.05	<0.05		<0.08		
Carrots		1	<5.0	<15	<0.50	0.14	<0.09	<0.05		<0.05		
Eggs		1	<5.0	<15	<0.50	<0.10	<0.10	0.06		<0.05		
Pork		1	<5.0	32	<0.50	0.16	<0.07	<0.05		<0.06		
Potatoes		2	<5.0	<15	<0.50	<0.15	<0.07	<0.07		<0.07		
Potatoes	max					0.19	<0.10	<0.10		<0.08		
Rosehips		1	<5.0	31	<0.50	0.74	0.37	0.44		<0.06		
Turnips		1	<5.0	<15	<0.50	0.21	<0.06	0.11		<0.06		
Grass		6	<5.0	<20	<1.7	<0.22	<0.21	<0.18	<0.10	<0.10	1.5	230
Grass	max			31	6.9	0.61	<0.36	0.49	<0.15	<0.15	4.1	350
Soil		3	<5.0	<15	<4.7	2.2	<0.10	12	0.69	<0.15	140	1100
Soil	max				8.8	5.4	<0.12	16	0.94	<0.16	180	1300
Freshwater	Loch Ascog	1	<1.0				<0.01	<0.01		<0.01	<0.010	0.26
Freshwater	Camphill	1	<1.0				<0.17	<0.01		<0.01	<0.010	0.043
Freshwater	Outerwards	1	<1.0				<0.01	<0.01		<0.01	<0.010	0.070

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

Table 3.5(b) Monitoring of radiation dose rates near Hunterston nuclear power stations, 2021

Location	Ground type	No. of sampling observations	μGy h^{-1}
Mean gamma dose rates at 1m over substrate			
Meigle Bay	Sediment	2	0.051
Largs Bay	Sediment	2	0.064
Millport	Sediment	2	0.049
Kilchattan Bay	Sediment	2	<0.057
Gull's Walk	Sediment	2	<0.050
Hunterston	Sediment	1	<0.047
Hunterston	Stones	1	0.062
0.5 m north of pipeline	Sediment	2	<0.054
0.5km south of pipeline	Sediment	1	0.055
0.5km south of pipeline	Stones	1	0.054
Ardneil Bay	Sediment	2	<0.050
Ardrossan North Bay	Sediment	2	<0.047
Ardrossan South Bay	Sediment	2	<0.047
Milstonford	Grass	1	0.051
Biglies	Grass	1	0.053
Carlung House	Grass	1	0.056
Beta dose rates			μSv h^{-1}
Millport	Sand	1	<1.0
0.5km north of pipeline	Sediment	1	<1.0
0.5km south of pipeline	Sediment	1	<1.0

Table 3.5(c) Radioactivity in air near Hunterston nuclear power stations, 2021

Location	No. of sampling observations	Mean radioactivity concentration, mBq m^{-3}			
		^{131}I	^{137}Cs	Gross alpha	Gross beta
Fairlie	7	<0.010	<0.010	<0.034	<0.24
West Kilbride	6	<0.013	<0.010	<0.016	<0.23
Low Ballees	7	<0.012	<0.010	0.020	<0.24

Table 3.6(a) Concentrations of radionuclides in food and the environment near Sizewell nuclear power stations, 2021

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	27	<25			0.11	
Skates/Rays	Sizewell	1	<25	<25			0.23	
Oysters	River Alde	1	<25	<25	14		<0.07	0.00043
Crabs	Sizewell	1	<25	<25			<0.09	
Sediment	Aldeburgh	2[E]				<1.1	<0.19	
Sediment	Southwold harbour	2[E]				<3.6	4.3	
Sediment	Minsmere river outfall	2[E]				<1.5	2.8	
Seawater	Sizewell beach	2[E]		<3.8	<5.4		<0.26	

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		<0.34				
Skates/Rays	Sizewell	1		<0.12				
Oysters	River Alde	1	0.0032	0.0019	*	0.000062		
Crabs	Sizewell	1		<0.18				
Sediment	Aldeburgh	2[E]		<0.33				
Sediment	Southwold harbour	2[E]		<0.80				1100
Sediment	Minsmere river outfall	2[E]		<0.50				
Seawater	Sizewell beach	2[E]		<0.34			<2.6	13

Material	Location or selection[b]	No. of sampling observations[c]	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}					
			^{3}H	^{14}C	^{35}S	^{137}Cs	Gross alpha	Gross beta
Terrestrial samples								
Milk		2	<2.4	18	<0.36	<0.04		
Milk	max		<2.5		<0.43			
Potatoes		1	<2.0	31	<0.20	<0.06		
Barley		1	<3.3	110	1.2	<0.05		
Grass	Sizewell belts	2[E]	<17	17		<0.97		
Grass	Sizewell common	2[E]	<9.2	20		<0.88		
Freshwater	Minsmere nature reserve	2[E]	<3.6		<0.14	<0.24	<0.038	0.33
Freshwater	The Meare	2[E]	<3.6		<0.15	<0.25	<0.028	0.18
Freshwater	Leisure Park	2[E]	<3.5		<0.16	<0.22	<0.036	0.34

[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 3.6(b) Monitoring of radiation dose rates near Sizewell nuclear power stations, 2021

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	0.052
Dunwich	Sand and shingle	2	0.053
Aldeburgh	Sand and shingle	2	0.051
Southwold Harbour	Mud and silt	2	0.069

Table 3.7(a) Concentrations of radionuclides in food and the environment near Torness nuclear power station, 2021

Material	Location	No. of sampling observations	Mean radioactivity concentration (fresh)[a], $Bq\ kg^{-1}$					
			^{14}C	^{54}Mn	^{60}Co	^{99}Tc	^{110m}Ag	^{137}Cs
Marine samples								
Cod	White Sands	2		<0.10	<0.10		<0.11	0.27
Mackerel	Pipeline	2		<0.10	<0.10		<0.11	0.13
Crabs	Torness	1	26	<0.10	<0.10	<0.16	<0.10	<0.10
Lobsters	Torness	1	16	<0.10	<0.10	2.4	<0.10	<0.10
Nephrops	Dunbar	2		<0.11	<0.10		<0.13	<0.12
Winkles	Pipeline	2		<0.19	<0.30		1.5	<0.18
Fucus vesiculosus	Pipeline	2		<0.37	0.30		<0.26	<0.12
Fucus vesiculosus	Thorntonloch	2		<0.14	<0.10	16	<0.11	0.13
Fucus vesiculosus	White Sands	2		<0.10	<0.10		<0.11	0.15
Fucus vesiculosus	Coldingham Bay	2		<0.10	<0.10		<0.10	<0.10
Fucus vesiculosus	Pease Bay	2		<0.10	<0.10		<0.10	<0.10
Sediment	Dunbar	1		<0.10	<0.10		<0.10	1.1
Sediment	Barns Ness	1		<0.10	<0.10		<0.10	1.5
Sediment	Thorntonloch	1		<0.10	<0.10		<0.10	0.86
Sediment	Heckies Hole	1		<0.10	<0.10		<0.10	0.58
Sediment	Belhaven Bay	1		<0.10	<0.10		<0.10	0.23
Sediment	Coldingham Bay	1		<0.10	<0.10		<0.10	0.66
Sediment	Pease Bay	1		<0.10	<0.10		<0.10	0.89
Seawater[b]	Pipeline	2		<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	<0.14			<0.11		
Mackerel	Pipeline	2	<0.13			<0.11		
Crabs	Torness	1	<0.10			<0.10		
Lobsters	Torness	1	<0.11			<0.10		
Nephrops	Dunbar	2	<0.18	0.0014	0.0043	0.0066		
Winkles	Pipeline	2	<0.19			<0.12	4.9	150
Fucus vesiculosus	Pipeline	2	<0.14			<0.12		
Fucus vesiculosus	Thorntonloch	2	<0.17			<0.13		
Fucus vesiculosus	White Sands	2	<0.17			<0.12		
Fucus vesiculosus	Coldingham Bay	2	<0.13			<0.10		
Fucus vesiculosus	Pease Bay	2	<0.11			<0.10		
Sediment	Dunbar	1	0.86			<0.15		
Sediment	Barns Ness	1	0.47			<0.27		
Sediment	Thorntonloch	1	<0.21			<0.21		
Sediment	Heckies Hole	1	0.29			<0.21		
Sediment	Belhaven Bay	1	<0.19			<0.19		
Sediment	Coldingham Bay	1	0.45			0.26		
Sediment	Pease Bay	1	<0.22			<0.22		
Seawater[b]	Pipeline	2	<0.10			<0.10		

Table 3.7(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	<16	<0.50	<0.05	<0.13	<0.10
Milk	max						<0.15	<0.11
Apples		1	<5.0	<15	<0.50	<0.05	<0.10	<0.05
Beetroot		1	<5.0	<15	<0.50	<0.05	0.14	<0.08
Cabbage		1	<5.0	<15	<0.50	<0.05	<0.10	<0.07
Carrots		1	<5.0	<15	<0.50	<0.05	0.20	<0.05
Eggs		1	<5.0	20	<0.50	<0.05	<0.10	<0.08
Goose		1	<5.0	25	<0.50	<0.05	<0.10	<0.05
Green Beans		1	<5.0	<15	<0.50	<0.10	0.10	<0.16
Lamb		1	<5.0	26	<0.50	<0.05	<0.10	<0.07
Leeks		1	<5.0	<15	<0.50	<0.05	<0.10	<0.05
Mushrooms		1	<5.0	<15	<0.50	<0.05	<0.10	<0.10
Potatoes		1	<5.0	17	<0.50	<0.05	<0.10	<0.05
Rosehips		1	<5.0	30	<0.50	<0.05	0.11	<0.14
Turnips		1	<5.0	<15	<0.50	<0.05	0.19	<0.05
Venison		1	<5.0	<16	<0.50	<0.05	<0.10	<0.05
Grass		6	<5.0	27	<1.4	<0.05	0.20	<0.29
Grass	max		<5.1	35	<2.1	<0.06	0.31	<0.46
Soil		3	<5.0	<15	<1.8	<0.09	0.64	<0.20
Soil	max			<16	<2.7	<0.11	0.99	<0.39
Freshwater	Hopes Reservoir	1	<1.0			<0.01		<0.01
Freshwater	Thorter's Reservoir	1	<1.0			<0.01		<0.01
Freshwater	Whiteadder	1	<1.0			<0.01		<0.02
Freshwater	Thornton Loch Burn	1	<1.0			<0.01		<0.02

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							
Apples		1	<0.05	<0.05		<0.05		
Beetroot		1	<0.05	<0.05		<0.05		
Cabbage		1	<0.05	<0.05		<0.05		
Carrots		1	<0.05	<0.05		<0.07		
Eggs		1	<0.06	<0.05		<0.06		
Goose		1	<0.05	0.74		<0.06		
Green Beans		1	<0.10	0.19		<0.11		
Lamb		1	<0.05	0.13		<0.09		
Leeks		1	<0.05	<0.05		<0.08		
Mushrooms		1	<0.06	<0.07		<0.06		
Potatoes		1	<0.05	<0.05		<0.07		
Rosehips		1	<0.05	<0.05		<0.07		
Turnips		1	<0.05	<0.05		<0.07		
Venison		1	<0.05	<0.05		<0.06		
Grass		6	<0.06	<0.09	<0.11	<0.11	2.2	320
Grass	max		<0.07	<0.23	<0.15	<0.15	3.8	380
Soil		3	<0.11	12	1.5	<0.30	190	1300
Soil	max		<0.15	29	1.6	<0.42	210	1500
Freshwater	Hopes Reservoir	1	<0.01	<0.01		<0.01	<0.010	0.016
Freshwater	Thorter's Reservoir	1	<0.01	<0.01		<0.01	<0.010	0.022
Freshwater	Whiteadder	1	<0.01	<0.01		<0.01	<0.010	0.064
Freshwater	Thornton Loch Burn	1	<0.01	0.05		<0.01	0.011	0.14

[a] Except for milk and seawater where units are Bq l^{-1} and for sediment and soil where dry concentrations apply
[b] The concentration of ^{3}H was <3.9 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

Table 3.7(b) Monitoring of radiation dose rates near Torness nuclear power station, 2021

Location	Ground type	No. of sampling observations	$\mu Gy\ h^{-1}$
Mean gamma dose rates at 1m over substrate			
Heckies Hole	Sediment	2	0.052
Dunbar Inner Harbour	Sediment	2	0.081
Belhaven Bay	Sediment	2	<0.052
Barns Ness	Sediment	2	<0.055
Skateraw	Sediment	2	0.052
Thorntonloch	Sediment	1	0.068
Thorntonloch beach	Sediment	2	<0.049
Ferneylea	Grass	1	0.080
Pease Bay	Sediment	2	<0.054
St Abbs Head	Rocks	2	0.081
Coldingham Bay	Sediment	2	0.053
West Meikle Pinkerton	Grass	1	0.068
Mean beta dose rates on fishing gear			$\mu Sv\ h^{-1}$
Torness	Lobster Pots	2	<1.0

Table 3.7(c) Radioactivity in air near Torness nuclear power station, 2021

Location	No. of sampling observations	Mean radioactivity concentration, $mBq\ m^{-3}$				
		^{60}Co	^{131}I	^{137}Cs	Gross alpha	Gross beta
Innerwick	8	<0.011	<0.033	<0.010	<0.0085	<0.20
Cockburnspath	6	<0.010	<0.030	<0.010	<0.012	<0.20
West Barns	8	<0.010	<0.026	<0.010	<0.018	<0.20

Table 3.8(a) Concentrations of radionuclides in food and the environment near Berkeley and Oldbury nuclear power stations, 2021

Material	Location	No. of sampling observ-ations	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}										
			^{3}H	^{14}C	^{99}Tc	^{137}Cs	^{238}Pu	^{239}Pu + ^{240}Pu	^{241}Am	^{242}Cm	^{243}Cm + ^{244}Cm	Gross alpha	Gross beta
Marine samples													
Jack Mackerel	Beachley	1				<0.25			<0.42				
Elvers	River Severn	1				<0.15			<0.12				
Mullet	Severn Beach	1	<25			0.15			<0.12				
Shrimps	Guscar	1		16		<0.10	0.00012	0.00067	0.0011	*	*		
Seaweed	2km south west of Berkeley	2[E]			<0.86	<0.75			<0.92				
Sediment	0.5km south of Oldbury	2[E]				11			<0.81				
Sediment	2km south west of Berkeley	2[E]				14			<0.82				
Sediment	Sharpness	2[E]				12			<0.82				
Sediment	Ledges	2[E]				9.1			<0.90				
Seawater	2km south west of Berkeley	2[E]	<3.6			<0.20			<0.30			<1.3	5.3

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	Gross alpha	Gross beta
Terrestrial samples								
Milk		4	<3.0	18	<0.33	<0.04		
Milk	max		<3.3	20	<0.45			
Apples		1	<2.0	13	0.40	<0.03		
Grass		1	9.9	23	<0.30	<0.14		
Freshwater	Gloucester and Sharpness Canal	2[E]	<3.6		<0.11	<0.22	<0.033	0.24

* 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 3.8(b) Monitoring of radiation dose rates near Berkeley and Oldbury nuclear power stations, 2021

Location	Ground type	No. of sampling observations	μGy h^{-1}
Mean gamma dose rates at 1m over substrate			
0.5km south of Oldbury	Mud	2	0.080
2km south west of Berkeley	Mud	2	0.073
Guscar Rocks	Mud	2	0.078
Lydney Rocks	Mud	2	0.097
Sharpness	Mud	2	0.078
Ledges	Mud	2	0.075

Table 3.9(a) Concentrations of radionuclides in food and the environment near Bradwell nuclear power station, 2021

Material	Location	No. of sampling observations	Mean radioactivity concentration (fresh)[a], $Bq\ kg^{-1}$					
			^{3}H	^{90}Sr	^{99}Tc	^{137}Cs	^{238}Pu	$^{239}Pu + ^{240}Pu$
Marine samples								
Skate	Pipeline	1				0.10		
Lobster	West Mersea	1				<0.07		
Pacific oysters	Blackwater Estuary	1				<0.11	0.00022	0.0015
Samphire	Tollesbury	1			<0.094	0.22		
Seaweed	Waterside	2[E]			1.0	<0.56		
Seaweed	West Mersea	1[E]			<0.17	<0.62		
Sediment	Bradwell Pipeline	2[E]				<1.4		
Sediment	Waterside	2[E]				2.9		
Sediment	N side Blackwater Estuary	2[E]				4.0		
Sediment	Maldon Harbour	2[E]				8.3		
Sediment	West Mersea Beach Huts	2[E]				0.56		
Sediment	West Mersea Boatyard	2[E]				2.1		
Seawater	Bradwell Pipeline	2[E]	<3.6			<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							
Skate	Pipeline	1	<0.06				
Lobster	West Mersea	1	<0.18				
Pacific oysters	Blackwater Estuary	1	0.00089	*	0.000025		
Samphire	Tollesbury	1	<0.07				
Seaweed	Waterside	2[E]	<0.69				
Seaweed	West Mersea	1[E]	<0.54				
Sediment	Bradwell Pipeline	2[E]	<0.53				
Sediment	Waterside	2[E]	<0.61				
Sediment	N side Blackwater Estuary	2[E]	<0.75				
Sediment	Maldon Harbour	2[E]	<0.72				
Sediment	West Mersea Beach Huts	2[E]	<0.45				
Sediment	West Mersea Boatyard	2[E]	<0.58				
Seawater	Bradwell Pipeline	2[E]	<0.34			<2.3	14

Material	Location or selection[b]	No. of sampling observations[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	<2.6	23		<0.04	<0.15		
Milk	max		<2.8	26		<0.05	<0.19		
Cabbage		1	<2.0	22		<0.05	<0.17		
Lucerne		1	10	27		<0.06	<0.14		
Freshwater	Coastal ditch, between power station and shore	2[E]	<3.7		<0.024	<0.25		0.54	3.6
Freshwater	Coastal ditch, east face of sector building	2[E]	<3.8			<0.20		<0.38	3.1
Freshwater	Coastal ditch, east face of turbine hall	2[E]	<3.8		<0.13	<0.31		<0.43	4.0
Freshwater	Coastal ditch, drain pit overflow	2[E]	<3.9			<0.27		<0.38	4.2

* Not detected by the method used

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

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

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

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

Table 3.9(b) Monitoring of radiation dose rates near Bradwell nuclear power station, 2021

Location	Ground type	No. of sampling observations	μGy h^{-1}
Mean gamma dose rates at 1m over substrate			
Bradwell Beach	Mud and sand	1	0.062
Bradwell Beach	Sand	1	0.058
Bradwell Beach opposite power station N side of estuary	Mud and salt marsh	2	0.066
Waterside	Mud	1	0.064
Waterside	Mud and pebbles	1	0.056
Maldon Harbour	Mud and salt marsh	2	0.063
West Mersea Beach Huts	Mud and silt	1	0.065
West Mersea Beach Huts	Sand	1	0.065
SE of West Mersea boatyard	Mud and pebbles	1	0.062
SE of West Mersea boatyard	Mud and shells	1	0.054

Table 3.10(a) Concentrations of radionuclides in food and the environment near Chapelcross nuclear power station, 2021

Material	Location	No. of sampling observations	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}							
			^{3}H	^{14}C	^{60}Co	^{90}Sr	^{95}Zr	^{99}Tc	^{106}Ru	^{110m}Ag
Marine samples										
Shrimps	Annan	2	<5.0		<0.10	<0.10	<0.10	<0.20	<0.24	<0.10
Salmon	Inner Solway	1	<5.0		<0.10		<0.10		<0.26	<0.10
Trout	Inner Solway	1	<5.0		<0.10		<0.14		<0.46	<0.10
Mussels	North Solway	2	<5.0	54	<0.10	0.25	<0.44	16	<0.93	<0.18
Fucus vesiculosus	Pipeline	4			<0.10		<0.21	39	<0.65	<0.12
Fucus vesiculosus	Browhouses	2			<0.10		<0.10	38	<0.30	<0.10
Fucus vesiculosus	Dornoch Brow	2			<0.10		<0.11	25	<0.35	<0.10
Sediment	Priestside Bank	1			<0.10		<0.12		<0.68	<0.12
Sediment	Pipeline	4	<5.2		0.29		<0.38		<1.1	<0.18
Sediment	Dornoch Brow	1			0.23		<0.14		<0.87	<0.13
Sediment	Powfoot	1			<0.10		<0.12		<0.66	<0.11
Sediment	Redkirk	1			<0.10		<0.10		<0.28	<0.10
Sediment	Stormont	1			<0.14		<0.20		<0.72	<0.12
Seawater	Pipeline	1	<1.0		<0.10		<0.10		<0.19	<0.10

Material	Location	No. of sampling observations	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}							
			^{125}Sb	^{137}Cs	^{154}Eu	^{155}Eu	^{238}Pu	$^{239}Pu + {}^{240}Pu$	^{241}Am	Gross alpha
Marine samples										
Shrimps	Annan	2	<0.10	<0.10	<0.10	<0.17	0.0022	0.0080	0.026	
Salmon	Inner Solway	1	<0.10	<0.10	<0.10	<0.10			<0.10	
Trout	Inner Solway	1	<0.14	1.1	<0.10	<0.12			<0.10	
Mussels	North Solway	2	<0.27	1.6	<0.11	<0.17	0.49	3.1	6.2	
Fucus vesiculosus	Pipeline	4	<0.21	12	<0.12	<0.24	0.66	4.4	16	19
Fucus vesiculosus	Browhouses	2	<0.11	14	<0.10	0.35	1.5	9.4	16	28
Fucus vesiculosus	Dornoch Brow	2	<0.12	6.5	<0.10	0.23	0.98	5.9	6.3	15
Sediment	Priestside Bank	1	<0.25	31	<0.20	<0.38	5.3	27	50	
Sediment	Pipeline	4	<0.45	140	<0.30	1.3	15	100	200	
Sediment	Dornoch Brow	1	<0.35	93	<0.24	1.4	11	76	170	
Sediment	Powfoot	1	<0.15	24	<0.19	<0.33	1.9	14	27	
Sediment	Redkirk	1	<0.10	23	<0.10	<0.42	4.6	28	56	
Sediment	Stormont	1	<0.27	60	<0.19	<0.71	4.8	36	70	
Seawater	Pipeline	1	<0.10	<0.10	<0.10	<0.10			<0.10	

Table 3.10(a) continued

Material	Location or selection[b]	No. of sampling observations[c]	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}										
			^{3}H	^{14}C	^{35}S	^{90}Sr	^{95}Nb	^{106}Ru	^{137}Cs	^{155}Eu	^{241}Am	Gross alpha	Gross beta
Terrestrial samples													
Milk		10	<5.3	<15	<0.52	<0.10	<0.09	<0.17	<0.05		<0.05		
Milk	max		<7.7		<0.65		<0.13	<0.19					
Apples		1	<5.0	<15	<0.50	0.24	<0.05	<0.12	<0.05		<0.05		
Beef		1	<5.0	30	<0.50	<0.10	<0.05	<0.30	<0.05		<0.10		
Cabbage		1	<5.0	<15	<0.50	<0.10	<0.05	<0.19	<0.05		<0.08		
Carrots		2	<5.0	<15	<0.50	<0.13	<0.07	<0.31	<0.35		<0.06		
Carrots	max					0.16	<0.08	<0.40	0.66				
Cauliflower		1	<5.0	<15	<0.50	<0.10	<0.15	<0.43	<0.05		<0.07		
Eggs		2	<5.0	23	<0.50	<0.10	<0.11	<0.35	<0.05		<0.06		
Eggs	max			27			<0.15	<0.46	0.06				
Honey		1	<5.0	24	2.8	<0.10	<0.05	<0.23	0.70		<0.10		
Pork		1	<5.0	37	<0.50	<0.10	<0.05	<0.20	<0.50		<0.07		
Potatoes		2	<5.0	21	<0.50	<0.14	<0.09	<0.27	<0.07		<0.09		
Potatoes	max			27		<0.18	<0.12	<0.38	<0.09		<0.14		
Rhubarb		1	<5.0	<15	<0.50	<0.10	<0.05	<0.25	<0.05		<0.05		
Rosehips		1	<5.0	27	<0.50	0.24	<0.05	<0.19	0.06		<0.07		
Grass		4	<5.0	19	<0.69	0.27	<0.56	<0.27	<0.05	<0.08	<0.08	0.78	330
Grass	max			24	1.1	0.39	<0.91	<0.37		<0.12	<0.11	1.1	460
Soil		4	<5.4	<15	<6.1	0.85	<0.29	<0.41	6.9	1.4	<0.35	200	1400
Soil	max		6.4	15	<12	1.6	<0.43	<0.49	13	1.6	0.77	220	1700
Freshwater	Purdomstone	1	<1.0				<0.01	<0.03	<0.01		<0.01	<0.011	0.047
Freshwater	Winterhope	1	<1.0				<0.01	<0.03	<0.01		<0.01	<0.010	0.050
Freshwater	Black Esk	1	<1.0				<0.01	<0.03	<0.01		<0.01	<0.010	0.071
Freshwater	Gullielands Burn	1	14				<0.01	<0.03	<0.01		<0.01	0.019	0.19

[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 3.10(b) Monitoring of radiation dose rates near Chapelcross nuclear power station, 2021

Location	Material or ground type	No. of sampling observations	μGy h^{-1}
Mean gamma dose rates at 1m over substrate			
Glencaple Harbour	Sediment	2	0.060
Priestside Bank	Salt marsh	1	0.054
Priestside Bank	Sediment	1	0.061
Powfoot Merse	Salt marsh	1	0.066
Powfoot Merse	Sediment	1	0.067
Gullielands	Grass	1	0.069
Seafield	Salt marsh	1	0.064
Seafield	Sediment	1	0.065
Woodhead	Grass	1	0.066
East Bretton	Grass	1	0.067
Pipeline	Salt marsh	2	0.065
Pipeline	Sediment	2	0.073
Dumbretton	Grass	1	0.068
Battlehill	Sediment	2	0.072
Dornoch Brow	Sediment	2	0.071
Dornoch Brow Merse	Salt marsh	2	0.072
Browhouses	Sediment	2	0.060
Redkirk	Salt marsh	1	0.069
Redkirk	Sediment	1	0.072
Stormont	Sediment	2	0.068
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 3.10(c) Radioactivity in air near Chapelcross nuclear power station, 2021

Location	No. of sampling observations	Mean radioactivity concentration, mBq m^{-3}		
		^{137}Cs	Gross alpha	Gross beta
Eastriggs	8	<0.010	0.013	<0.20
Brydekirk	4	<0.010	0.016	<0.20

Table 3.11(a) Concentrations of radionuclides in food and the environment near Dungeness nuclear power stations, 2021

Material	Location	No. of sampling observ-ations	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}						
			Organic ^{3}H	^{3}H	^{14}C	^{60}Co	^{90}Sr	^{99}Tc	^{137}Cs
Marine samples									
Cod	Pipeline	1	<25	<25		<0.05			<0.05
Sole	Pipeline	1	<25	<25		<0.11			<0.09
Crabs	Pipeline	1	<25	<25		<0.05			<0.05
Scallop	Pipeline	1	<25	<25	20	<0.06	<0.028		<0.06
Sea kale	Dungeness Beach	1				<0.04			<0.04
Seaweed	Folkestone Harbour	2[E]				<0.46		<0.62	<0.36
Sediment	Rye Harbour	2[E]				<0.48			<0.38
Sediment	Camber Sands	2[E]				<0.36			<0.30
Sediment	Pilot Sands	2[E]				<0.29			<0.21
Seawater	Dungeness South	2[E]		<3.6		<0.31			<0.23

Material	Location	No. of sampling observ-ations	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}						
			^{238}Pu	^{239}Pu + ^{240}Pu	^{241}Am	^{242}Cm	^{243}Cm + ^{244}Cm	Gross alpha	Gross beta
Marine samples									
Cod	Pipeline	1			<0.15				
Sole	Pipeline	1			<0.08				
Crabs	Pipeline	1			<0.05				
Scallop	Pipeline	1	0.00036	0.0021	0.00065	0.000028	0.000017		
Sea kale	Dungeness Beach	1			<0.14				
Seaweed	Folkestone Harbour	2[E]			<0.88				
Sediment	Rye Harbour	2[E]	<0.070	<0.22	<0.63				690
Sediment	Camber Sands	2[E]			<0.51				
Sediment	Pilot Sands	2[E]			<0.39				
Seawater	Dungeness South	2[E]			<0.34			<3.7	14

Material	Location or selection[b]	No. of sampling observ-ations[c]	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}						
			^{3}H	^{14}C	^{35}S	^{60}Co	^{137}Cs	Gross alpha	Gross beta
Terrestrial Samples									
Milk		2	<2.5	17	<0.33	<0.05	<0.04		
Milk	max		<2.9	18	<0.38		<0.05		
Potato		1	<2.6	26	<0.10	<0.06	<0.05		
Grass		1	<4.2	120	<0.40	<0.50	<0.46		
Grass	Lydd	2[E]	<13	28		<1.7	<1.4		
Grass	Denge Marsh	2[E]	<14	30		<1.5	<1.2		
Freshwater	Long Pits	2[E]	<3.9		<0.18	<0.32	<0.23	<0.017	0.098
Freshwater	Pumping station Well number 1	1[E]	<3.6		<0.064	<0.32	<0.27	<0.018	0.096
Freshwater	Pumping station Well number 2	1[E]	<3.5		<0.29	<0.36	<0.26	<0.012	0.099
Freshwater	Reservoir	1[E]	<3.5		<0.28	<0.36	<0.24	<0.015	0.093

* 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 3.11(b) Monitoring of radiation dose rates near Dungeness nuclear power stations, 2021

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	0.053
Greatstone on Sea	Sand and silt	2	0.058
Pilot Sands	Sand and silt	1	0.054
Pilot Sands	Shingle	1	0.048
Dungeness West	Shingle	2	0.054
Jury's Gap	Sand	1	0.064
Jury's Gap	Shingle	1	0.065
Rye Bay	Sand	1	0.061
Rye Bay	Sand and shingle	1	0.056

Table 3.12(a) Concentrations of radionuclides in food and the environment near Trawsfynydd nuclear power station, 2021

Material	Location	No. of sampling observations	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}					
			^{3}H	^{14}C	^{60}Co	^{90}Sr	^{137}Cs	^{238}Pu
Freshwater samples								
Rainbow trout	Trawsfynydd Lake	2		28	<0.08	0.18	0.25	0.000014
Sediment	Lake shore near café	2[E]			<0.55	<0.83	220	<0.40
Sediment	1.5km SE of power station	2[E]			<0.55	<0.78	300	<0.63
Sediment	Pipeline	1[E]			<0.66	<0.92	180	<0.60
Sediment	SE of footbridge	2[E]			<0.97	<1.1	190	<0.38
Sediment	Cae Adda	2[E]			<0.51	<0.79	190	<0.82
Freshwater	Pipeline	2[E]	<3.7		<0.26		<0.22	
Freshwater	Gwylan Stream	2[E]	<3.7		<0.30		<0.25	
Freshwater	Afon Prysor	2[E]	<3.7		<0.28		<0.22	
Freshwater	1.5km SE of power station	2[E]	<3.6		<0.20		<0.17	
Freshwater	Afon Tafarn-helyg	2[E]	<3.8		<0.28		<0.22	

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	0.000028	0.000039	*	*		
Sediment	Lake shore near café	2[E]	<0.48	<1.1				
Sediment	1.5km SE of power station	2[E]	<0.85	1.6				
Sediment	Pipeline	1[E]	<0.51	1.7				
Sediment	SE of footbridge	2[E]	1.5	<1.8				
Sediment	Cae Adda	2[E]	2.4	<2.4				
Freshwater	Pipeline	2[E]					<0.021	0.047
Freshwater	Gwylan Stream	2[E]					<0.019	0.040
Freshwater	Afon Prysor	2[E]					<0.022	0.039
Freshwater	1.5km SE of power station	2[E]					<0.020	0.065
Freshwater	Afon Tafarn-helyg	2[E]					<0.018	0.038

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	<2.4	20	<0.033	<0.05	<0.047			<0.25
Milk	max		<2.6	22	0.043	<0.06	<0.060			<0.28
Potatoes		1	<2.0	39		0.17		<0.000044	0.00010	0.000067
Grass		1	<3.7	81		2.9		0.00019	0.0073	0.0039

* 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, 2021

Location	Ground type	No. of sampling observations	$\mu Gy\ h^{-1}$
Mean gamma dose rates at 1m over substrate			
Lake shore (pipeline)	Rock	1	0.089
Lake shore (pipeline)	Stones	1	0.086
Lake shore (SE of footbridge)	Grass and stones	1	0.097
Lake shore (SE of footbridge)	Stones	1	0.099
Lake shore (1.5km SE)	Rock and stones	2	0.088
Cae Adda	Stones	2	0.081
Lake shore	Pebbles and stones	1	0.093
Lake shore	Stones	1	0.091

Table 3.13(a) Concentrations of radionuclides in food and the environment near Wylfa nuclear power station, 2021

Material	Location	No. of sampling observations	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}						
			Organic ^{3}H	^{3}H	^{14}C	^{99}Tc	^{137}Cs	^{238}Pu	^{239}Pu + ^{240}Pu
Marine samples									
Plaice	Pipeline	1	<25	<25	29		0.39		
Crabs	Pipeline	1	<25	<25	29		0.13		
Lobsters	Pipeline	1	<25	<25	31	11	0.23	0.0032	0.020
Winkles	Cemaes Bay	1	<25	<25	27	2.7	0.15	0.014	0.095
Seaweed	Cemaes Bay	2[E]				9.9	<0.52		
Sediment	Cemaes Bay	2[E]					2.5		
Sediment	Cemlyn Bay West	2[E]					1.7		
Seawater	Cemaes Bay	2[E]		<3.5			<0.26		

Material	Location	No. of sampling observations	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}					
			^{241}Pu	^{241}Am	^{242}Cm	^{243}Cm + ^{244}Cm	Gross alpha	Gross beta
Marine samples								
Plaice	Pipeline	1		<0.09				
Crabs	Pipeline	1		<0.15				
Lobsters	Pipeline	1	<0.56	0.21	*	0.00032		80
Winkles	Cemaes Bay	1	0.33	0.14	*	*		87
Seaweed	Cemaes Bay	2[E]		<0.63				
Sediment	Cemaes Bay	2[E]		1.2				
Sediment	Cemlyn Bay West	2[E]		<1.1				
Seawater	Cemaes Bay	2[E]		<0.31			<3.7	13

Material	Location or selection[b]	No. of sampling observations[c]	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}				
			^{3}H	^{14}C	^{35}S	^{137}Cs	^{241}Am
Terrestrial samples							
Milk		2	<2.4	23	<0.23	<0.05	<0.11
Milk	max		<2.6	24	<0.28		<0.13
Potatoes		1	<2.0	29	<0.10	<0.05	<0.16
Grass		1	<2.3	46	4.1	<0.43	<1.5
Grass	Foel Fawr	2[E]	<11	12		<0.84	
Grass	Wylfa Head Nature Reserve	2[E]	<13	19		<0.92	

* 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, 2021

Location	Ground type	No. of sampling observations	μGy h^{-1}
Mean gamma dose rates at 1m over substrate			
Cemaes Bay	Pebbles and sand	1	0.070
Cemaes Bay	Sand and stones	1	0.067
Cemlyn Bay West	Shingle	2	0.065
Porth Yr Ogof	Shingle	2	0.068

4. Research and radiochemical production establishments

Highlights

- 'total doses' (research) for the representative person were less than 3% of the annual dose limit in 2021 (for sites that were assessed)
- 'total doses' (radiochemical production) for the representative person were approximately 8% of the annual dose limit in 2021

Dounreay, Highland

- 'total dose' for the representative person was 0.026mSv and increased in 2021

GE Healthcare Limited, Grove Centre, Amersham, Buckinghamshire

- 'total dose' for the representative person was 0.083mSv and decreased in 2021
- gaseous discharges of radionuclides other than alpha emitters, short-lived radionuclides, and tritium, increased in 2021

Harwell, Oxfordshire

- 'total dose' for the representative person was less than 0.005mSv and decreased in 2021

Winfrith, Dorset

- 'total dose' for the representative person was 0.006mSv and decreased in 2021

This section considers the results of monitoring near research establishments (Dounreay, Harwell, Winfrith and 2 minor research sites) and 1 site associated with the radiopharmaceutical industry (Grove Centre, Amersham). The 2 minor research sites considered in this section are the Imperial College Reactor Centre and the fusion energy research 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. DSRL became a wholly owned subsidiary of the NDA on the first of April 2021. 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, also a wholly owned subsidiary of the NDA.

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.

The site at Amersham is operated by GE Healthcare Limited, a company manufacturing radiochemical products for the healthcare and life science research markets. A permit issued by the Environment Agency is in effect at the Amersham site, authorising the discharge of radioactive wastes.

Regular monitoring of the environment was undertaken near all sites to assess the effects of discharges. Independent monitoring of the environment around the sites is conducted by the Environment Agency, FSA and SEPA.

In 2021, gaseous and liquid discharges were below regulated limits for each of the establishments (see Appendix 2, Table A2.1 and Table A2.2). Solid waste transfers in 2021 from nuclear establishments in Scotland (Dounreay) are also given in Appendix 2 (Table A2.4).

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 3 reactors are now shut down and undergoing decommissioning.

From 2005, the NDA became responsible for the UK's civil nuclear liabilities which included those at Dounreay. Consequently, the 3 existing radioactive waste disposal authorisations were transferred to a new site licensed company (Dounreay Site Restoration Limited, DSRL), before DSRL took over the site management contract. In July 2020, it was announced that DSRL ownership would transfer to the NDA. The official transition of DSRL ownership occurred on 1 April 2021.

In December 2021, SEPA granted a variation to the Dounreay site EASR permit to allow receipt of radioactive waste in the form of debris within fuel transport flasks. The variation also allows receipt of radioactive waste in the form of items found during environmental monitoring activities. It does not make any changes to the authorised gaseous and aqueous limits included within DSRL's permit. Any future radioactive waste received in fuel transport flasks at Dounreay will be returned to Sellafield.

In February 2022, SEPA issued an Information Notice to DSRL to obtain details of DSRL's options assessment for the non-active drainage system at Dounreay. This follows the identification of very low levels of radioactivity in samples taken from the non-active drainage system which is not an authorised disposal route for radioactive waste. Although the concentrations of radionuclides measured in the samples do not give rise to concern in relation to public health, DSRL are required to address its EASR permit compliance requirements in relation to liquid discharges to the marine environment from the non-active drainage system.

In 2021, radioactive waste discharges from the Dounreay site 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 2020 (Appendix 2, Table A2.1 and Table A2.2). Solid waste transfers from Dounreay in 2021 are also given in Appendix 2 (Table A2.4).

The most recent habits survey was conducted in 2018 [152]. This habits survey did not identify any occupancy in the area of Oigin's Geo (see Figure 4.2), as an external exposure pathway.

SEPA granted an authorisation in 2013 to DSRL for the Low-Level Radioactive Waste Disposal Facility (LLWF) that is located adjacent to the main Dounreay site. The first phase of the disposal site comprised the construction and operation of 2 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 2 vaults, with phase 2 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.

Doses to the public

The 'total dose' from all pathways and sources of radiation was 0.026mSv in 2021 (Table 4.1), or less than 3% of the dose limit, and up from 0.009mSv in 2020. As in 2020, the representative person was adults consuming game meat at high rates in 2021. The increase in 'total dose' was mostly due to an increased caesium-137 concentration observed in game meat (venison).

The trend in the annual 'total dose' over the period 2010 to 2021 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 to 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. As in 2021, 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).

The annual dose to a consumer of terrestrial foodstuffs was 0.017mSv in 2021, or less than 2% of the dose limit for members of the public of 1mSv, and up from 0.015mSv in 2020. The reason for the increase in dose was the same as that contributing to the 'total dose'. 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 less than the 'total dose' in 2021 (0.021mSv) and up from 0.007mSv in 2020. The reason for the increase in dose was mainly due to higher concentrations of plutonium-239+240 and americium-241 reported in molluscs collected in 2021 (not collected in 2020). The dose (external pathways only) to members of the public visiting Oigin's Geo, based on previously collected habits data [153] and 2019 monitoring data, was less than 0.005mSv. The most recent habits survey was conducted in 2018 [152]. This habits survey did not identify any occupancy in the area of Oigin's Geo, a coastal feature to the east of Dounreay (see Figure 4.2), as an external exposure pathway.

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 naval reactor test establishment (NRTE)), which is operated by the MOD's Submarine Delivery Agency. Monitoring conducted in 2021 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. As in recent years, goats' milk samples were not sampled, as no milk sample was available in 2021.

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 Table 4.2(a) and Table 4.2(c).

The concentrations of radionuclides at Dounreay were generally low and relatively similar to those in previous years. In 2021, strontium-90, caesium-137, plutonium-239+240 and americium-241 were positively detected in a few food samples. As in 2020, antimony-125 and iodine-129 concentrations were all reported as less than values in 2021. Activity concentrations in air samples at locations near to the site (Table 4.2(c)) were reported as less than values, apart from gross alpha from the location near Shebster (just above the LoD).

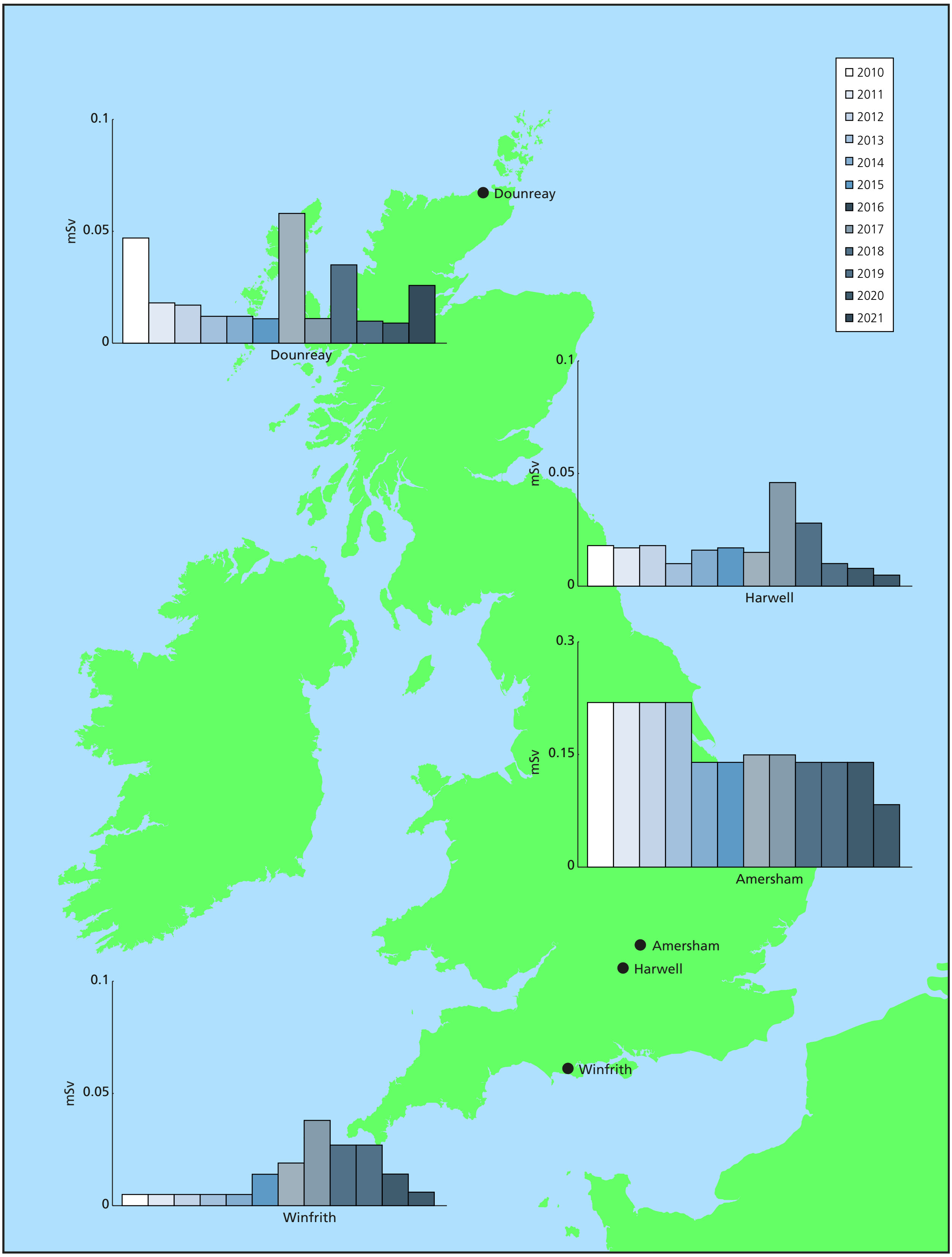


Figure 4.1 'Total dose' at research establishments, 2010–2021. (Small doses less than or equal to 0.005mSv are recorded as being 0.005mSv). Note different scale for Amersham.

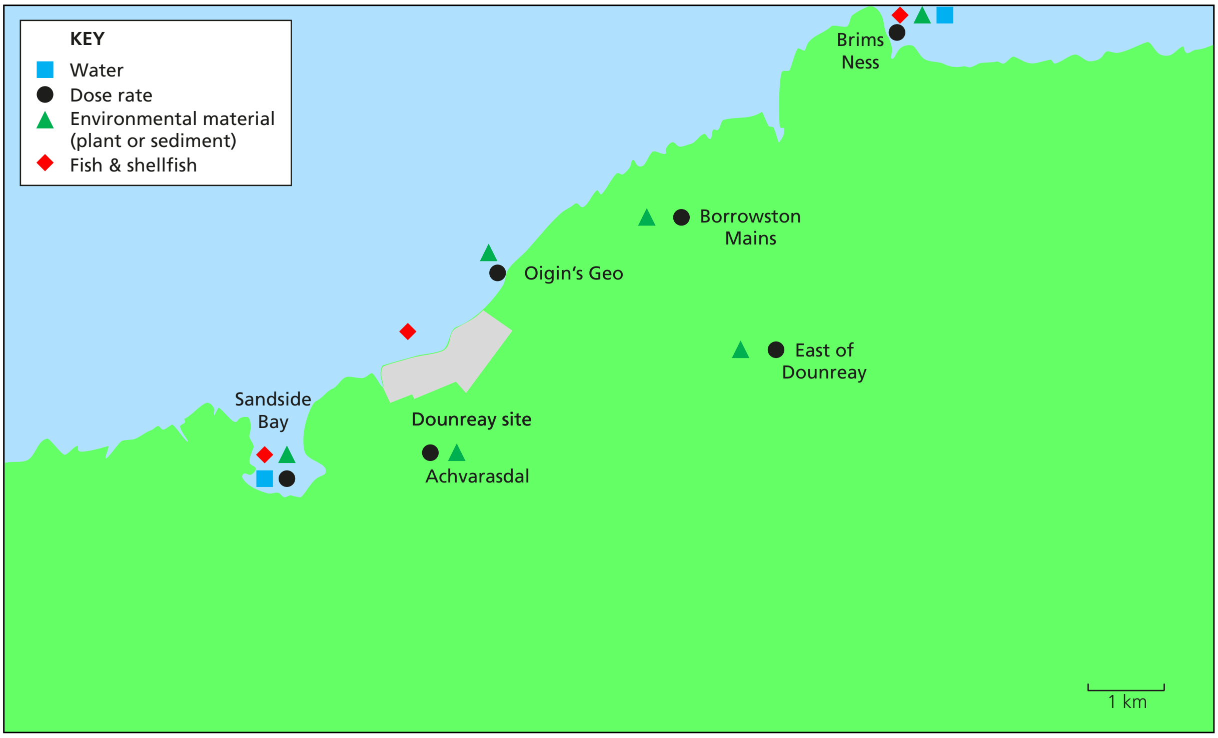


Figure 4.2 Monitoring locations at Dounreay, 2021
(not including farms or air sampling locations)

Monitoring for caesium-137 in a venison sample was continued in 2021 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 31Bq kg^{-1}, higher than the data reported in 2020 (7.6Bq kg^{-1}) but still less elevated than those enhanced concentrations measured in other game in previous years (venison: 42Bq kg^{-1}, 160Bq kg^{-1} and 69Bq kg^{-1} in 2018, 2016 and 2009, respectively; rabbit: 110Bq 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. Unlike in 2020, honey was not collected in 2021. Caesium-137 was positively detected in honey in recent (24, 23 and 38Bq kg^{-1} in 2020, 2019 and 2016, respectively). Earlier RIFE reports have provided results and interpretation of honey monitoring (for example [47]).

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 (which operated from 1958 to 2005), and a minor contribution from the adjoining reactor site (Vulcan NRTE).

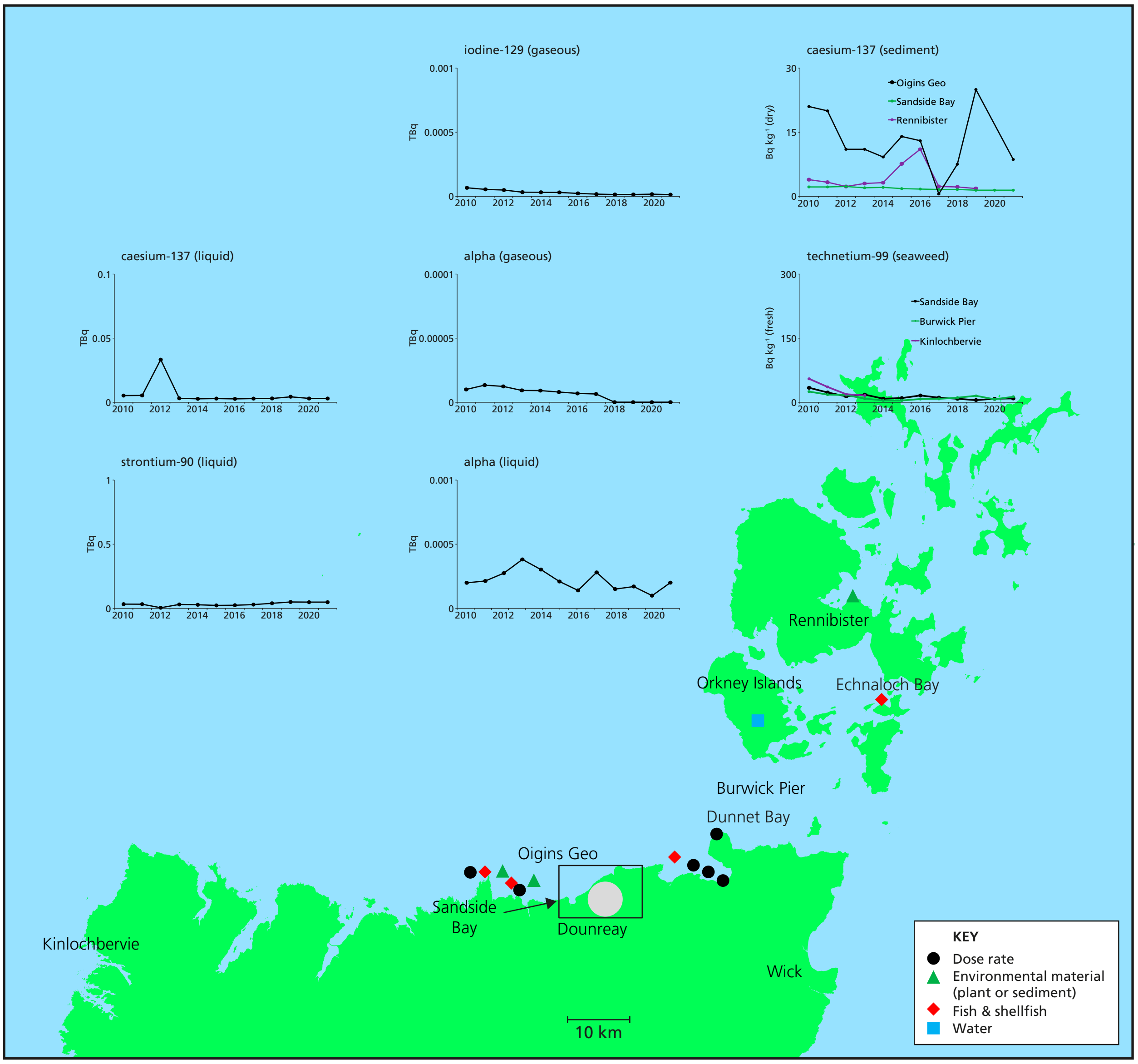


Figure 4.3 Monitoring locations, discharges of gaseous and liquid radioactive wastes and monitoring of the environment in the north of Scotland, 2020 (not including farms or air sampling locations). The rectangle around the Dounreay site is the area presented in Figure 4.2.

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[14] Order are collected under consent granted in 1997 by the Scottish Office and revised in 2011 by the FSS (then FSA in Scotland).

Crabs, mussel and winkle samples were collected from areas along the Caithness coastline. Additionally, sediment and seaweed were sampled in 2021 as indicator materials (but no seawater). The results for marine samples, and gamma and beta dose rates, are given in Table 4.2(a) and Table 4.2(b). Activity concentrations were generally

[14] The FEPA Order was made in 1997 following the discovery of fragments of irradiated nuclear fuel on the seabed near Dounreay, by United Kingdom atomic energy authority (UKAEA), and prohibits the collection of seafoods within a 2km radius of the discharge pipeline.

low in 2021 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 3 locations. Overall, gamma dose rates in 2021 were higher than those observed in 2020. Beta dose rate measurements were reported as less than values (Table 4.2(b)) in 2021.

During 2021, DSRL continued monitoring of local public beaches, using vehicle mounted detectors, for radioactive fragments in compliance with the requirements of the authorisation granted by SEPA. In 2021, 5 fragments were recovered from Sandside Bay and 5 from the Dounreay foreshore. The caesium-137 activity measured in the fragments recovered from Sandside Bay ranged between 4.3kBq and 42kBq (similar to ranges observed in recent years).

As previously reported in 2016, one piece of irradiated nuclear fuel (fragment) was detected and recovered from the Dounreay foreshore solely due to the presence of americium-241. Unlike fragments normally detected and removed, the presence of caesium-137 contamination was not detected in this fragment.

Simulated digestion analysis was undertaken on the fragment and the results from this work indicated that it would not represent a realistic risk to public health from inadvertent ingestion. The results of the digestion analysis indicated that only extremely low quantities of americium-241 were released and as a result the fragment would not represent a realistic risk to public health from ingestion. Due to alpha emissions, ingestion of the Am-241 particle would be considered the more limiting pathway for radiation exposure.

The Particles Retrieval Advisory Group (Dounreay) (PRAG (D)) and SEPA requested that the site operator determine the possibility of a large population of high Am-241/low Cs-137 bearing fragments being present on either Sandside beach or the Dounreay foreshore.

During July and August 2021, DSRL performed a beach monitoring trial at the west foreshore and Sandside Beach using the monitoring system which is in operation at Sellafield. The monitoring system is known as the FIDLER (Field Instrument for the Detection of Low Energy Radiation) system and includes additional detectors to assist with the detection of ‘alpha rich’ fragments. No particles were found during the beach monitoring trial. PRAG(D) concluded that the monitoring with the FIDLER detectors indicated that there could not be a large population of alpha rich fragments present on the upper sediment on the beach which could pose a realistic risk to health. Considering the results of the digestion analysis (low hazard) and large area monitoring (low population), PRAG(D) recommended that there is no need for changes to be made to DSRL's beach monitoring arrangements.

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 [154]. Since the work of DPAG[15] was concluded, PRAG (D) has published reports in 2010 and 2011 [155] [156]. 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 [157]. The report considered the extent and effectiveness of the offshore recovery programme to reduce the numbers of particles. The report concluded that any noticeable change in the rate or radioactive content of the particles arriving on the nearest public beach (Sandside Bay) will take several years to assess and recommended that in the interim the monitoring of local beaches should continue.

In 2007, FSA reviewed the Dounreay FEPA Order. A risk assessment, that was peer-reviewed by UKHSA (formerly HPA and PHE), indicated that the food chain risk was very small [158]. 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 (now completed) 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 sole remaining nuclear licenced site is located at Amersham, in Buckinghamshire. It consists of a range of plants previously used for manufacturing diagnostic imaging products for use in medicine and research, which are now closed and are being decommissioned.

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 [159].

[15] 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.

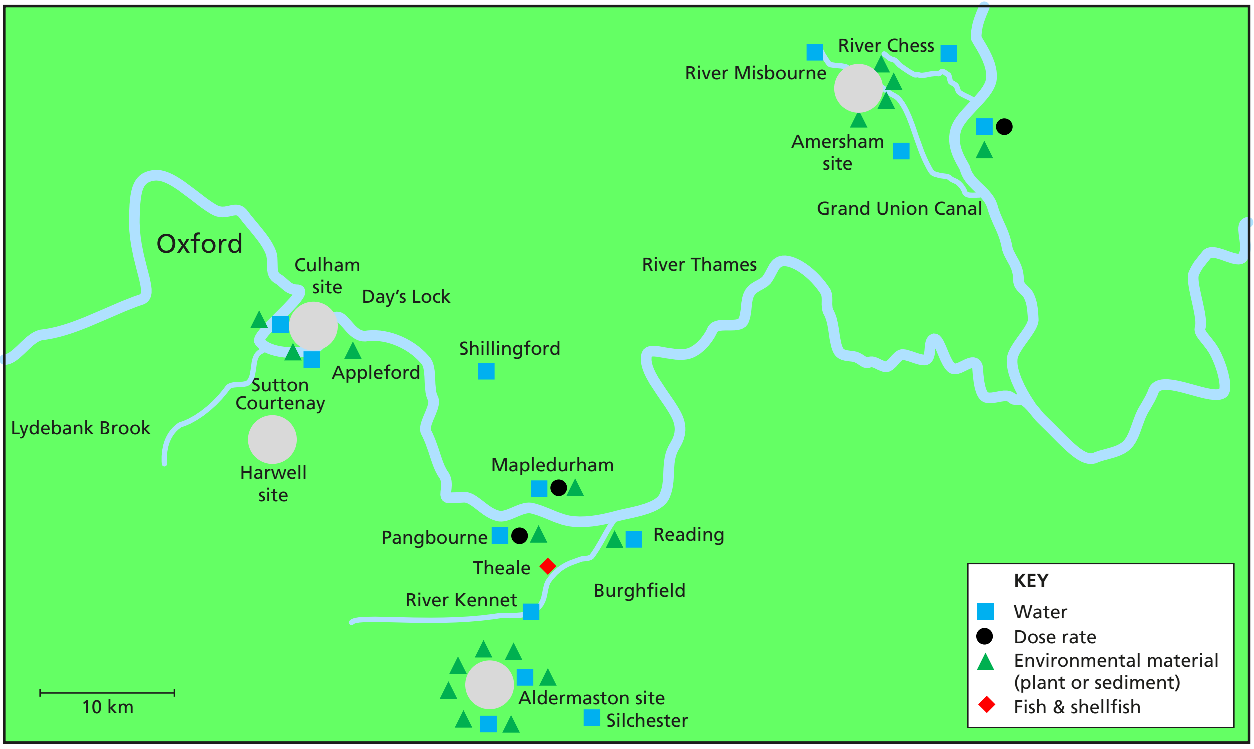


Figure 4.4 Monitoring locations at Thames sites, 2021 (not including farms)

Doses to the public

The 'total dose' from all pathways and sources of radiation was conservatively estimated to be 0.083mSv in 2021 (Table 4.1) or approximately 8% of the dose limit, and decreased from 2020. The dominant contribution to 'total dose' was from direct radiation from stored radioactive waste. The previous dominant contribution (to 'total dose') was from direct radiation associated with radiochemicals manufactured elsewhere and brought to the Grove Centre site for storage and subsequent distribution. The Grove Centre is no longer used as a distribution hub. The representative person was adults living in the vicinity of the site in 2021. 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 2010 to 2021 is given in Figure 4.1. 'Total doses' remained broadly similar over time (up until 2013) and were dominated by direct radiation. The lower values from 2014 onwards are due to changes in working practices for distribution activities, with products spending less time in the dispatch yard – as well as the construction of a shield wall on the western side of a building that contains legacy radioactive wastes. All distribution activity ceased in 2019. Dose from the site is now dominated radiation from the waste store. The 'total dose' is expected to be no more than the conservative estimated value of 0.083mSv.

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 2021 (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 0.006mSv and unchanged from 2020. As in previous years, gaseous discharges of radon-222 remain the dominant contributor in 2021. 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. As in recent years, the dose to a local angler was less than 0.005mSv in 2021.

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 1kg 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 [160]. 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 0.005mSv in 2021 and unchanged from 2020.

Gaseous discharges and terrestrial monitoring

The Amersham facility is permitted to discharge gaseous radioactive wastes via stacks on the site. Rebalancing of the ventilation systems in the buildings where radium waste is stored has resulted in radon emissions decreasing by about 20% since 2019. Discharges of radionuclides other than alpha emitters, short lived radionuclides and tritium, increased from Amersham in 2021, in comparison to releases in 2020. The Amersham facility discharged approximately 1GBq of krypton-85 from legacy cylinders, via an approved stack. This was agreed beforehand with the Environment Agency as BAT as no other use could be found for the gas and the environmental impact was determined to be insignificant. The results for the terrestrial monitoring for 2021 are given in Table 4.3(a) and Table 4.3(b). Unlike in 2020, sulphur-35 was positively detected in food (barley) in 2021. As in previous years, caesium-137 was detected in soil near the site 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 2021 are given in Table 4.3(a). Activity concentrations in freshwater were mostly reported as less than values in 2021. As in 2020 and due to the COVID-19 pandemic, samples of effluent and sludge from Maple Lodge STW could not be collected in 2021. Tritium, gross alpha and gross beta concentrations in water were below the investigation levels for drinking water in the Water Supply (Water Quality) (Amendment) 2018 Regulations (retained from the European Directive 2013/51). Gamma dose rates over grass were generally indistinguishable from natural background in 2021 (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 the UK's first Atomic Energy Research Establishment and is situated approximately 5km 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 5 research reactors of various types. Two of the reactors have been completely removed, and the fuel has been removed from the remaining 3 reactors. During 2021, the final remediation work was completed for the decommissioned Liquid Effluent Treatment Plant (LETP) and radiological sampling is now underway to support the permit surrender for this area and the old sewage treatment plant. On completion, this land will be handed back to the Harwell Science Park for future development.

Decommissioning work at the Harwell site is well underway with a project to transfer nuclear materials away from the site expected to be completed by 2025. Intermediate level waste (from Harwell, Winfrith and Culham) will be stored in a designated facility on the Harwell site during a quiescent period of 'care and maintenance'. At the final site clearance stage, the two reactors DIDO and PLUTO are due to be demolished and the remaining radioactive waste transferred to the GDF for final disposal. The most recent habits survey was conducted in 2015 [161].

Doses to the public

The 'total dose' from all pathways and sources of radiation was less than 0.005mSv in 2021 (Table 4.1), which was less than 0.5% of the dose limit, and down from 0.008mSv in 2020. The representative person was prenatal children of adults spending time over sediments, a change from previous years (adults living near to the site). The decrease in 'total dose' was mostly attributed to a lower estimate of direct radiation from the site in 2021 (Table 1.1). The trend in annual 'total dose' over the period 2010 to 2021 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 also less than 0.005mSv (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, with some reported as nil, in 2021. 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 2021 are shown in Table 4.4. In 2021, tritium and caesium-137 concentrations in terrestrial samples were 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, and the discharge pipeline removed. Further information is available via: https://www.gov.uk/government/publications/decommissioning-of-the-harwell-site-discharge-pipeline.

Discharges of surface water drainage from the Harwell site are made via the Lydebank Brook, north of the site, which is a permitted route. As in 2020, discharges from Lydebank Brook were very low. Figure 4.5 shows trends of discharges over time (2010 to 2021) 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. Due to on-going access issues at Day's Lock, the Environment Agency have replaced this sampling location with River Thames above Shillingford. Concentrations of tritium, cobalt-60 and caesium-137 in freshwater were reported as less than values (as in recent years). The caesium-137 concentration in sediment continued to be enhanced above background levels in 2021 but is small in terms of any radiological effect. As in 2020, plutonium-239+240 was positively detected in the sediment sample collected near Shillingford and the concentrations of all radionuclides in flounder from the lower reaches of the Thames were reported as less than values in 2021.

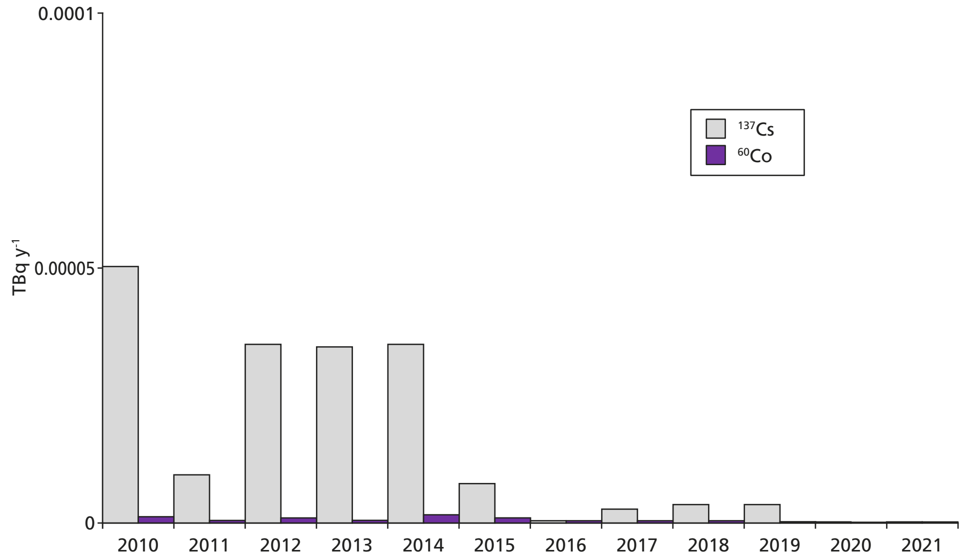


Figure 4.5 Trends in liquid discharges of caesium-137 and cobalt-60 from Harwell, Oxfordshire 2010–2021

4.4 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 9 research and development reactors. The last operational reactor at Winfrith closed in 1995. Seven of the reactors have been decommissioned. The final two; steam generating heavy water and 'Dragon' (high temperature gas-cooled) reactors and supporting site facilities, are in the process of being decommissioned. It is the end state intention of Magnox, to return most of the land to a brownfield heathland site with public access.

The Tradebe Inutec site is a radiological waste processing facility, for the wider nuclear industry, located adjacent to the main Winfrith site. In early 2019, Tradebe Inutec acquired buildings and land at Winfrith from the NDA and the ONR and Environment Agency granted a new nuclear site licence and environmental permit transfer (respectively) to Inutec Limited (who trade as Tradebe Inutec). Prior to this, Tradebe Inutec had been operating as a tenant of Magnox Limited.

Magnox Winfrith and Tradebe Inutec undertake separate site environmental monitoring programmes as required by their respective environmental permits. However, in RIFE, Magnox Winfrith and Tradebe Inutec 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 (covering both the Magnox and Tradebe Inutec sites) was conducted in 2019 [162].

Doses to the public

In 2021, the 'total dose' from all pathways and sources of radiation was 0.006mSv (Table 4.1), or less than 1% of the dose limit, and down from 0.014mSv in 2020. The decrease of the dose was almost entirely attributed to a lower estimate of direct radiation from the site in 2021 (Table 1.1). The representative person was adults living near the site and unchanged from 2020. 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.

The dose to a high-rate consumer of locally grown food was less than 0.005mSv in 2021. The reason for the small decrease in dose (from 0.005mSv in 2020) was mostly due to lower concentrations of carbon-14 in milk.

The dose to a high-rate consumer of fish and shellfish was less than 0.005mSv in 2021 and down from less 0.006mSv in 2020. The main reason for this decrease in dose was due to a lower gamma dose rate measurement over a different substrate at Weymouth Bay (pebbles and sand).

Gaseous discharges and terrestrial monitoring

At Magnox Winfrith, gaseous radioactive waste is discharged via various stacks to the local environment. As in previous years, discharges were very low in 2021.

Gaseous discharges from Tradebe Inutec are also made via stacks to the local environment and are given in Appendix 2 (Table A2.1). Discharges were all less than 1% of the discharge limits.

The main 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 4.6. Data for 2021 are given in Table 4.5(a). Results from terrestrial samples provide little indication of an effect due to gaseous discharges. As in 2020, the carbon-14 concentrations in locally produced milk were above 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 Water Supply (Water Quality) (Amendment) 2018 Regulations (retained from the European Directive 2013/51).

Figure 4.6 Monitoring locations at Winfrith, 2021 (not including farms)

Liquid waste discharges and aquatic monitoring

Liquid wastes, from the Magnox Winfrith site, are disposed via a pipeline to deep water in Weymouth Bay. As in previous years, discharges continued at very low rates in 2021 (reported as <1% of the annual limit or nil).

Figure 4.7 shows trends of liquid discharges over time (2010 to 2021) 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.

Liquid waste from Tradebe Inutec is transferred off site and discharged into Southampton Water under a non-nuclear permit.

Analyses of seafood and marine indicator materials and measurements of external radiation over muddy intertidal areas were conducted. Data for 2021 are given in Table 4.5(a) and Table 4.5(b). Concentrations of radionuclides in the marine environment were low and similar to those in previous years. Unlike in 2020, technetium-99 and caesium-137 were positively detected in seaweed collected at Lulworth Cove and Weymouth Bay fish (skates and rays), respectively. Gamma dose rates were slightly lower than those in 2020.

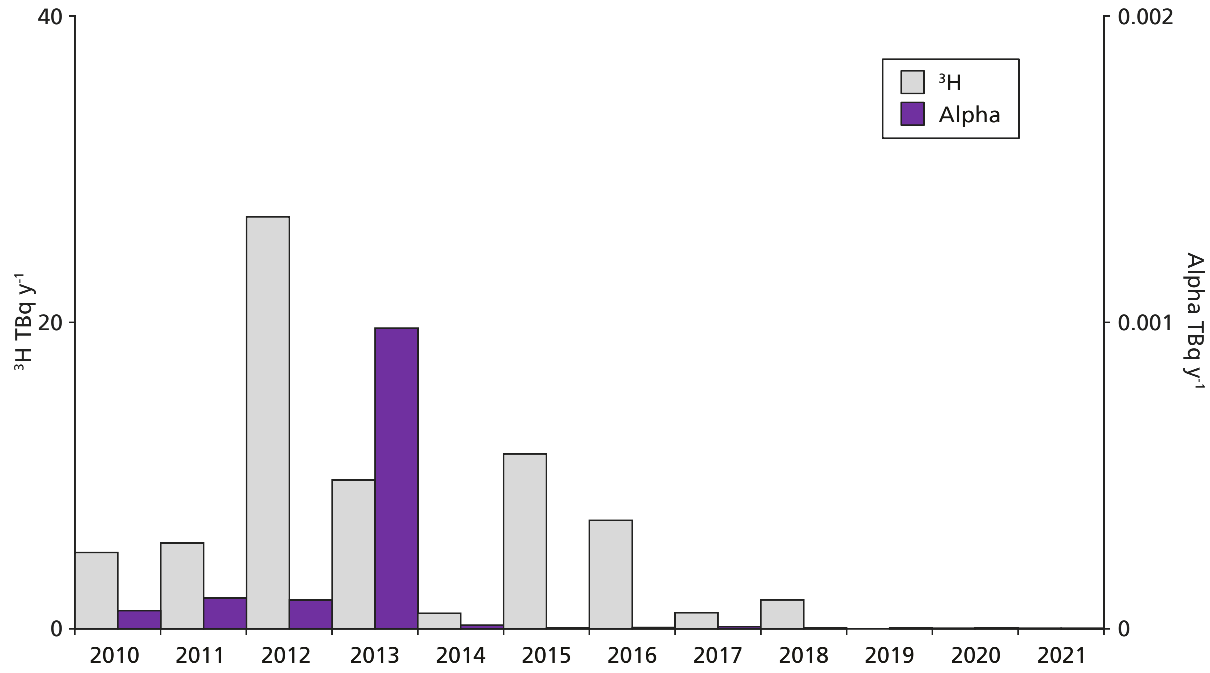


Figure 4.7 Trends in liquid discharges of tritium and alpha emitting radionuclides from Winfrith, Dorset 2010–2021

4.5 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 2021 due to operation of these sites.

4.5.1 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 (including tritium and caesium-137), from using the River Thames directly as drinking water downstream of the discharge point at Culham in 2021, was estimated to be much less than 0.005mSv in 2021 (Table 4.1).

Monitoring of soil and grass around Culham and of sediment and water from the River Thames was undertaken in 2021. Locations and data are shown in Figure 4.4 and Table 4.6, 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 were reported as less than values. Overall, no effects were detected due to site operation. The reported caesium-137 concentration in the downstream sediment (23Bq kg^{-1}) was slightly higher in 2021, in comparison to that in 2020 (19Bq kg^{-1}). Caesium-137 concentrations in the River Thames sediment are not attributable to Culham but were due to past discharges from Harwell, and fallout from Chernobyl and nuclear weapons testing.

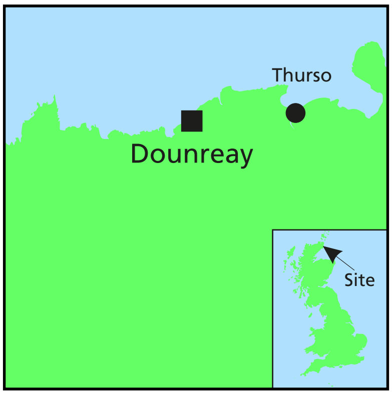
4.5.2 Imperial College Reactor Centre, Ascot, Berkshire

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 completely de-fuelled in 2014. The site has now been fully decommissioned and was de-licenced in March 2022.

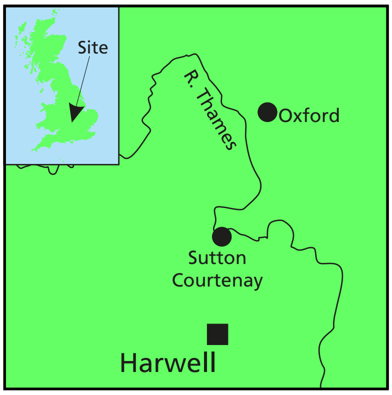
As in recent years, gaseous discharges were reported as nil in 2021 (Appendix 2, Table A2.1). Liquid discharges were also reported as nil in 2021 (Appendix 2, Table A2.2). The final decommissioning operations involving the discharge of radioactive liquid effluents occurred in 2020. Monitoring of the 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.

LOCATION MAPS

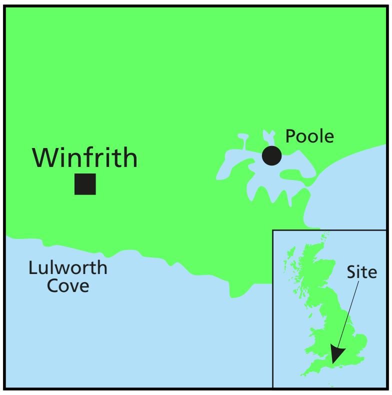


Dounreay

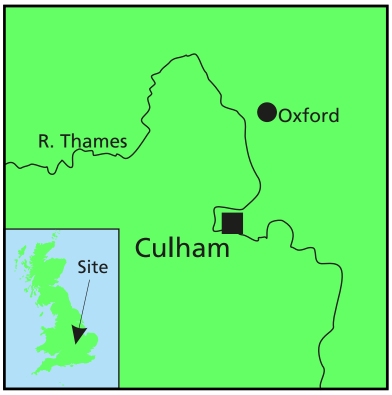
Amersham



Harwell



Winfrith



Culham

Table 4.1 Individual doses - Research and radiochemical production sites, 2021

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
Dounreay								
'Total dose' - all sources	**Adult game meat consumers**	**0.026**	**<0.005**	**0.026**	**-**	**-**	**-**	**-**
Source specific doses	Seafood consumers	0.021	0.009	-	0.011	-	-	-
	Inhabitants and consumers of locally grown food	0.017	-	0.017	-	-	<0.005	-
Amersham								
'Total dose' - all sources	**Local adult inhabitants (0-0.25km)**	**0.083[d]**	**-**	**<0.005**	**<0.005**	**-**	**<0.005**	**0.080**
Source specific doses	Anglers	<0.005	<0.005	-	<0.005	-	-	-
	Infant inhabitants and consumers of locally grown food	0.006[d]	-	<0.005	-	-	<0.005	-
	Workers at Maple Lodge STW	<0.005	-	-	<0.005	<0.005	-	-
Harwell								
'Total dose' - all sources	**Prenatal children of occupants over riverbank**	**<0.005**	**<0.005**	**-**	**<0.005**	**-**	**-**	**-**
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 (0.5-1km)**	**0.006**	**<0.005**	**<0.005**	**<0.005**	**-**	**<0.005**	**0.006**
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	-
Culham								
Source specific dose	Drinkers of river water	<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, 2021

Material	Location	No. of sampling observations	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}					
			^{60}Co	^{90}Sr	^{99}Tc	^{125}Sb	^{137}Cs	^{154}Eu
Marine samples								
Cod	Scrabster	2	<0.10			<0.21	0.28	<0.10
Crabs	Pipeline	2	<0.10	<0.10	<0.27	<0.13	<0.17	<0.10
Crabs	Strathy	2	<0.10			<0.17	<0.10	<0.10
Crabs	Melvich Bay	2	<0.10		0.24	<0.15	<0.10	<0.10
Mussels	Echnaloch Bay	1	<0.10			<0.14	<0.10	<0.10
Winkles	Brims Ness	4	<0.10	<0.10		<0.19	<0.11	<0.10
Winkles	Sandside Bay	4	<0.10	<0.10	0.44	<0.18	<0.12	<0.10
Fucus vesiculosus	Brims Ness	4	<0.10			<0.12	<0.11	<0.10
Fucus vesiculosus	Sandside Bay	4	<0.10		8.8	<0.12	<0.11	<0.10
Fucus vesiculosus	Burwick Pier	4	<0.10		13	<0.17	<0.14	<0.11
Sediment	Brims Ness	1	<0.10			<0.15	0.69	<0.13
Sediment	Strathy	1	<0.10			<0.14	0.76	<0.11
Sediment	Melvich Bay	1	<0.10			<0.14	0.75	<0.11
Sediment	Sandside Bay	1	<0.10			<0.15	1.4	<0.11
Sediment	Rennibister	1	<0.10			<0.15	8.6	<0.13

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	<0.16	0.0016	0.0025	0.0057		
Crabs	Pipeline	2	<0.10	0.012	0.024	0.089	1.5	160
Crabs	Strathy	2	<0.12	0.00090	0.0070	0.011		
Crabs	Melvich Bay	2	<0.11	0.0027	0.0099	0.011		
Mussels	Echnaloch Bay	1	<0.12			<0.10		
Winkles	Brims Ness	4	<0.13	0.23	1.5	1.2		
Winkles	Sandside Bay	4	<0.13	0.023	0.094	0.49		
Fucus vesiculosus	Brims Ness	4	<0.12			<0.10	5.4	420
Fucus vesiculosus	Sandside Bay	4	<0.12			<0.20	4.8	480
Fucus vesiculosus	Burwick Pier	4	<0.15			<0.11		
Sediment	Brims Ness	1	<0.24	1.9	9.5	9.4		
Sediment	Strathy	1	<0.21	0.19	0.93	1.3		
Sediment	Melvich Bay	1	<0.19	0.46	2.8	2.9		
Sediment	Sandside Bay	1	<0.23	2.7	13	14		
Sediment	Rennibister	1	0.93	0.10	1.00	1.5		

Table 4.2(a) continued

Material	Location or selection[b]	No. of sampling observations	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}							
			^{3}H	^{60}Co	^{90}Sr	^{125}Sb	^{129}I	^{137}Cs	^{155}Eu	^{234}U
Terrestrial samples - Annual										
Beef muscle		1	<5.0	<0.05	<0.10	<0.06	<0.064	0.14	<0.07	<0.050
Beef offal		1	<5.0	<0.05	<0.10	<0.09	<0.11	0.066	<0.11	<0.050
Cabbage		1	<5.0	<0.06	<0.10	<0.14	<0.074	<0.05	<0.11	
Carrots		1	11	<0.06	<0.10	<0.14	<0.14	<0.05	<0.11	
Cauliflower		1	<5.0	<0.05	<0.10	<0.12	<0.10	<0.05	<0.10	
Eggs		1	<5.0	<0.05	<0.10	<0.13	<0.078	2.9	<0.09	
Lamb muscle		1	<5.0	<0.05	<0.10	<0.05	<0.075	0.28	<0.07	<0.050
Mushrooms		1	<5.0	<0.05	0.10	<0.13	<0.050	0.80	<0.08	
Onion		1	<5.0	<0.05	0.05	<0.06	<0.050	<0.05		
Pheasant		1	<5.0		<0.10	<0.08	<0.68	0.63	<0.11	
Potatoes		1	<5.0	<0.05	<0.10	<0.07	<0.050	<0.050	<0.08	
Rosehips		1	<5.0	<0.05	0.60	<0.11	<0.050	0.79		
Swede		1	<5.0	<0.05	0.19	<0.08	<0.050	0.17		
Venison		1	5.2	<0.05	<0.10	<0.07	<0.097	31	<0.07	
Grass		3	<5.0	<0.05	0.53		<0.062	<0.30	<0.10	<0.57
	max				0.55		<0.064	0.45	<0.11	<0.78
Soil		3	<5.0	<0.05	0.73		<0.25	16	1.9	<13
Soil	max				0.84		<0.26	18	2.1	<25
Freshwater	Loch Calder	1	<1.1	<0.01				<0.01		
Freshwater	Loch Shurrery	1	<1.1	<0.01				<0.01		
Freshwater	Loch Baligill	1	<1.1	<0.01				0.01		
Freshwater	Heldale Water	1	<1.1	<0.01				<0.01		

Material	Location or selection[b]	No. of sampling observations	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}						
			^{235}U	^{238}U	^{238}Pu	$^{239}Pu+$ ^{240}Pu	^{241}Am	Gross alpha	Gross beta
Terrestrial samples - 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		
Cabbage		1					<0.07		
Carrots		1			<0.050	<0.050	<0.050		
Cauliflower		1			<0.050	<0.050	<0.050		
Eggs		1			<0.050	<0.050	<0.050		
Lamb muscle		1	<0.050	<0.050	<0.050	<0.050	<0.050		
Mushrooms		1			<0.050	0.050	0.15		
Onion		1			<0.050	<0.050	<0.050		
Pheasant		1			<0.050	<0.050	<0.050		
Potatoes		1			<0.050	<0.050	0.050		
Rosehips		1			<0.050	<0.050	0.050		
Swede		1			<0.050	<0.050	0.050		
Venison		1			<0.050	<0.050	<0.050		
Grass		3	<0.098	<0.57	<0.050	<0.050	<0.054		
	max		<0.16	<0.75			<0.061		
Soil		3	<0.72	<13	<0.13	0.40	<0.16		
Soil	max		<1.3	<23	<0.28	0.46	0.21		
Freshwater	Loch Calder	1					<0.01	0.011	0.054
Freshwater	Loch Shurrery	1					<0.01	0.011	0.049
Freshwater	Loch Baligill	1					<0.01	<0.010	0.041
Freshwater	Heldale Water	1					<0.01	0.011	0.040

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

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

Table 4.2(b) Monitoring of radiation dose rates near Dounreay, 2021

Location	Material or ground type	No. of sampling observations	μGy h^{-1}
Mean gamma dose rates at 1m over substrate			
Sandside Bay	Sediment	2	0.062
Sandside Bay	Winkle Bed	2	0.094
Brims Ness	Rocks	1	0.078
Brims Ness	Sediment	1	0.077
Melvich	Salt marsh	2	0.059
Melvich Sands	Sediment	2	<0.050
Strathy Sands	Sediment	2	0.050
Thurso riverbank	Sediment	2	0.085
Achvarasdal	Grass	2	0.078
Thurso Park	Grass	1	0.088
Thurso Park	Sediment	1	0.089
Borrowston Mains	Grass	2	0.077
Castletown Harbour	Sediment	2	0.089
Dunnet Bay	Sediment	2	0.052
Hallam	Grass	2	0.080
Mean beta dose rates			μSv h^{-1}
Sandside Bay	Sand	1	<1.0
Sandside Bay	Sediment	1	<1.0
Thurso riverbank	Sediment and rocks	2	<1.0
Castletown Harbour	Sand	2	<1.0

Table 4.2(c) Radioactivity in air near Dounreay, 2021

Location	No. of sampling observations	Mean radioactivity concentration, mBq m^{-3}			
		^{131}I	^{137}Cs	Gross alpha	Gross beta
Shebster	7	<0.032	<0.010	0.012	<0.20
Reay	8	<0.025	<0.010	<0.010	<0.20
Balmore	8	<0.035	<0.010	<0.011	<0.20

Table 4.3(a) Concentrations of radionuclides in food and the environment near Amersham, 2021

Material	Location	No. of sampling observ-ations	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}				
			^{3}H	^{131}I	^{137}Cs	Gross alpha	Gross beta
Freshwater samples							
Flounder	Woolwich Reach	1	<25	*	<0.07		
Sediment	Upstream of outfall (Grand Union Canal)	2[E]		<2.0	4.2	170	400
Sediment	Downstream of outfall (Grand Union Canal)	2[E]		<0.37	1.1	92	180
Freshwater	Downstream of outfall (Grand Union Canal)	1[E]	<3.3	<0.25	<0.20	<0.036	0.57
Freshwater	River Chess	1[E]	<3.6	<0.28	<0.26	<0.077	<0.033
Freshwater	River Misbourne - downstream	1[E]	<3.2	<0.33	<0.27	<0.032	0.071

Material	Location or selection[b]	No. of sampling observ-ations[c]	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}					
			^{3}H	^{35}S	^{131}I	^{137}Cs	Gross alpha	Gross beta
Terrestrial samples								
Milk		1	<2.4	<0.30	<0.0020	<0.06		
Potato		1	<2.3	<0.20		<0.05		
Barley		1	<3.7	1.5		<0.07		
Grass	Orchard next to site	1[E]			<1.1	<1.1	<2.2	230
Grass	Water Meadows (River Chess)	1[E]			<1.3	<1.3	<2.2	330
Soil	Orchard next to site	1[E]			<0.49	9.7	420	870
Soil	Water Meadows (River Chess)	1[E]			<0.62	7.3	170	490

* Not detected by the method used

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

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

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

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, 2021

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	1	0.063
Bank of Grand Union Canal (downstream)	Grass and stones	1	0.066
Downstream of outfall (Grand Union Canal)	Grass	1	0.059
Downstream of outfall (Grand Union Canal)	Grass and mud	1	0.063
Upstream of outfall (Grand Union Canal)	Grass	1	0.060
Upstream of outfall (Grand Union Canal)	Grass and sand	1	0.055
Water Meadows (River Chess)	Grass	1	0.062
Orchard next to site	Grass	1	0.082

Table 4.4 Concentrations of radionuclides in food and the environment near Harwell, 2021[d]

Material	Location	No. of sampling observ-ations	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}								
			^{3}H	^{60}Co	^{131}I	^{137}Cs	^{238}Pu	^{239}Pu + ^{240}Pu	^{241}Am	Gross alpha	Gross beta
Freshwater samples											
Flounder	Woolwich Reach	1	<25	<0.04	*	<0.07			<0.16		
Sediment	River Thames (Sutton Courtenay)	1[E]		<0.38		13	<0.10	<0.48	<0.65	180	380
Sediment	River Thames (Shillingford)	1[E]		<1.3		5.5	<0.080	0.27	<0.44	340	660
Freshwater	River Thames (Long Wittenham)	4[E]	<3.6	<0.35		<0.29				<0.040	0.22
Freshwater	River Thames (Shillingford)	4[E]	<3.6	<0.28		<0.25				<0.053	0.23

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	<2.4	<2.4	<0.04
Milk	max				
Strawberries		1	<2.0	<2.0	<0.02
Wheat		1	<3.5	<3.5	<0.03

* Not detected by the method used
[a] Except for milk where units are Bq l^{-1}, and for sediment where dry concentrations apply
[b] Data are arithmetic means unless stated as 'max' in this column. 'Max' data are selected to be maxima. If no 'max' value is given the mean value is the most appropriate for dose assessments
[c] The number of farms from which milk is sampled. The number of analyses is greater than this and depends on the bulking regime
[d] The gamma dose rates in air at 1 m over grass; mud at Sutton Courtney were 0.072 µGy h^{-1} and 0.069 µGy h^{-1} , respectively
[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 Winfrith, 2021

Material	Location	No. of sampling observ-ations	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}									
			^{14}C	^{99}Tc	^{137}Cs	^{238}Pu	^{239}Pu + ^{240}Pu	^{241}Am	^{242}Cm	^{243}Cm + ^{244}Cm	Gross alpha	Gross beta
Marine samples												
Skates/Rays	Weymouth Bay	1			0.28			<0.13				
Crabs	Lulworth Banks	1	27		<0.08			<0.16				
Oysters	Lulworth Ledges	1			<0.02	0.00022	0.0014	0.0014	*	*		
Seaweed	Bognor Rocks	2[E]		<0.66	<0.58			<0.74				
Seaweed	Lulworth Cove	1[E]		1.0	<0.46			<0.70				
Seawater	Lulworth Cove	1[E]			<0.21			<0.35			<2.6	15

Material	Location or selection[b]	No. of sampling observations[c]	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}					
			Organic ^{3}H	^{3}H	^{14}C	^{137}Cs	Gross alpha	Gross beta
Terrestrial samples								
Milk		2	<2.4	<2.4	19	<0.05		
Milk	max					<0.06		
Cabbage		1	<2.4	<2.4	7.6	<0.05		
Oats		1	31	31	98	<0.06		
Grass	Near Newburgh Farm Cottages	2[E]		<15	20	<1.1	<2.3	280
Grass	Adjacent to railway	2[E]		<16	20	<1.2	<1.9	250
Sediment	North of site	1[E]				1.3	<66	<130
Sediment	R Frome (upstream)	1[E]				0.97	<70	<92
Sediment	R Frome (downstream)	1[E]				8.0	380	740
Sediment	R Win, east of site	1[E]				<0.17	<63	<120
Freshwater	North of site	2[E]		<5.7		<0.20	0.038	0.091
Freshwater	R Frome (upstream)	2[E]		<3.4		<0.24	<0.041	0.096
Freshwater	R Frome (downstream)	2[E]		<3.3		<0.20	<0.038	0.090
Freshwater	R Win, east of site	2[E]		<3.4		<0.25	<0.031	0.12

* Not detected by the method used

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

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

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

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

Table 4.5(b) Monitoring of radiation dose rates near Winfrith, 2021

Location	Ground type	No. of sampling observations	μGy h^{-1}
Mean gamma dose rates at 1m over substrate			
Weymouth Bay	Pebbles and sand	1	0.055
Osmington Mills	Rock and shingle	1	0.062
Durdle Door	Sand and shingle	1	0.050
Lulworth Cove	Sand and shingle	1	0.056
Swanage Bay	Sand and shingle	1	0.055
Poole Harbour	Sand and shingle	1	0.052

Table 4.6 Concentrations of radionuclides in the environment near Culham, 2021

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	<3.5			<0.26	<0.044	0.20
Freshwater	River Thames (downstream)	2	<3.5			<0.23	<0.043	0.22
Grass	0.6km east of site perimeter	2	<14	20		<1.0		260
Sediment	River Thames (upstream)	1				3.3		
Sediment	River Thames (downstream)	2				23		
Soil	1km east of site perimeter	1	<5.8	8.5		2.6		520

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

5. Defence establishments

Highlights

- 'total doses' for the representative person were approximately 4% of the dose limit for all sites assessed

Aldermaston, Berkshire

- 'total dose' for the representative person was 0.008mSv and increased in 2021

Barrow, Cumbria

- 'total dose' for the representative person was 0.044mSv and decreased in 2021

Derby, Derbyshire

- 'total dose' for the representative person was less than 0.005mSv and unchanged in 2021

Devonport, Devon

- 'total dose' for the representative person was less than 0.005mSv and unchanged in 2021
- gaseous discharges of tritium decreased in 2021

Faslane and Coulport, Argyll and Bute

- 'total dose' for the representative person was 0.007mSv and decreased in 2021

Rosyth, Fife

- 'total dose' for the representative person was 0.011mSv and increased in 2021
- gaseous and liquid discharges increased in 2021

This section considers the results of monitoring, under the responsibility of the Environment Agency, FSA, FSS and SEPA, undertaken routinely near 9 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 and liquid discharges from Burghfield, Berkshire). Monitoring at nuclear submarine berths is also conducted by the MOD (for example [163]).

In 2021, gaseous and liquid discharges were below regulated limits for each of the defence establishments (see Appendix 2, Table A2.1 and Table A2.2). Solid waste transfers in 2021 from nuclear establishments in Scotland (Coulport, Faslane, Rosyth and Vulcan) are also given in Appendix 2 (Table A2.4).

5.1 Aldermaston and Burghfield

AWE has two major sites located in Berkshire: AWE Aldermaston and AWE Burghfield. 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 the UK's nuclear stockpile are managed, on behalf of the MOD, by AWE plc (which is a non-departmental public body, wholly owned by the MOD). AWE at Burghfield is responsible for the complex final assembly and maintenance of warheads whilst in service, as well as their decommissioning. 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 [164].

Doses to the public

In 2021, the 'total dose' from all pathways and sources of radiation was 0.008mSv (Table 5.1), or approximately 1% of the dose limit, which has increased slightly compared to 2020 (<0.005mSv). The small increase is due to increased concentrations of isotopes of uranium in milk. The representative person was infants (1-year-old) consuming milk at high-rates, and unchanged from that in 2020.

Source specific assessments for high-rate consumers of locally grown foods, for sewage workers and for anglers, gave exposures that were also less than 0.005mSv in 2020 (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 1kg 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 2021 are given in Table 5.2(a). In 2021, 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 both 2020 and 2021 (where comparisons can be drawn at the same location). Caesium-137 concentrations in all food and grass samples were reported as less than values in 2021. Concentrations of uranium isotopes in milk in 2021 were higher when compared to those values in

2020. Natural background or fallout concentrations from global 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 treatment works at Silchester (Figure 4.4), and to the Aldermaston Stream from the Aldermaston site. A time-series trend of generally decreasing tritium discharges from Aldermaston (2010 to 2021) 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, [165]). 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. Discharges of radioactive liquid effluent from Burghfield are made to a sewage treatment works located on the Burghfield site. Environmental monitoring of the River Thames (Pangbourne and Mapledurham) has continued to assess the effect of historical discharges.

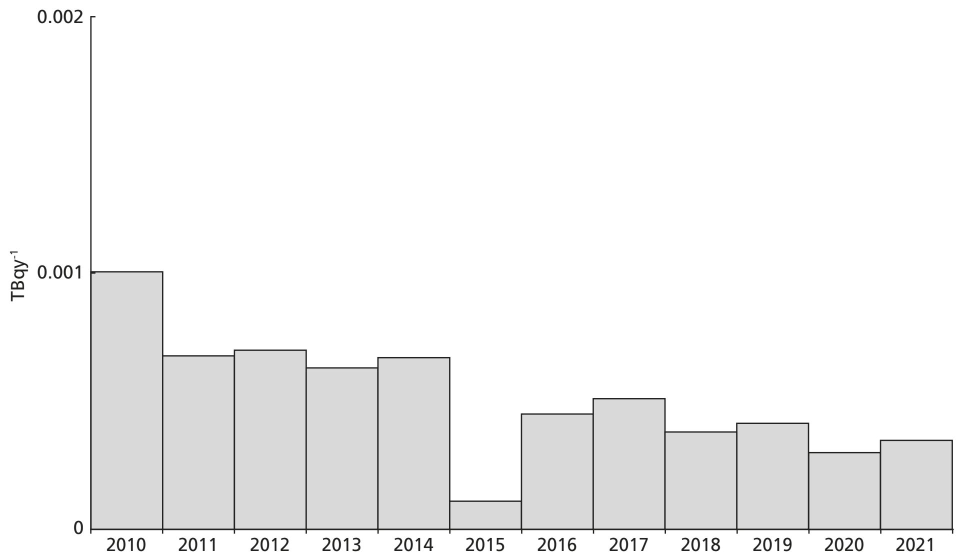


Figure 5.1 Trends in liquid discharges of tritium from Aldermaston, Berkshire 2010–2021 (including discharges to Silchester sewer and Aldermaston Stream)

Activity concentrations for freshwater, fish, crayfish, sediment samples (including gully pot sediments from road drains), and measurements of gamma dose rates, are given in Table 5.2(a) and Table 5.2(b). The Environment Agency continued their enhanced environmental monitoring of sediments and freshwater samples in 2021 (as in recent years). The concentrations of artificial radioactivity detected in the Thames catchment were very low in 2021 and generally similar to those in 2020. In 2021, tritium concentrations in freshwater and terrestrial samples were all reported as less than values. Iodine-131 was not positively detected in food samples in 2021. Activity concentrations of artificial radionuclides in shellfish were very low in 2021 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 2021, 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 Water Supply (Water Quality) (Amendment) 2018 Regulations (based upon 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% of the annual limit) in 2021. The most recent habits survey was undertaken in 2012 [166].

The ‘total dose’ from all pathways and sources of radiation was 0.044mSv (Table 5.1) in 2021, or approximately 4% of the dose limit, and down from 0.061mSv in 2020. Virtually all of this dose was due to the effects of Sellafield discharges. The representative person was adults living on a local houseboat. The decrease in ‘total dose’ was mostly due to lower gamma dose rates over mud and sand (at both Askam Pier and Roa Island), and to a lesser extent, gamma dose rates being measured over different ground types, from one year to the next.

Source specific assessments for a high-rate consumer of locally grown food and a person living on a local houseboat gave exposures that were less than the ‘total dose’ in 2021 (Table 5.1). No assessment of seafood consumption was undertaken in 2021 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 [167].

The FSA’s terrestrial monitoring is limited to vegetable and grass (or silage) sampling. The Environment Agency monitors gamma 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) and Table 5.3(b). No effects of discharges from Barrow were apparent in the concentrations of radioactivity in vegetables and silage, most reported as less than values. In 2021, the reported gross beta concentration in sediment (in the vicinity of the discharge point) was lower in 2021, in comparison to that in 2020. The gamma dose rates in intertidal areas near Barrow in 2021 are given in Table 5.3(b) and Table 2.9. As in previous years, gamma dose rates were enhanced above those expected due to natural background, and generally similar to those in 2020. 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 2 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 (for example, at a permitted landfill site or by incineration). The most recent habits survey was undertaken in 2021 [168].

Doses to the public

The ‘total dose’ from all pathways and sources of radiation was less than 0.005mSv in 2021 (Table 5.1), which is less than 0.5% of the dose limit, and unchanged from 2020. The representative person was infants consuming locally sourced water. Source specific assessments for consumption of fish, crustaceans and drinking river water at high-rates, and spent time on river-washed areas gave exposures that were also less than 0.005mSv in 2021 (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 2021 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 Water Supply (Water Quality) (Amendment) 2018 Regulations (based upon the European Directive 2013/51), and the dose from using the river as a source of drinking water was much less than 0.005mSv (Table 5.1).

Caesium-137 detected in sediments from local water courses was most likely from historic 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. RRSL formerly used the quarry for the controlled burial of solid low level radioactive waste. Concentrations of uranium isotopes detected in the sample in 2021 were broadly similar to those reported elsewhere in Derbyshire (Table 7.7).

5.4 Devonport, Devon

The Devonport Royal Dockyard consists of 2 parts and is operated by His Majesty's Naval Base (HMNB) (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 [169]. The routine monitoring programme in 2021 consisted of measurements of gamma dose rate and analysis of grass, vegetables, fish, shellfish and other indicator materials (Table 5.3(a) and Table 5.3(b)).

Doses to the public

The 'total dose' from all pathways and sources of radiation was less than 0.005mSv in 2021 (Table 5.1), which was less than 0.5% of the dose limit, and unchanged from 2020. 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 on intertidal areas. The trend in annual 'total doses' at Devonport remains less than 0.005mSv (Figure 6.1, [170]).

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, gave exposures that were also less than 0.005mSv in 2021 (Table 5.1).

Gaseous discharges and terrestrial monitoring

Discharges of tritium decreased in 2021 in comparison to those releases in 2020. Grass and vegetable samples were analysed for a number of radionuclides. Activity concentrations in terrestrial samples are reported as less than values in 2021.

Liquid waste discharges and aquatic monitoring

Discharges of tritium, cobalt-60 and "other radionuclides" to the Hamoaze (estuary) were generally similar in 2021, in comparison to those releases in 2020. The trends of tritium and cobalt-60 discharges over time (2010 to 2021) 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, [165]). The underlying reason for the overall decrease in cobalt-60 discharges over nearly 3 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.

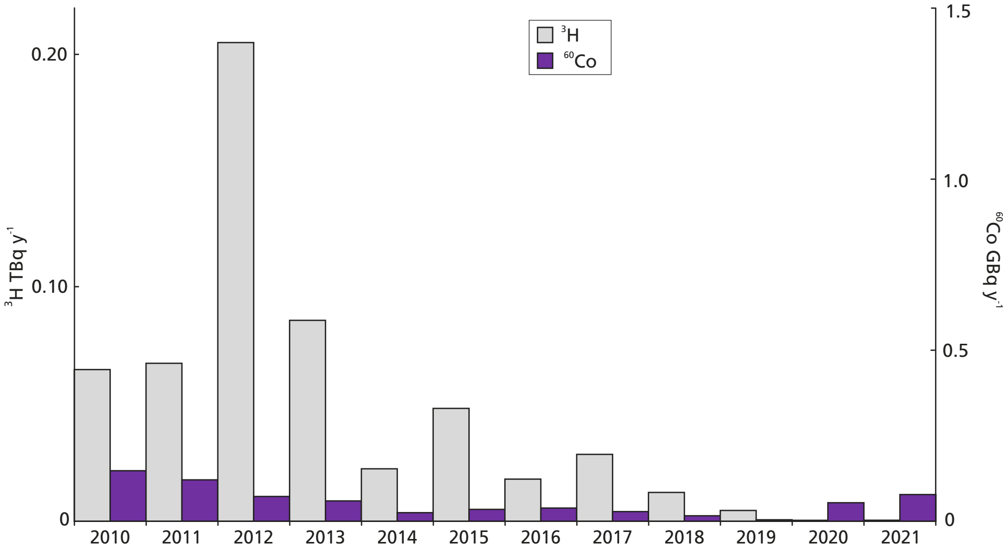


Figure 5.2 Trends in liquid discharges of tritium and cobalt-60 from Devonport, Devon 2010–2021

In marine samples, concentrations of tritium and cobalt-60 are reported as less than values in 2021. 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 2021. Gamma dose rates in the vicinity of Devonport in 2021, 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 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. The construction of a new radioactive waste treatment facility at Faslane continued during 2021 although the project has been subject to delays. The expected in-service date is now 2023. An application for a revised LoA that includes discharges from the facility was submitted to SEPA in 2019 and SEPA consulted on the application in 2020. Determination of the application was impacted by a cyber-attack on SEPA in December 2020, however work on the determination has now recommenced.

In 2021, gaseous tritium discharges (from Coulport) were lower in 2021 compared to those discharges in 2020 and liquid discharges in 2021 (from Faslane) were similar, in comparison to those releases in 2020 (see Appendix 2, Table A2.1 and Table 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 2021 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 [171].

The 'total dose' from all pathways and sources of radiation was 0.007mSv in 2021 (Table 5.1), which was less than 1% of the dose limit and down from 0.008mSv in 2020. The representative person was adults consuming fish at high rates. Activity concentrations in fish (not collected in 2021) were estimated using reported environmental fish data in 2021, sampled outside the aquatic habits survey area of this site (but within the Firth of Clyde). The small decrease in 'total dose' in 2021 was mostly due to a lower gamma dose rate at Helensburgh, in comparison to that in 2020. The assessment of this 'total dose' was highly conservative (due to the assumption of fish data). In 2021, source specific assessments for a high-rate consumer of shellfish and a consumer of locally grown food (based on limited data) gave exposures of 0.008mSv and less than 0.005mSv, respectively. The main reason for the change in dose (from 0.009mSv in 2020) to the consumer of 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 meat, domestic fruit, honey, water, grass and soil sampling. The results in 2021 are given in Table 5.3(a) and Table 5.3(b) and were generally similar to those in 2020. Caesium-137 was positively detected at a low concentration in honey (as in recent years) and domestic fruit. Radionuclide concentrations were generally reported as less than values in 2021. 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 (Table 5.3(b)). The tritium, gross alpha and gross beta concentrations were much lower than the investigation levels in the Water Supply (Water Quality) (Amendment) 2018 Regulations (retained from the European Directive 2013/51).

5.6 Holy Loch, Argyll and Bute

A small programme of monitoring at Holy Loch continued during 2021 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 similar to those values reported in 2020. The most recent habits survey to determine the consumption and occupancy rates by members of the public was undertaken in 1989 [172].

The external radiation dose to a person spending time on the loch shore was 0.007mSv in 2021, which was less than 1% of the dose limit for members of the public of 1mSv and unchanged from 2020 (Table 5.1).

5.7 Rosyth, Fife

The Rosyth naval dockyard is located on the north bank of the River Forth in Fife, 3km west of the Forth Road Bridge and some 50km 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 are required to continue managing 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 7 redundant nuclear submarines currently stored afloat at the dockyard site. The authorisation was transitioned to a permit under the Environmental Authorisations (Scotland) Regulations 2018 (EASR18) with a new permit being issued in March 2019. A LoA (effective from 2016) to the MOD allows the transfer of LLW from the 7 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 [173] 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 0.011mSv in 2021 (Table 5.1), which is approximately 1% of the dose limit. In 2021, the representative person was adults spending time over sediments. The increase in 'total dose' from 2020 was attributed to higher gamma dose rates over sand observed in 2021. The source specific assessment for marine pathways (fishermen and beach users) was estimated to be 0.014mSv in 2021 (an increase from 0.006mSv in 2020, based on 2019 data). The reason for the increase in dose is the same as that contributing to the maximum 'total dose'.

The gaseous and liquid discharges from Rosyth in 2021 are given in Appendix 2 (Table A2.1 and Table A2.2, respectively), and solid waste transfers in Table A2.4. Gaseous discharges of tritium and carbon-14 were slightly increased in 2021 compared to 2020 but remained low. Liquid wastes are discharged via a dedicated pipeline to the Firth of Forth. Liquid discharges of tritium decreased in 2021 in comparison to that in 2020.

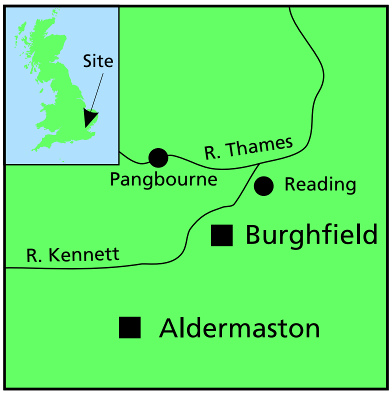
SEPA's routine monitoring programme included analysis of fish, shellfish, environmental indicator materials and measurements of gamma dose rates in intertidal areas. Results are shown in Table 5.3(a). The radioactivity concentrations in freshwater measured were low in 2021, and similar to those in recent 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 2020, based on 2019 data) and difficult to distinguish from natural background, although the dose rates were lower in sediment at Port Edgar in 2020 (based on 2019 data). The gross alpha concentration in a surface water sample from the Holl Reservoir remained below the investigation level (<0.010Bq kg^{-1}, Table 5.3(a)).

5.8 Vulcan NRTE, Highland

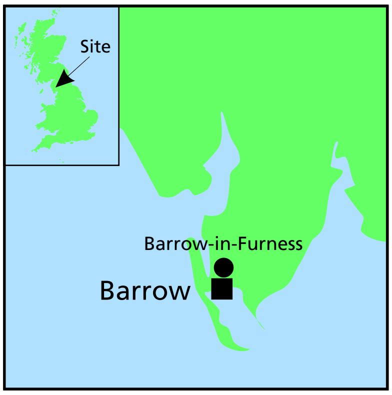
The Vulcan Naval Reactor Test Establishment (NRTE) is operated by the Submarine Delivery Agency, part of the MOD, and its purpose was to prototype submarine nuclear reactors. It is located adjacent to the Dounreay site, and the impact of its discharges is considered along with those from Dounreay (in 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. Magnox Limited issued a statement regarding future decommissioning and stated “Magnox, together with Dounreay, will be part of a joint working team exploring the option of transferring the future decommissioning of the MOD’s Vulcan site to the NDA Group. Any transfer would be subject to regulatory approval and sign-off by Government and is unlikely to take place before 2026.”

Gaseous discharges, and solid waste transfers, from Vulcan NRTE in 2021 are given in Appendix 2 (Table A2.1 and Table A2.4, respectively).

LOCATION MAPS

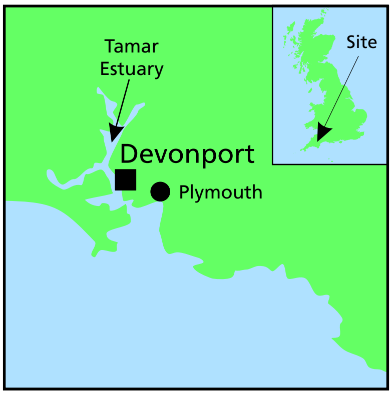


Aldermaston

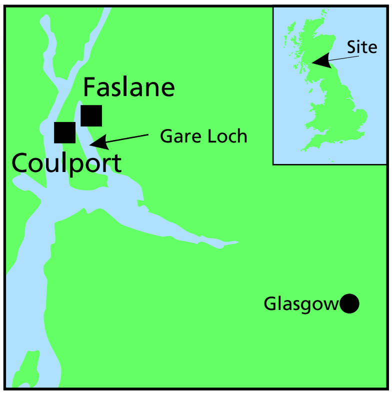


Barrow

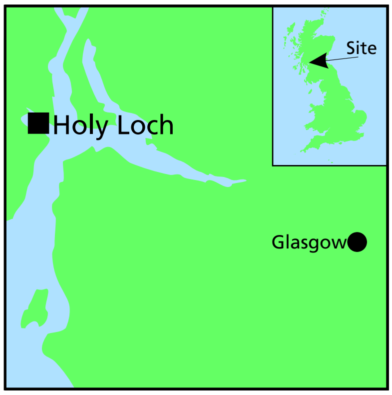
Derby



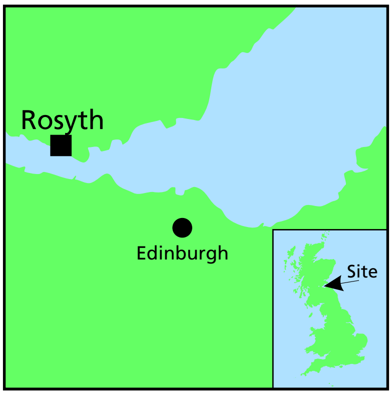
Devonport



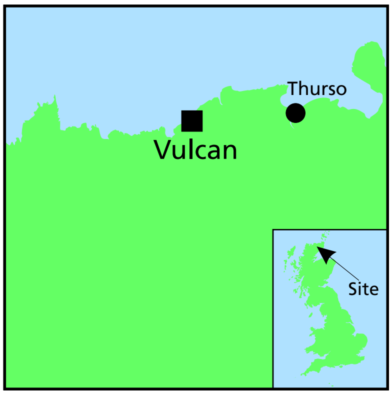
Faslane



Holy Loch



Rosyth



Vulcan

Table 5.1 Individual doses - defence sites, 2021

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
Aldermaston and Burghfield							
'Total dose' - all sources	**Infant milk consumers**	**0.008**	**-**	**0.008**	**-**	**-**	**-**
Source specific doses	Anglers	<0.005	<0.005	-	<0.005	-	-
	Infant inhabitants and consumers of locally grown food	<0.005	-	<0.005	-	-	<0.005
	Workers at Silchester STW	<0.005	-	-	<0.005	<0.005	-
Barrow							
'Total dose' - all sources	**Adult occupants on houseboats[g]**	**0.044**	**-**	**-**	**0.044**	**-**	**-**
Source specific doses	Houseboat occupants[g]	0.043	-	-	0.043	-	-
	Prenatal children of consumers of locally grown food	<0.005	-	<0.005	-	-	-
Derby							
'Total dose' - all sources	**Infant consumers of locally sourced water**	**<0.005**	**<0.005**	**-**	**<0.005**	**<0.005**	**-**
Source specific doses	Anglers consuming fish, shellfish and drinking water	<0.005	<0.005	-	<0.005	<0.005	-
	Children Inhabitants and consumers of locally grown food	<0.005	-	<0.005	-	-	<0.005
Devonport							
'Total dose' - all sources	**Adult consumers of marine plants and algae**	**<0.005**	**<0.005**	**-**	**<0.005**	**-**	**-**
Source specific doses	Seafood consumers	<0.005	<0.005	-	<0.005	-	-
	Houseboat occupants	<0.005	-	-	<0.005	-	-
	Prenatal children of Inhabitants and consumers of locally grown food	<0.005	-	<0.005	-	-	<0.005
Faslane							
'Total dose' - all sources	**Adult fish consumers**	**0.007**	**0.007**	**-**	**<0.005**	**-**	**-**
Source specific doses	Seafood consumers	0.008	0.008	-	<0.005	-	-
	Consumers of locally grown food	<0.005	-	<0.005	-	-	-
Holy Loch							
Source specific doses	Anglers	0.007	-	-	0.007	-	-
Rosyth							
'Total dose' - all sources	**Adult occupants over sediment**	**0.011**	**<0.005**	**-**	**0.011**	**-**	**-**
Source specific doses	Fishermen and beach users	0.014	<0.005	-	0.011	-	-

[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, 2021

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	*	<0.07			
Signal crayfish	Ufton Bridge - Theale	1	<25	<25	<11	<0.06	0.018	0.00068	0.013
Sediment	Pangbourne	2[E]				<0.80	17	<0.89	18
Sediment	Mapledurham	2[E]				13	12	<0.86	11
Sediment	Aldermaston	4[E]				3.3	22	<1.2	21
Sediment	Spring Lane	4[E]				<2.3	16	<0.92	16
Sediment	Stream draining south	4[E]				<0.64	27	<1.7	29
Sediment	Near Chamber 39 of PPL	4[E]				3.8	12	<0.88	12
Sediment	Oval pond near Chamber 14	4[E]				<1.4	16	<1.0	18
Sediment	River Kennet	4[E]				3.3	13	<1.1	13
Gully pot sediment	Aldermaston Gate	1[E]		<12		<0.73	16	<0.72	16
Gully pot sediment	Falcon Gate	1[E]		<25		<1.7	14	0.72	14
Gully pot sediment	Burghfield Gate	1[E]		<18		1.5	16	0.89	17
Freshwater	Pangbourne	2[E]		<3.6		<0.29	0.0088	<0.00096	0.0080
Freshwater	Mapledurham	2[E]		<3.4		<0.19	0.0085	<0.00085	0.0073
Freshwater	Aldermaston	4[E]		<3.7		<0.25	0.0070	<0.0018	0.0044
Freshwater	Spring Lane	4[E]		<3.5		<0.25	<0.0020	<0.0012	<0.0015
Freshwater	Stream draining south	4[E]		<3.7		<0.30	<0.0031	<0.00082	<0.0027
Freshwater	Near Chamber 39 of PPL	4[E]		<3.6		<0.25	0.0091	<0.0011	0.0055
Freshwater	Oval pond near Chamber 14	4[E]		<3.6		<0.27	<0.0015	<0.0010	<0.0013
Freshwater	River Kennet	4[E]		<3.6		<0.26	0.0061	<0.00067	0.0048
Freshwater	Hosehill Lake	4[E]		<3.7		<0.30	<0.0043	<0.0013	<0.0031

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			<0.16				
Signal crayfish	Ufton Bridge - Theale	1	0.000017	0.000071	0.00016	*	*		
Sediment	Pangbourne	2[E]	<0.080	<0.46	<0.54			340	660
Sediment	Mapledurham	2[E]	<0.17	<0.31	<0.52			110	330
Sediment	Aldermaston	4[E]	<0.20	3.0	<1.2			300	690
Sediment	Spring Lane	4[E]	<0.26	<0.36	<0.98			220	570
Sediment	Stream draining south	4[E]	<0.42	<0.40	<0.77			400	1200
Sediment	Near Chamber 39 of PPL	4[E]	<0.17	<0.55	<0.70			190	470
Sediment	Oval pond near Chamber 14	4[E]	<0.33	<0.40	<0.75			200	680
Sediment	River Kennet	4[E]	<0.24	<0.37	<0.73			170	400
Gully pot sediment	Aldermaston Gate	1[E]	<0.080	0.57	<1.4			290	590
Gully pot sediment	Falcon Gate	1[E]	<0.080	<0.26	<1.6			150	540
Gully pot sediment	Burghfield Gate	1[E]	<0.057	<0.18	<1.4			160	580
Freshwater	Pangbourne	2[E]	<0.0010	<0.0016	<0.038			<0.059	0.19
Freshwater	Mapledurham	2[E]	<0.0012	<0.0017	<0.0025			<0.042	0.24
Freshwater	Aldermaston	4[E]	<0.0016	<0.0018	<0.0022			<0.033	0.23
Freshwater	Spring Lane	4[E]	<0.0022	<0.0029	<0.0025			<0.021	0.13
Freshwater	Stream draining south	4[E]	<0.0020	<0.0019	<0.0024			<0.027	0.18
Freshwater	Near Chamber 39 of PPL	4[E]	<0.0022	<0.0017	<0.0028			<0.042	0.099
Freshwater	Oval pond near Chamber 14	4[E]	<0.0018	<0.0016	<0.0022			<0.023	0.063
Freshwater	River Kennet	4[E]	<0.0024	<0.0024	<0.0026			<0.032	0.094
Freshwater	Hosehill Lake	4[E]	<0.0019	<0.0020	<0.0029			<0.024	0.37

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	<2.5	<0.04	0.021	<0.0010	0.018
Milk	max		<2.6		0.037	0.0016	0.032
Potato		1	<6.3	<0.05	0.0096	<0.00047	0.011
Wheat		1	<3.4	<0.04	<0.00042	0.00050	0.0028
Grass and herbage	0.25km east of Main gate	1[E]	<25	<0.93	0.14	<0.012	0.14
Grass and herbage	Opposite Gate 36	1[E]	<13	<0.80	0.049	<0.0017	0.051
Grass and herbage	Opposite Gate 26A	1[E]	<11	<1.2	0.15	<0.022	0.094
Grass and herbage	Tadley, Perimeter fence	1[E]	<11	<1.2	0.33	<0.095	<0.061
Soil	0.25km east of Main gate	1[E]	<14	5.4	12	<0.79	12
Soil	Opposite Gate 36	1[E]	<17	11	9.4	<0.55	9.6
Soil	Opposite Gate 26A	1[E]	<3.7	15	12	<0.64	13
Soil	Tadley, Perimeter fence	1[E]	<9.7	5.4	24	<1.1	23

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	<0.000030	<0.000026	<0.000034		
Milk	max		<0.000034	<0.000030	<0.000041		
Potato		1	<0.000029	0.00012	0.00017		
Wheat		1	<0.000053	<0.000053	0.0000030		
Grass and herbage	0.25km east of Main gate	1[E]	<0.0077	<0.026		<2.9	320
Grass and herbage	Opposite Gate 36	1[E]	<0.010	<0.025		<2.3	280
Grass and herbage	Opposite Gate 26A	1[E]	<0.027	<0.12		<1.5	250
Grass and herbage	Tadley, Perimeter fence	1[E]	<0.023	<0.13		<1.4	210
Soil	0.25km east of Main gate	1[E]	<0.064	<0.20		140	350
Soil	Opposite Gate 36	1[E]	<0.056	0.39		<84	310
Soil	Opposite Gate 26A	1[E]	<0.070	<0.40		120	280
Soil	Tadley, Perimeter fence	1[E]	<0.15	<0.48		190	730

* 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, 2021

Location	Ground type	No. of sampling observations	μGy h^{-1}
Mean gamma dose rates at 1m over substrate			
Pangbourne, riverbank	Grass	1	0.058
Pangbourne, riverbank	Grass and mud	1	0.061
Mapledurham, riverbank	Grass	1	0.060
Mapledurham, riverbank	Grass and mud	1	0.058

Table 5.3(a) Concentrations of radionuclides in food and the environment near defence establishments, 2021

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]		<2.0		<0.06	<0.06	<0.12	<0.11	<0.05
Grass	Barrow	1[F]		<2.1		<0.17	<20	<0.44	*	<0.16
Sediment	Walney Channel - N of discharge point	2				<0.46	<0.41	<1.6		57
Derby										
Potatoes	Derby	1[F]				<0.05	<0.10	<0.10	<0.08	<0.04
Barely	Wheat	1[F]				<0.08	<0.09	<0.15	<0.21	<0.07
Sediment	River Derwent, upstream	1				<0.39				2.4
Sediment	Fritchley Brook	1				<0.45				1.2
Sediment	River Derwent, downstream	4				<0.98				<1.8
Water	River Derwent, upstream	1				<0.31				
Water[c]	Fritchley Brook	1		<3.5		<0.33				<0.25
Water	River Derwent, downstream	4				<0.32				
Devonport										
Ballan wrasse	Plymouth Sound	1[F]	<25	<25	25	<0.07	<0.32	<0.14	<12	0.15
Crabs	Plymouth Sound	1[F]			21	<0.05	<0.11	<0.10	<4.7	<0.04
Shrimp	River Lynher	1[F]			28	<0.04	<0.37	<0.12	*	<0.04
Mussels	River Lynher	1[F]	<25	<25	11	<0.06	<0.16	<0.12	*	<0.10
Seaweed[d]	Beach near Royal Albert Bridge	2				<0.68				
Sediment[e]	Beach near Royal Albert Bridge	2		<7.9		<0.63				2.2
Sediment[e]	Tor Point South	2		<6.8		<0.78				
Sediment	Lopwell	2		<13		<0.61				4.9
Seawater	Torpoint South	1		<3.4	<11	<0.30				
Seawater	Millbrook Lake	1		<3.2	10	<0.23				
Grass		1[F]		<2.8		<0.06	<0.15	<0.12	*	<0.05
Potatoes		1[F]		<2.0		<0.05	<0.08	<0.09	<0.70	<0.04
Faslane										
Winkles	Rhu	1				<0.10	<0.1	<0.17		0.74
Fucus vesiculosus	Garelochhead	1				<0.10	<0.19	<0.21		0.20
Fucus vesiculosus	Carnban	1				<0.10	<0.16	<0.20		0.33
Fucus vesiculosus	Rhu	1				<0.10	<0.10	<0.14		0.35
Fucus vesiculosus	Cairndhu Point	1				<0.10	<0.10	<0.10		0.33
Fucus vesiculosus	Helensburgh	1				<0.10	<0.10	<0.15		0.25
Sediment	Garelochhead	1				<0.10	<0.10	<0.10		2.4
Sediment	Carnban	1				<0.10	<0.14	<0.20		0.25
Sediment	Rhu	1				<0.10	<0.24	<0.22		4.3
Seawater	Carnban	2		<1.0		<0.10	<0.10	<0.12		<0.10
Beef muscle	Faslane	1				<0.05	<0.06			0.06
Blackberries	Faslane	1				<0.05	<0.12			1.6
Honey	Faslane	1				<0.05	<0.05			0.25
Grass	Auchengaich Reservoir	1		<5.0		<0.05	<0.17			0.34
Grass	Lochan Ghlas Laoigh	1		<5.0		<0.06	<0.49			0.35
Soil	Auchengaich	1		<5.0		<0.05	0.11			13
Soil	Lochan Ghlas Laoigh	1		5.0		<0.06	<0.39			44
Freshwater	Helensburgh Reservoir	1		<1.0		<0.01	<0.05			0.04
Freshwater	Loch Finlas	1		<1.0		<0.01	<0.01			<0.01
Freshwater	Auchengaich Reservoir	1		<1.1		<0.01	<0.01			<0.01
Freshwater	Lochan Ghlas Laoigh	1		<1.1		<0.01	<0.01			0.01
Freshwater	Loch Eck	1		<1.0		<0.01	<0.01			<0.01
Freshwater	Loch Lomond	1		<1.0		<0.01	<0.01			<0.01

Table 5.3(a) continued

Material	Location or selection[a]	No. of sampling observ-ations	Mean radioactivity concentration (fresh)[b], Bq kg^{-1}							
			Organic ^{3}H	^{3}H	^{14}C	^{60}Co	^{95}Nb	^{125}Sb	^{131}I	^{137}Cs
Holy Loch										
Sediment	Mid-Loch	1				<0.10	<0.14	<0.17		2.3
Rosyth										
Winkles	St David's Bay	1				<0.10	<0.53	<0.22		0.23
Fucus vesiculosus	East of dockyard	1				<0.10	<0.11	<0.10		<0.10
Sediment	East of dockyard	1				<0.10	<0.10	<0.10		1.8
Sediment	Port Edgar	1				<0.22	<0.92	<0.60		9.4
Sediment	West of dockyard	1				<0.10	<0.10	<0.10		0.63
Sediment	East Ness Pier	1				<0.10	<0.21	<0.16		11
Sediment	Blackness Castle	1				<0.10	<0.23	<0.22		3.0
Sediment	Charlestown Pier	1				<0.10	<0.11	<0.16		1.3
Seawater	East of dockyard	2		<1.0		<0.10	<0.10	<0.10		<0.10
Freshwater	Castlehill Reservoir	1		<1.0		<0.01	<0.01			<0.01
Freshwater	Holl Reservoir	1		<1.0		<0.01	<0.01			<0.01
Freshwater	Gartmorn Dam	1		<1.0		<0.01	<0.01			<0.01
Freshwater	Morton No. 2 Reservoir	1		<1.0		<0.01	<0.01			<0.01

Material	Location or selection[a]	No. of sampling 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]	<0.20	<0.15				<0.13		
Grass	Barrow	1[F]	<0.52	<0.45				<0.55		
Sediment	Walney Channel - N of discharge point	2	<1.2	<0.82				160	390	790
Derby										
Potatoes	Derby	1[F]	<0.17	<0.22	0.0065	<0.00046	0.0061	<0.26		
Barely	Wheat	1[F]	<0.26	<0.19	<0.00046	<0.00046	<0.00046	<0.12		
Sediment	River Derwent, upstream	1			20	1.1	19		310	520
Sediment	Fritchley Brook	1			22	0.99	25		310	730
Sediment	River Derwent, downstream	4			22	<1.2	22		280	640
Water	River Derwent, upstream	1							0.033	0.16
Water[c]	Fritchley Brook	1			0.018	<0.00021	0.012		0.028	0.20
Water	River Derwent, downstream	4							<0.047	0.17
Devonport										
Ballan wrasse	Plymouth Sound	1[F]	<0.22	<0.14				<0.10		
Crabs	Plymouth Sound	1[F]	<0.14	<0.10				<0.05		
Shrimp	River Lynher	1[F]	<0.14	<0.14				<0.17		
Mussels	River Lynher	1[F]	<0.16	<0.10				<0.04		
Sediment[e]	Beach near Royal Albert Bridge	2						3.0		
Grass		1[F]	<0.20	<0.12				<0.13		
Potatoes		1[F]	<0.17	<0.13				<0.16		

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										
Winkles	Rhu	1	<0.10	<0.13				0.24		
Fucus vesiculosus	Garelochhead	1	<0.11	<0.19				<0.12		
Fucus vesiculosus	Carnban	1	<0.10	<0.17				<0.11		
Fucus vesiculosus	Rhu	1	<0.10	<0.19				<0.22		
Fucus vesiculosus	Cairndhu Point	1	<0.10	<0.11				<0.13		
Fucus vesiculosus	Helensburgh	1	<0.10	<0.14				<0.10		
Sediment	Garelochhead	1	<0.10	0.57				<0.16		
Sediment	Carnban	1	<0.10	<0.15				0.16		
Sediment	Rhu	1	<0.19	1.1				0.57		
Seawater	Carnban	2	<0.10	<0.10				<0.10		
Beef muscle	Faslane	1						<0.09		
Blackberries	Faslane	1						<0.07		
Honey	Faslane	1						<0.05		
Grass	Auchengaich Reservoir	1		<0.15				<0.15		
Grass	Lochan Ghlas Laoigh	1		<0.11				<0.06		
Soil	Auchengaich	1		1.3				<0.23		
Soil	Lochan Ghlas Laoigh	1		2.1				1.2		
Freshwater	Helensburgh Reservoir	1						<0.01	<0.010	0.025
Freshwater	Loch Finlas	1						<0.01	0.011	0.18
Freshwater	Auchengaich Reservoir	1						<0.01	0.010	0.043
Freshwater	Lochan Ghlas Laoigh	1						<0.01	<0.010	0.095
Freshwater	Loch Eck	1						<0.01	<0.010	0.044
Freshwater	Loch Lomond	1						<0.01	<0.010	0.039
Holy Loch										
Sediment	Mid-Loch	1	<0.16	<0.23				<0.31		
Rosyth										
Winkles	St David's Bay	1	<0.10	<0.15				<0.10		
Fucus vesiculosus	East of dockyard	1	<0.10	<0.10				<0.10		
Sediment	East of dockyard	1	<0.10	0.50				<0.15		
Sediment	Port Edgar	1	<0.37	<0.60				2.2		
Sediment	West of dockyard	1	<0.10	0.34				0.20		
Sediment	East Ness Pier	1	<0.13	<0.25				<0.21		
Sediment	Blackness Castle	1	<0.19	0.76				0.49		
Sediment	Charlestown Pier	1	<0.14	<0.22				<0.26		
Seawater	East of dockyard	2	<0.10	<0.10				<0.10		
Freshwater	Castlehill Reservoir	1						<0.01	<0.010	<0.013
Freshwater	Holl Reservoir	1						<0.01	<0.011	0.076
Freshwater	Gartmorn Dam	1						<0.01	<0.011	0.092
Freshwater	Morton No. 2 Reservoir	1						<0.01	<0.010	0.057

* 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 <0.0077, <0.0024 and <0.0016 Bq l^{-1} respectively

[d] The concentration of ^{99}Tc was <0.40 Bq kg^{-1}

[e] The concentrations of ^{238}Pu and $^{239+240}Pu$ were <0.58 and <0.45 Bq kg^{-1}

[F] Measurements labelled "F" are made on behalf of the Food Standards Agency, all other measurements are made on behalf of the environment agencies

Table 5.3(b) Monitoring of radiation dose rates near defence establishments, 2021

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	4	0.072
Barrow	Walney Channel, N of discharge point	Mud and sand	4	0.077
Barrow	Roa Island	Mud and sand	1	0.084
Barrow	Roa Island	Pebbles and rock	1	0.075
Devonport	Torpoint South	Shingle	2	0.10
Devonport	Beach near Royal Albert Bridge	Mud	1	0.087
Devonport	Beach near Royal Albert Bridge	Shingle	1	0.089
Devonport	Lopwell	Mud and shingle	1	0.068
Devonport	Lopwell	Mud and silt	1	0.085
Faslane	Garelochhead	Sediment	2	0.052
Faslane	Gulley Bridge Pier	Sediment	2	0.058
Faslane	Rhu	Rocks	1	0.050
Faslane	Rhu	Sediment	1	0.048
Faslane	Helensburgh	Sediment	2	0.051
Faslane	Carnban	Sediment	2	0.058
Faslane	Rahane	Rocks	1	0.056
Faslane	Rahane	Sediment	1	0.059
Faslane	Rosneath Bay	Rocks	1	0.049
Faslane	Rosneath Bay	Sediment	1	<0.047
Faslane	Auchengaich	Grass	1	0.058
Faslane	Lochan Ghlas	Grass	1	0.064
Holy Loch	Kilmun Pier	Sediment	1	0.067
Holy Loch	Mid-Loch	Sediment	1	0.052
Holy Loch	North Sandbank	Sediment	1	0.064
Rosyth	Blackness Castle	Sediment	2	0.052
Rosyth	Charlestown Pier	Sediment	2	0.061
Rosyth	East Ness Pier	Sediment	2	0.060
Rosyth	East of Dockyard	Sediment	2	<0.057
Rosyth	Port Edgar	Sediment	2	0.056
Rosyth	West of Dockyard	Sediment	2	0.060

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

Highlights

- doses (dominated by the effects of legacy discharges from other sources) decreased at the LLWR in 2021
- doses at landfill sites were less than 0.5% of the dose limit in 2021
- doses (dominated by the effects of naturally occurring radionuclides from legacy discharges) decreased at Whitehaven in 2021

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 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 was 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.

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, southeast 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 are currently 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. In January 2022, NWS was launched. This brought together the operator of the LLWR, GDF developer Radioactive Waste Management Limited and the NDA group's integrated waste management programmes into a single organisation. A five-year plan has been published setting out the long-term future of the site through to final closure, expected in 2129 [174]. 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 2021, be distinguished from those due to Sellafield.

The current permit allows for continued solid radioactive waste disposal at the site, including permission to dispose of further radioactive waste beyond Vault 8, and limits disposals against a lifetime capacity for the site. In financial year 2017/18, the site commenced its long-term Repository Development Programme (RDP) [174]. In 2019, Revised Joint Waste Management Plans (JWMP) were published (in conjunction with LLW Repository Limited) for 3 radioactive waste-producing site licence companies (LLWR Limited, Magnox Limited and Sellafield Limited), covering the financial years (2019/20 to 2023/24). More information can be found at the UK government's website: https://www.gov.uk/government/collections/joint-waste-management-plans-jwmp.

Waste received at the site will have a final disposal location allocated to it at the appropriate time, consequently, in the future, once the closure of Vault 8 has commenced as part of the RDP works, it is intended to report the quantity of solid radioactive waste finally disposed at the site. In the meantime, while development work progresses on the final waste disposal location and capping arrangements, Table A2.3 records (for financial year 2021/22) 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 $533m^3$ of waste was received by the site with the intention of disposal in financial year 2021/22, bringing the cumulative total to $253,000m^3$. As started 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 routine 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 the Water Supply (Water Quality) (Amendment) 2018 Regulations (retained from 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 3 weeks, the annual dose would be less than 0.005mSv. Concentrations of some radionuclides (plutonium-238 and plutonium-239+240) in sediment from the Drigg stream were similar to those in previous years. They reflect the legacy of direct discharges of leachate from the disposal site into the stream [175]. 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 2021 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 Water Supply (Water Quality) (Amendment) 2018 Regulations (retained from 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 2021 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 undertaken in 2021 and the results have been included in the dose assessments for the site [114].

The ‘total dose’ from all pathways and sources of radiation was 0.21mSv in 2021, or 21% of the dose limit for members of the public of 1mSv (Table 1.2 and Table 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 0.029mSv in 2021 (Table 1.2). The representative person was infants living near the site. The increase in ‘total dose’ (from 0.023mSv in 2019) was due to a higher estimate of direct radiation from the site in 2021. A source specific assessment of exposure for consumers of locally grown terrestrial food (animals fed on oats), using 2021 modelled activity concentrations in animal products, gives an exposure that was 0.007mSv in 2021, and similar to that in recent years.

6.2 Metals Recycling Facility, Lillyhall, Cumbria

The Metals Recycling Facility (MRF), operated by 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. Techniques used include size reduction (if required) using conventional hot and cold cutting methods, 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 2021 (Appendix 2, Table A2.1 and Table A2.2). The permit includes conditions requiring Cyclife UK Limited to monitor discharges and undertake environmental monitoring. As in 2020, direct radiation from the site was less than 0.001mSv in 2021 (Table 1.1) and the radiological impact was very low.

A direct radiation observation survey was undertaken in 2018 [176]. This was the first habits survey to be carried out at the MRF and it was undertaken to ensure consistency with other nuclear licensed sites in the UK. The qualitative survey focussed on the area adjacent to the waste container park that had resulted in the elevated dose rates in 2016. Quantitative habits data were not obtained as the time spent by members of the public undertaking activities in the area was minimal.

6.3 Other landfill sites

Some organisations are granted permits by SEPA (in Scotland) and the Environment Agency (in England and Wales[16]) 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 2021 are shown in Figure 6.1 and the results are presented in Table 6.3 and Table 6.4.

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

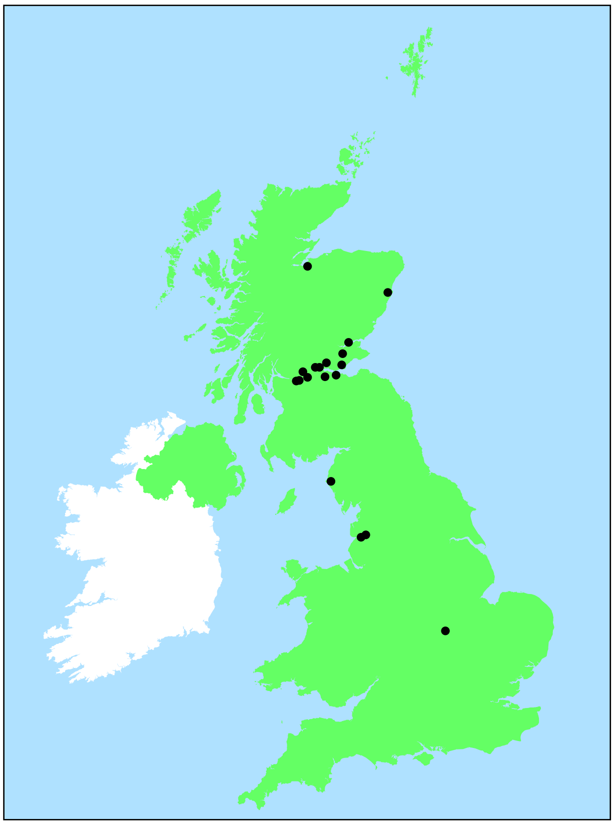


Figure 6.1 Landfill sites monitored in 2021

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 [177]. As in 2020, inadvertent ingestion of leachate (2.5l 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 0.005mSv in 2021 (Table 6.1), or less than 0.5% of the dose limit for members of the public of 1mSv. Similarly, the annual dose from ingestion of uranium isotopes in leachate from Clifton Marsh was also less than 0.005mSv in 2021.

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 very low-level waste (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 to provide a baseline and allow detection of any future changes. In 2021, 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 were 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 Water Supply (Water Quality) (Amendment) 2018 Regulations (retained from the European Directive 2013/51) of 0.1 and 1.0Bq 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 2021 was estimated to be less than 0.005mSv, or less than 0.5% of the dose limit for members of the public of 1mSv (Table 6.1). The assessment excludes potassium-40 because its presence is homeostatically controlled in the body.

After receiving a permit variation application from FCC Recycling (UK) Limited and subsequent consultation with the local public, professional bodies and stakeholders in 2019, the EA issued a permit variation in July 2021 that allows the site to receive radioactive waste at up to a maximum average activity of 200Bq g^{-1} (previously, a maximum average activity of 4Bq g^{-1}, or 40Bq g^{-1} for tritium). For further information, please visit the following website: (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 (for example [46]).

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.

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 [178]. 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 TENORM, meaning that, elevated levels of NORM 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 2021 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. Figure 6.2 to Figure 6.4 show how concentrations of polonium-210 in winkles, crabs and lobsters have generally decreased since 1998, with larger concentrations variations in lobsters since 2014. Concentrations in the early 1990s were in excess of 100Bq kg^{-1} (fresh weight). There were some small variations in concentrations of polonium-210 in local samples in 2021 (where comparisons can be made), in comparison with those in 2020. Polonium-210 concentrations were generally lower in both crab and lobster samples in 2021, 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 Figure 6.2 to Figure 6.4 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 [179].

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 [69].

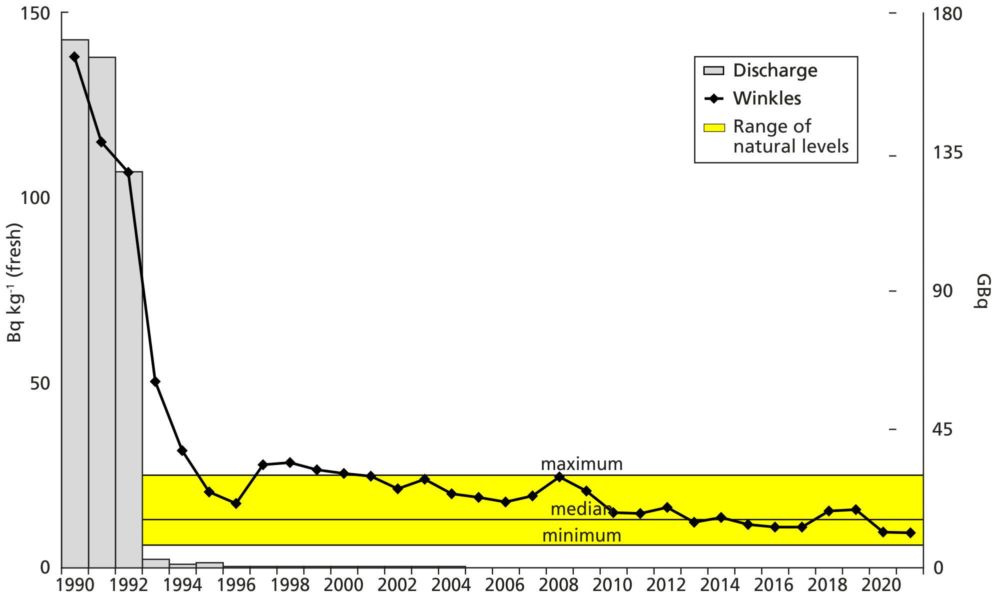


Figure 6.2 Polonium-210 discharge from Whitehaven and concentration in winkles at Parton, 1990–2021

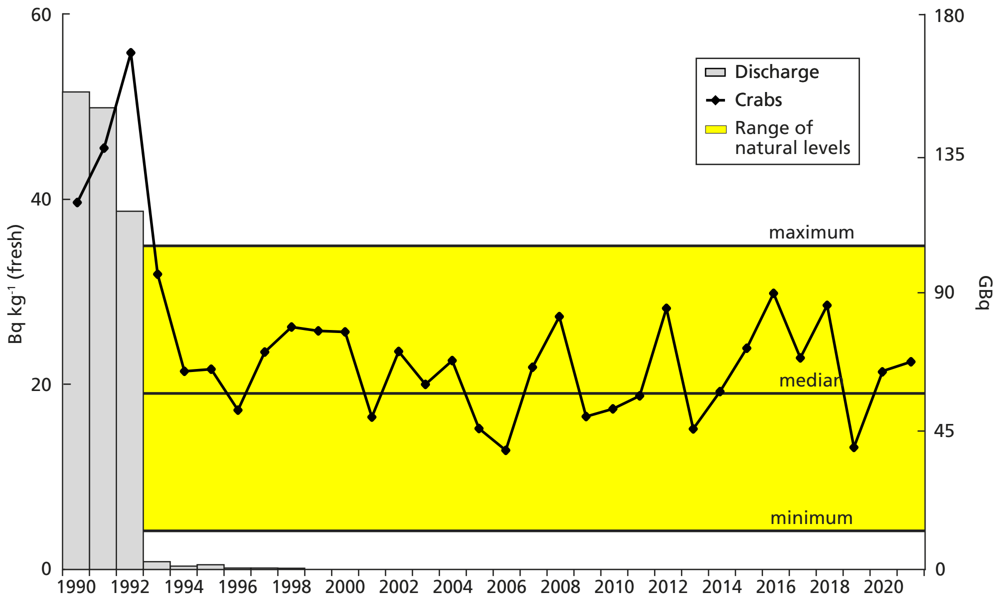


Figure 6.3 Polonium-210 discharge from Whitehaven and concentration in crabs at Parton, 1990–2021

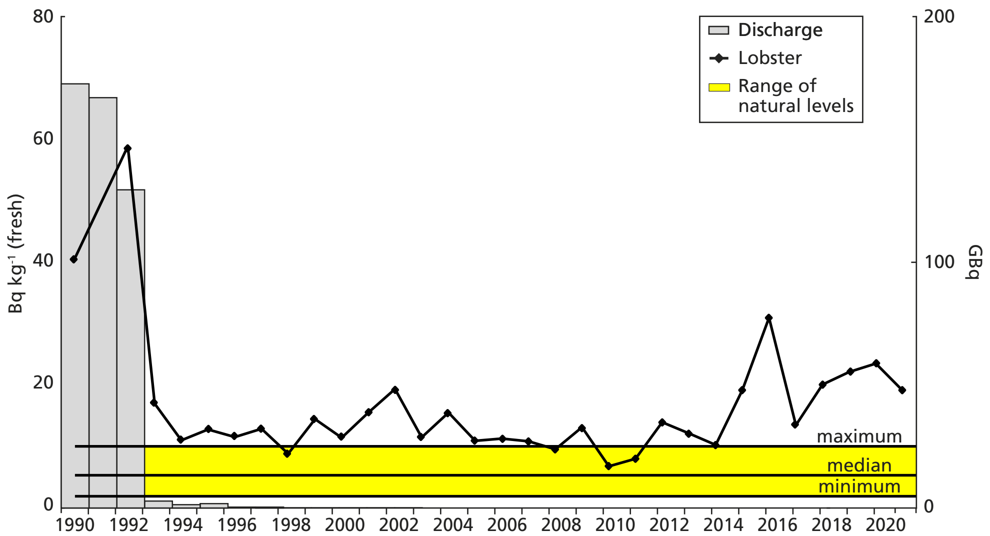


Figure 6.4 Polonium-210 discharge from Whitehaven and concentration in lobsters at Parton, 1990–2021

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 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 2021 [114]. 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 0.21mSv in 2021 (Table 6.1), or 21% of the dose limit to members of the public, and down from 0.31mSv in 2020. The dose includes the effects of all sources near the site: technically enhanced naturally occurring radionuclides from the non-nuclear industrial activity (in other words, TENORM) and Sellafield operations. The contribution to the 'total dose' from enhanced natural radionuclides was 0.19mSv and was lower in 2021, in comparison to that in 2020 (0.25mSv). The decrease in 'total dose' in 2021 was mostly attributed to the revision of habits information (reduction in the consumption rates and breadth of species consumed). 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 0.25mSv in 2021 (Table 6.1).

The longer-term trend in annual 'total dose' over the period 2010 to 2021 is shown in Figure 6.5. The variations in 'total dose' over the period 2011 to 2020 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, [47]).

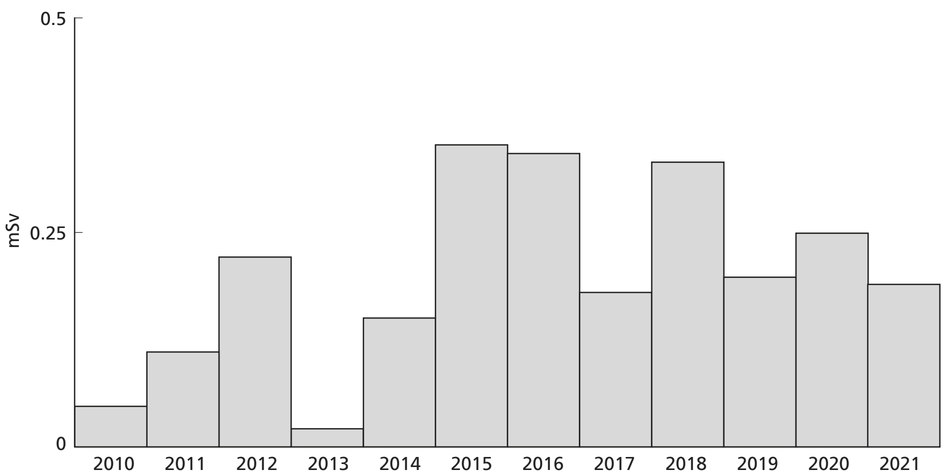


Figure 6.5 Trend in 'total dose' to seafood consumers from naturally-occurring radionuclides near Whitehaven, 2010–2021

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 activities or waste disposal sites [180].

Additional public protection measures were established following the increased number of particles and the discovery of some high activity particles in 2011. These were maintained between 2020 and 2021. 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 one-year programme of shellfish monitoring from February 2012 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), the Committee on Medical Aspects of Radiation in the Environment (COMARE) recommended that effective remediation of the affected area be undertaken as soon as is possible. This recommendation, amongst others, was subsequently published in 2014 in COMARE's 15th report. The MOD has progressed with addressing the contamination by initially publishing its Outline Management Options Appraisal Report in 2014, followed by a further publication in 2014 of its broad management strategy and timescale for implementation of its preferred management option. Copies of these reports are available on the UK government website: https://www.gov.uk/government/groups/committee-on-medical-aspects-of-radiation-in-the-environment-comare.

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 and an EASR permit to undertake the required work was granted by SEPA in May 2021. Remediation work is now under way and is expected to be completed by the end of 2023.

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 [181]. 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 [182] [183].

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 [181]. 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 industrial stacks and 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 2021 is given in Table 6.7 and Table 6.8. Data for Scotland are presented in Table 6.9 and Table 6.10 in terms of OSPAR regions (Region II represents the Greater North Sea and Region III the Celtic Sea). This change in format allows easier trend analysis to be performed for OSPAR. Data for 2020 are reported in the RIFE errata. 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 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 [184].

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 2021, 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 2021 were generally similar to those in 2020. 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 less than 0.005mSv in 2021, or approximately 0.5% of the dose limit for members of the public, and unchanged from 2020.

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 Nigg Bay, near Aberdeen Harbour was carried out in 2021 and are reported in Table 2.11. In 2021, the dose rate on sediment was 0.068μGy h^{-1} and similar to background.

LOCATION MAPS

LLWR near Drigg

Whitehaven

Table 6.1 Individual doses - industrial and landfill sites, 2021

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]	Gaseous plume related pathways	Direct radiation from site
'Total dose' - all sources									
Whitehaven and LLWR near Drigg	**Adult crustacean consumers**	**0.21**	**0.016**	**0.18**	**-**	**<0.005**	**-**	**<0.005**	**<0.005**
Source specific doses									
LLWR near Drigg	Infant consumers of locally grown food	0.007	-	-	0.007	-	-		
	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 2017-2021)	Seafood consumers	0.25[e]	0.039	0.19	-	0.019	-		

[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, 2021

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	^{129}I
Milk		1	<4.4	21	<0.03	<0.025	<0.06	<0.05	<0.0058	<0.29	<0.08	<0.0095
Eggs		1	<8.3	33	<0.05	<0.043	<0.30	<0.16		<0.47	<0.12	<0.044
Potatoes		1	<2.2	32	<0.03	0.039	<0.09	<0.07	<0.036	<0.24	<0.06	<0.017
Sheep muscle		1	<3.6	34	<0.03	<0.042	<0.06	<0.05	<0.035	<0.25	<0.07	<0.028
Sheep offal		1	<30	27	<0.10	0.053	<0.12	<0.10	<0.045	<0.43	<0.11	<0.024
Oats		1	<3.3	64	<0.04	0.43	<0.12	<0.12	<0.040	<0.30	<0.08	<0.040
Sediment	Drigg Stream	4[E]			<0.41	<1.2	<0.69	<0.32		<2.8	<1.5	
Freshwater	Drigg Stream	4[E]	<6.6		<0.28	<0.016						
Freshwater	Railway drain	1[E]	<4.0		<0.20	<0.064						

Material	Location or selection	No. of sampling observ-ations[a]	Mean radioactivity concentration (fresh)[b], Bq kg^{-1}								
			^{134}Cs	^{137}Cs	Total	^{144}Ce	^{210}Po	^{228}Th	^{230}Th	^{232}Th	^{234}U
Milk		1	<0.03	0.12		<0.27					
Eggs		1	<0.03	<0.05	<0.051	<0.33					
Potatoes		1	<0.05	0.24	0.24	<0.20					
Sheep muscle		1	<0.03	1.3	1.3	<0.21					
Sheep offal		1	<0.06	0.36	0.36	<0.30					
Oats		1	<0.04	0.41	0.41	<0.37					
Sediment	Drigg Stream	4[E]	<0.43	53		<1.6	8.0	9.6	8.8	8.6	17
Freshwater	Drigg Stream	4[E]	<0.29	<0.23			<0.0033	<0.0032	<0.0015	<0.00086	0.0082
Freshwater	Railway drain	1[E]	<0.23	<0.17			0.0060	<0.0024	0.0017	0.0070	0.0035

Material	Location or selection	No. of sampling observ-ations[a]	Mean radioactivity concentration (fresh)[b], Bq kg^{-1}							
			^{235}U	^{238}U	^{238}Pu	^{239}Pu + ^{240}Pu	^{241}Pu	^{241}Am	Gross alpha	Gross beta
Milk		1			<0.000033	<0.000037	<0.17	<0.000022		
Eggs		1			<0.00014	<0.00014	<0.78	0.000071		
Potatoes		1			0.000014	0.00044	<0.56	0.00059		
Sheep muscle		1			<0.000090	0.00011	<0.51	0.00022		
Sheep offal		1			0.00048	0.0040	<0.44	0.0051		
Oats		1			0.00029	0.0021	<0.50	0.0034		
Sediment	Drigg Stream	4[E]	<0.95	17	2.5	19	49	27	210	650
Freshwater	Drigg Stream	4[E]	<0.00079	0.0071	<0.0012	<0.0084	<0.061	<0.0096	0.036	0.30
Freshwater	Railway drain	1[E]	<0.00067	0.0030	<0.00040	0.0029	<0.057	<0.0021	0.050	0.26

[a] Except for milk and freshwater where units are Bq l^{-1}, and for sediment where dry concentrations apply
[b] The number of farms from which milk is sampled. The number of analyses is greater than this and depends on the bulking regime
[E] Measurements are made on behalf of the Food Standards Agency unless labelled "E". In that case they are made on behalf of the Environment Agency

Table 6.3 Concentrations of radionuclides in surface water leachate from landfill sites in Scotland, 2021

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	66	<15	<0.05	<0.05
City of Glasgow	Cathkin	1	68	<15	<0.05	<0.05
Clackmannanshire	Black Devon	1	12	<15	<0.05	<0.05
Dunbartonshire	Birdston	1	<5.0	<15	<0.05	<0.05
Dundee City	Riverside	1	2.7	<15	<0.05	<0.05
Edinburgh	Braehead	1	<5.0	<15	<0.05	<0.05
Fife	Balbarton	1	10	<15	<0.05	<0.05
Fife	Melville Wood	1	180	<15	<0.05	<0.05
Highland	Longman landfill	1	<5.0	<15	<0.05	<0.05
North Lanarkshire	Kilgarth	1	<5.0	<15	<0.05	<0.05
Stirling	Lower Polmaise	1	5.0	<15	<0.05	<0.05

Table 6.4 Concentrations of radionuclides in water from landfill sites in England and Wales, 2021

Location	Sample source	No. of sampling observations	Mean radioactivity concentration, Bq l^{-1}					
			^{3}H	^{40}K	^{60}Co	^{137}Cs	^{228}Th	^{230}Th
Lancashire								
Clifton Marsh	Borehole 6	2	<3.9	<6.3	<0.33	<0.27	<0.0063	<0.0015
Clifton Marsh	Borehole 19	2	<3.8	<5.0	<0.26	<0.23	<0.0051	<0.0011
Clifton Marsh	Borehole 40	2	<3.6	<6.4	<0.33	<0.28	<0.0023	<0.00085
Clifton Marsh	Borehole 59	2	7.4	<4.8	<0.26	<0.23	<0.0039	<0.0013

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	<0.0015	0.031	<0.0016	0.030	<0.19	1.0
Clifton Marsh	Borehole 19	2	<0.00059	0.058	0.0031	0.054	<0.26	1.9
Clifton Marsh	Borehole 40	2	<0.00064	0.0045	<0.00077	0.0037	<0.091	1.2
Clifton Marsh	Borehole 59	2	<0.00088	0.0047	<0.00047	0.0038	0.090	1.1

Table 6.5 Concentrations of radionuclides in water near the East Northants Resource Management Facility landfill site, 2021

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	<4.0	<4.1	<0.20	0.015	<0.0041	<0.0019	<0.0017	0.027	<0.0013	0.024	<0.12	0.27
K15A Groundwater borehole	<4.0	<8.5	<0.35	0.019	<0.0045	0.0018	<0.00050	0.017	<0.0012	0.014	<0.16	0.10
K17 Northern perimeter Groundwater borehole	<4.0	<8.0	<0.29	0.035	<0.0021	0.0014	<0.00077	0.039	<0.0021	0.032	0.30	2.3
Horse Water spring		<3.5	<0.18								<0.071	0.41
Willow brook		<6.8	<0.29								<0.064	0.90

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

Table 6.6 Concentrations of naturally occurring radionuclides in the environment, 2021[a]

Material	Location	No. of sampling observations	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	9.7	1.5						
Winkles	Nethertown	4	12	2.0	0.75	0.63	0.48	0.63	0.024	0.57
Winkles	Ravenglass	2	14	1.1						
Mussels	Whitehaven	2	43	2.6						
Prawns	Seascale	2	3.4	0.065						
Crabs	Parton	2	22	0.15						
Crabs	Sellafield coastal area	2	13	0.11	0.096	0.0099	0.0059	0.076	0.0022	0.065
Lobsters	Parton	2	19	0.060						
Lobsters	Sellafield coastal area	2	10	0.070						
Nephrops	Whitehaven	2	1.4	0.11	0.035	0.014	0.0091	0.025	0.0011	0.023
Cod	Parton	2	0.58	0.025						
Cod	Whitehaven	2	0.65	0.049						
Plaice	Whitehaven	2	2.2	0.26	0.050	0.00041	<0.000070	0.022	0.00092	0.018
Plaice	Drigg	2	1.9	0.27	0.043	<0.000064	<0.000064	0.039	0.0013	0.033
Annual samples (further afield)										
Winkles	South Gare (Hartlepool)	2	9.7	1.9						
Winkles	Middleton Sands	2	10							
Winkles	Kirkcudbright	1[S]	3.8							
Mussels	Morecambe	2	32							
Mussels	Ribble Estuary	1			0.17	0.043	0.020			
Limpets	Kirkcudbright	1[S]	5.7							
Crabs	Kirkcudbright	1[S]	30							
Lobsters	Kirkcudbright	1[S]	1.8							
Shrimps	Ribble Estuary	1			0.0054	0.0019	0.00073			
Wildfowl	Ribble Estuary	1				<0.00038	<0.00038			
Sediment	Kirkcudbright	2			13	0.53	13			
Sediment	Balcary Bay	1			6.1	0.56	5.0			

[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

Table 6.7 Discharges of gaseous radioactive wastes from non-nuclear establishments in England, Northern Ireland and Wales, 2021[a]

	Discharges during 2021, 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					3.5E+11	
^{14}C	1.5E+08				1.2E+12	Nil
^{18}F	2.2E+11				6.0E+11	
^{35}S					1.7E+08	
^{90}Sr					1.0E+00	
^{99m}Tc			6.5E+07			
^{106}Ru					1.3E+06	
^{125}I			2.2E+07		4.9E+07	
^{129}I					4.3E+04	
^{131}I			1.1E+08		1.6E+08	
^{131m}Xe						
^{137}Cs					7.8E+07	
Uranium Alpha					1.0E+00	
^{241}Pu					9.6E+02	
Plutonium Alpha					1.6E+06	
^{241}Am					4.2E+02	
Other Alpha Particulate			4.3E+06		8.7E+10	
Other Beta/Gamma				6.0E+09		
Other Beta/Gamma Particulate	5.9E+11		8.0E+08		7.3E+12	

[a] Excludes nuclear power, defence and radiochemical manufacturing specifically at (Amersham) industries. Includes other radiochemical production facilities (for example, the Pharmaron facility in Cardiff). Excludes discharges which are exempt from reporting. England and Wales discharge data refers to 2020

Table 6.8 Discharges of liquid radioactive waste from non-nuclear establishments in England, Northern Ireland and Wales, 2021[a]

	Discharges during 2021, 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	3.1E+09	1.4E+07	1.7E+08	6.7E+07	4.4E+12		
^{14}C	3.2E+08		5.0E+05		1.2E+11		
^{18}F	6.9E+11		3.4E+12	1.3E+11	4.4E+12		
^{32}P	1.2E+09		5.7E+06		3.7E+07		
^{33}P	1.7E+08		5.2E+08				
^{35}S	2.4E+09		4.8E+08		6.5E+08		
^{51}Cr	2.6E+08		1.0E+07	Nil			
^{57}Co			7.8E+07				
^{58}Co							
^{60}Co					1.2E+06		
^{67}Ga	3.1E+08		3.2E+09				
^{75}Se	1.6E+07		3.8E+09	1.2E+08	7.5E+07		
^{89}Sr							
^{90}Sr					1.0E+01		
^{90}Y			1.1E+11	9.6E+08			
^{99}Tc					4.4E+02		
^{99m}Tc	3.6E+10		3.8E+13	1.4E+11	7.9E+11		
^{111}In	7.0E+07		7.6E+10	2.9E+10	1.0E+08		
^{123}I	1.0E+07		7.6E+11	2.5E+10	1.3E+10		
^{125}I	1.6E+09	1.3E+05	3.7E+08		1.0E+10		
^{129}I					1.0E+00		
^{131}I			6.9E+12	1.9E+11	1.4E+11		
^{134}Cs							
^{137}Cs					2.8E+09		
^{153}Sm			1.4E+09	Nil			
^{177}Lu	1.8E+08		8.7E+12		1.4E+12		
^{201}Tl	4.5E+07		5.2E+09				
^{223}Ra			1.2E+10		1.9E+07		
^{230}Th					5.6E+08		
^{232}Th					6.8E+08		
Uranium Alpha	7.4E+04				8.9E+08		
^{237}Np					1.0E+00		
^{241}Pu					8.7E+03		
Plutonium Alpha					2.0E+03		
^{241}Am					3.8E+03		
^{242}Cm					5.0E+00		
Total Alpha	1.1E+05		1.2E+10	Nil	5.9E+10	Nil	
Total Beta/Gamma (Excl Tritium)	7.2E+11		5.4E+13		6.5E+12		
Other Alpha Particulate	1.2E+03		8.4E+08		1.4E+06		
Other Beta/Gamma	3.5E+10		5.7E+12	Nil	5.5E+10	Nil	
Other Beta/Gamma Particulate					3.1E+08		

a Excludes nuclear power, defence and radiochemical manufacturing specifically at (Amersham) industries. Includes other radiochemical production facilities (for example, the Pharmanon facility at Cardiff). Excludes discharges which are exempt from reporting. England and Wales discharge data refers to 2020
b Excluding specific radionuclides

Table 6.9 Discharges of gaseous radioactive wastes from non-nuclear establishments in Scotland by OSPAR region, 2021[a]

	Discharges during 2021, Bq					
	OSPAR Region II - Greater North Sea			OSPAR Region III - Celtic Seas		
	Education (Universities and Colleges)	Hospitals	Other (Research, manufacturing and public sector)	Education (Universities and Colleges)	Hospitals	Other (Research, manufacturing and public sector)
^{3}H	Nil	Nil	Nil	Nil	Nil	Nil
^{14}C	Nil	Nil	Nil	1.24E+07	Nil	Nil
^{18}F	Nil	Nil	Nil	Nil	2.1E+10	Nil
^{85}Kr	Nil	Nil	Nil	Nil	Nil	Nil
^{125}I	Nil	Nil	Nil	Nil	Nil	Nil
^{131}I	Nil	Nil	Nil	Nil	Nil	Nil
^{133}Xe	Nil	Nil	Nil	Nil	Nil	Nil
^{137}Cs	Nil	Nil	Nil	Nil	Nil	Nil
Group of Two or More Specified Radionuclides	Nil	Nil	Nil	Nil	Nil	8.0E+05
Other Alpha	Nil	Nil	Nil	Nil	Nil	5.0E+00
Other Beta/Gamma	1.5E+11	Nil	Nil	Nil	Nil	5.3E+05
Other Radionuclides Not Listed	1.8E+10	Nil	Nil	Nil	2.0E+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, 2021[a]

	Discharges during 2021, 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	3.4E+08	Nil	2.7E+09	Nil	3.1E+08	1.0E+07	3.2E+08
^{14}C	1.7E+07	Nil	7.4E+09	Nil	2.5E+07	Nil	6.5E+04
^{18}F	Nil	1.3E+11	Nil	Nil	Nil	2.9E+11	Nil
^{22}Na	Nil	Nil	Nil	Nil	Nil	Nil	Nil
^{32}P	2.4E+08	Nil	1.8E+07	Nil	4.1E+08	3.0E+05	5.4E+08
^{33}P	Nil	Nil	1.8E+09	Nil	Nil	Nil	Nil
^{35}S	7.7E+07	Nil	2.7E+07	Nil	2.1E+09	Nil	2.5E+08
^{51}Cr	Nil	Nil	Nil	Nil	Nil	Nil	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	7.5E+07	Nil	Nil	Nil	1.9E+07	Nil
^{89}Sr	Nil	Nil	Nil	Nil	Nil	Nil	Nil
^{90}Sr	Nil	Nil	Nil	Nil	Nil	Nil	Nil
^{90}Y	Nil	1.2E+08	Nil	Nil	Nil	Nil	Nil
^{99m}Tc	Nil	3.2E+12	Nil	Nil	Nil	2.0E+12	1.3E+08
^{111}In	Nil	3.5E+09	Nil	Nil	Nil	1.2E+09	Nil
^{123}I	Nil	3.7E+10	Nil	Nil	Nil	3.9E+10	Nil
^{125}I	4.1E+05	1.0E+07	Nil	Nil	Nil	4.8E+06	Nil
^{131}I	3.5E+09	2.5E+11	Nil	Nil	Nil	2.4E+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	8.5E+09	Nil
^{210}Pb	Nil	Nil	3.0E+05	1.8E+08	Nil	Nil	Nil
^{210}Po	Nil	Nil	5.2E+05	2.7E+08	Nil	Nil	Nil
^{226}Ra	Nil	Nil	2.1E+05	8.8E+08	Nil	Nil	Nil
^{228}Ra	Nil	Nil	5.0E+04	1.1E+09	Nil	Nil	Nil
^{232}Th	Nil	Nil	Nil	Nil	Nil	Nil	9.9E+05
Uranium Alpha	Nil	Nil	1.7E+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	1.7E+07
Other Alpha	Nil	2.8E+08	Nil	Nil	Nil	Nil	1.0E+04
Other Beta/ Gamma[b]	1.2E+11	1.4E+09	Nil	Nil	1.0E+03	6.9E+11	4.0E+06
Other Radionuclide Not Listed	Nil	3.8E+08	6.5E+07	Nil	Nil	3.7E+08	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, 2021[a]

Location	Material and selection[b]	No. of sampling observ-ations	Mean radioactivity concentration (fresh)[b], Bq kg^{-1}											
			^{3}H	^{14}C	^{54}Mn	^{90}Sr	^{95}Nb	^{99}Tc	^{125}Sb	^{131}I	^{137}Cs	^{155}Eu	^{241}Am	Gross beta
Between Finlaystone and Woodhall	Mussels	1		<15	<0.12		<0.13	1.9	<0.39	<0.10	<0.14	<0.31	<0.19	
Between Finlaystone and Woodhall	Fucus vesiculosus	1		<15	<0.10		<0.10	20	<0.13	3.6	0.24	0.12	<0.10	
Dalmuir Clydebank	Sediment	1		<15	<0.10		<0.10		<0.10	<0.10	7.7	<0.13	0.68	
Downstream of Dalmuir	Freshwater	4			<0.10		<0.10		<0.11	<0.10	<0.10	<0.13	<0.12	
River Clyde	Freshwater	4	<1.0			<0.005					<0.11			12
Firth of Forth	Freshwater	4	<1.0			<0.005					<0.02			2.9
Daldowie	Sludge pellets	4			<0.10		<0.10		<0.23	81	2.8	<0.39	<0.45	

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 2021

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

7. Regional monitoring

Highlights

- Doses for the representative person were approximately 1% (or less) of the annual public dose limit in 2021

Regional monitoring in areas remote from nuclear licensed sites has continued in 2021:

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 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, sediments, drinking water and seawater.

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 [185].

The results of monitoring for 2021 are given in Table 7.1, due to continuing COVID-19 restrictions, no samples were collected or analysed from Alderney. There was evidence of routine releases from the nuclear industry in some food and environmental samples (for example, technetium-99). 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 2021, the dose to a representative person, consuming large amounts of fish and shellfish was estimated to be less than 0.005mSv, or less than 0.5% 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 (for example [186]) and the data indicated 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 (for example [46]). 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/regulation-directorate/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 Table 7.2(a) and Table 7.2(b).

In 2021, the main effect of discharges from Sellafield was observed in concentrations of technetium-99 in shellfish and seaweed samples. These were similar to values reported in recent years, reflecting the considerably decreased inputs to the Irish Sea (see also Section 2.3.3). Caesium-137 concentrations were low and generally similar to those in 2020. As expected, low concentrations of transuranic radionuclides were also detected in 2021. 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 [187]. The gamma dose rates over intertidal areas were similar to those in previous years.

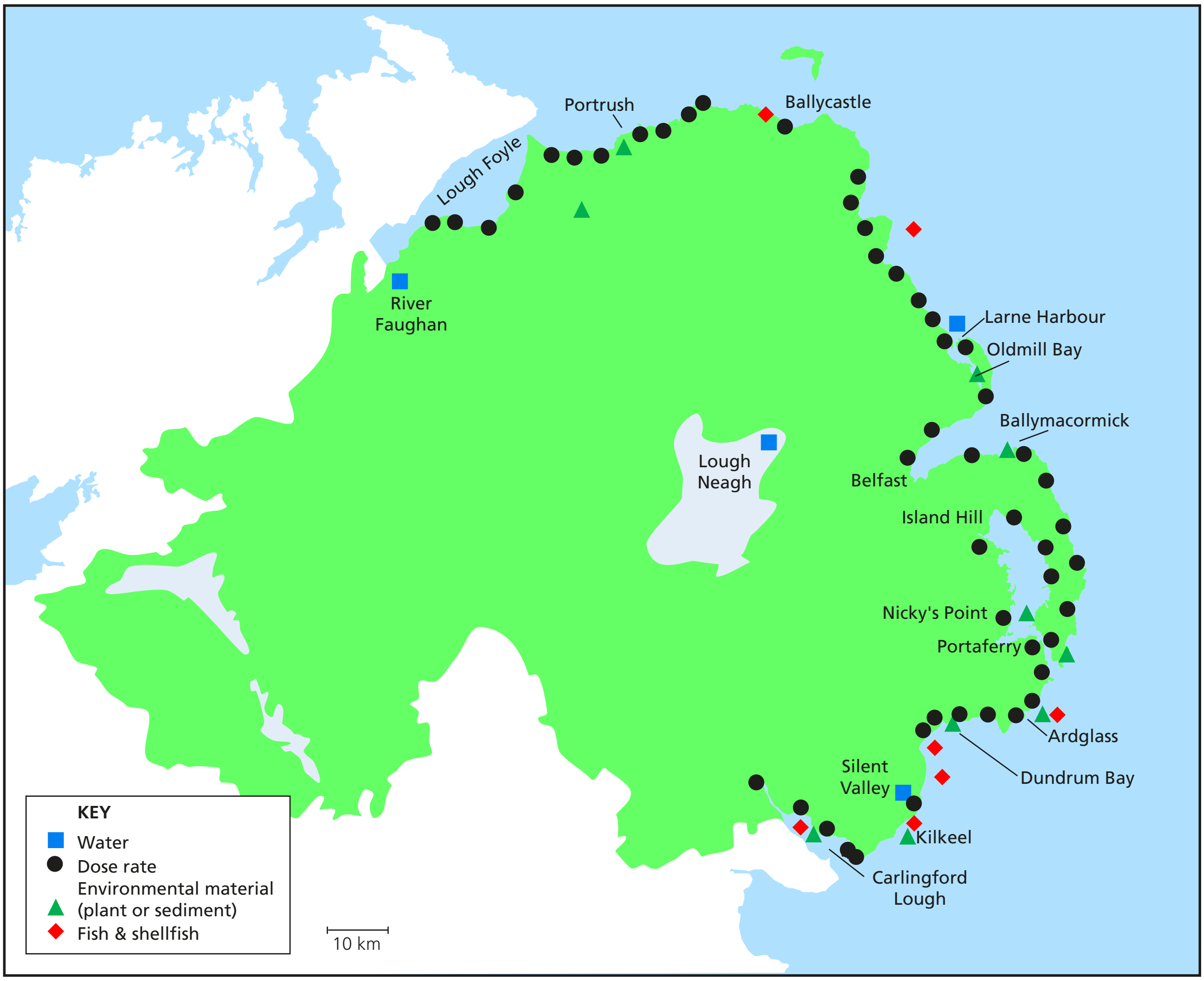


Figure 7.1 Monitoring locations in Northern Ireland, 2021

A survey of consumption and occupancy in coastal regions of Northern Ireland established the habits of people consuming large quantities of fish and shellfish [188]. Based on the monitoring results from the marine environment in 2021, the annual dose from the consumption of seafood and exposure over intertidal areas was 0.007mSv (Table 2.15), or less than 1% 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.

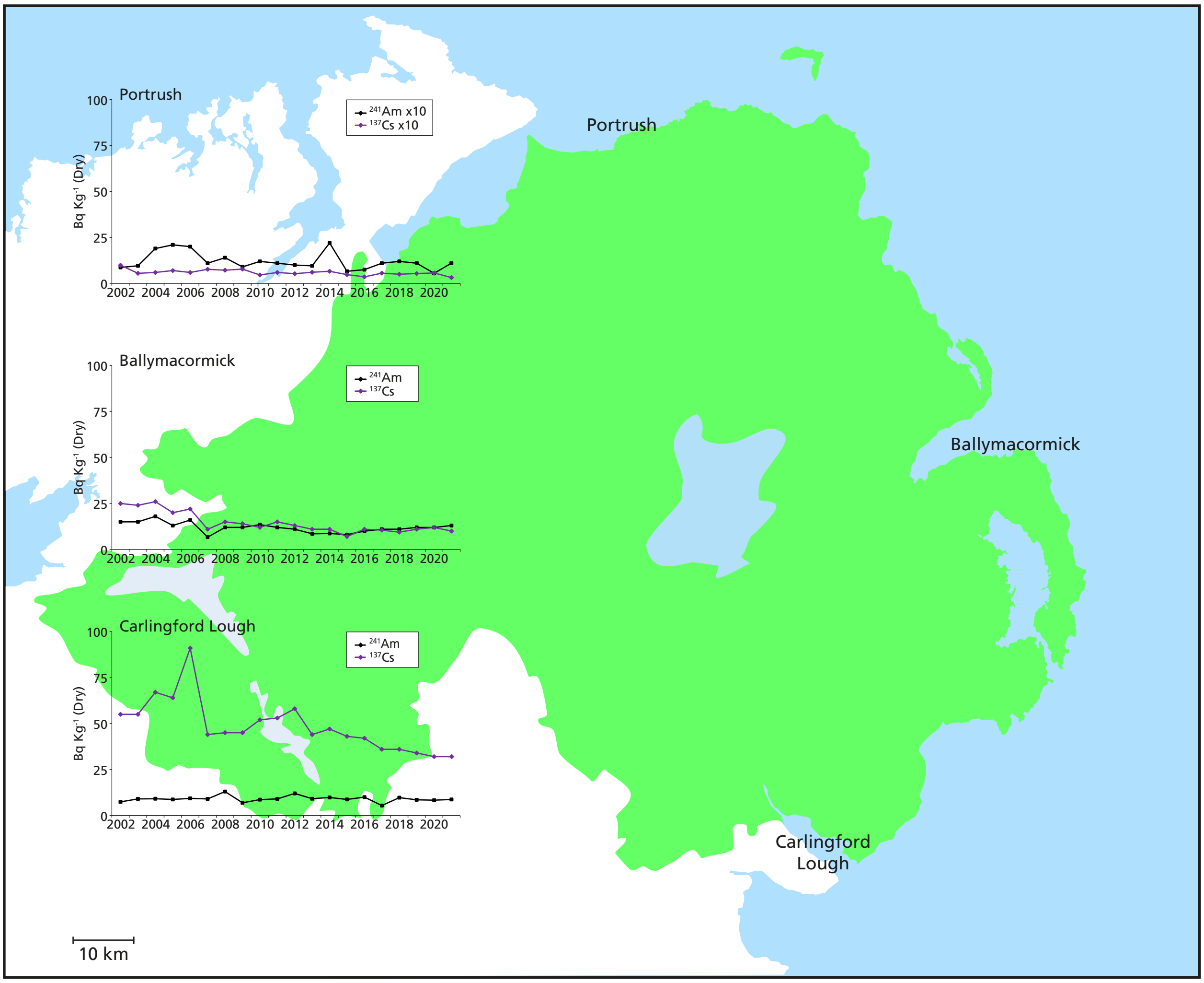


Figure 7.2 Concentrations of americium-241 and caesium-137 in coastal sediments in Northern Ireland, 2002–2021

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) previously formed the basis of the UK submission to the EC under Article 36 of the Euratom Treaty. While these data are no longer supplied to the EC for England, Wales and Northern Ireland, they will continue to be published in the RIFE reports.

In 2021, 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 2021. The aim is to collect and analyse samples on a monthly basis, for their radionuclide content. This programme provides useful information with which to compare data from farms close to nuclear licensed sites and other establishments that may enhance values above background activity concentrations. Prior to the UK's exit from the EU, concentrations of radioactivity in the general diet were reported to the EC by the FSA (for England, Northern Ireland and Wales), and by SEPA (for Scotland). While these data are no longer supplied to the EC for England, Wales and Northern Ireland, they will continue to be published in the RIFE reports.

The results of milk monitoring for 2021 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 (Devon), Northern Ireland (Co. Antrim), Wales (Gwynedd) and Scotland (Nairnshire) were 40, 28, 17 and less than 16Bq l^{-1}, respectively. As in previous years, tritium concentrations were reported as less than values at all remote sites. In 2021, 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 0.037Bq l^{-1} in 2021 (0.035Bq l^{-1} in 2020). 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 2021, the most exposed age group was infants (1-year-old). For the range of radionuclides analysed, the annual dose was less than 0.005mSv or less than 0.5% of the dose limit. Previous surveys (for example, [189]) 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 artificial radionuclides would contribute less than 10% of the dose.

7.6 Crops

The programme of monitoring naturally occurring and artificial 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 (for example [64]).

7.7 Airborne particulate, rain, freshwater and groundwater

Radioactivity in rainwater and air was monitored at several UK locations as part of the programme of background sampling managed by the Environment Agency and SEPA. These data are collected on behalf of BEIS, NIEA and the Scottish and Welsh Governments. 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 2021. Caesium-137 concentrations in air, as in recent years, remain less than 0.01% 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 [136]. 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 2021 (Figure 7.3). These water data are collected by the Environment Agency (for England and Wales), NIEA (for Northern Ireland) and SEPA (for Scotland). 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 Table 7.6 to Table 7.8 (inclusive). Tritium concentrations were all substantially below the investigation level for drinking water of 100Bq l^{-1} in the Water Supply (Water Quality) (Amendment) 2018 Regulations (retained from European Directive 2013/51) (where applicable) and all are reported as less than values (except for three results). At Gullielands Burn (Table 7.6), which is near to the Chapelcross nuclear licensed site, the tritium concentration was 14Bq l^{-1} in 2021 (similar to that in recent years).

The mean annual dose from consuming drinking water in the UK was 0.015mSv in 2021 (Table 7.9), and lower than the mean annual dose in 2020 (0.046mSv). The highest annual dose was estimated to be 0.019mSv for drinking water from River Faughan, County Londonderry. 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 0.001mSv.

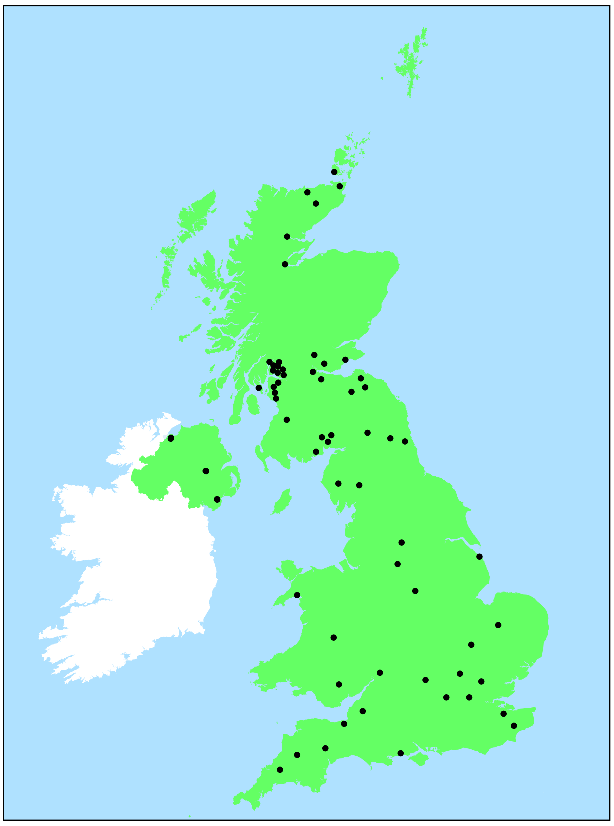


Figure 7.3 Drinking water sampling locations, 2021

Due to continuing COVID-19 restrictions, collection and analysis of groundwater samples from across Scotland was not performed in 2021. Results up to 2019 are included in earlier RIFE reports (for example, [20]).

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 [190].

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 feed and food originating in or consigned from Japan following the Fukushima Dai-ichi accident [191]. 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) and again in October 2019 (Regulation EU/2019/1787) [192]. This applied certain measures to some feed and food originating in or consigned from specific prefectures of Japan. The 2016 regulation (amended in 2017 and 2019) lifted restrictions on some or all agricultural and fisheries products from 10 Japanese prefectures. Applicable feed and food products from these prefectures intended to be imported to the UK had to be tested before leaving Japan and were subject to random testing in the UK. 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 provided in earlier RIFE reports (for example [47]). The list of applicable feeds and foods from the prefectures can be found in annex II of the legislation. These regulations were retained in the UK following the UK's exit from the EU and amended by the Food and Feed Hygiene and Safety (Miscellaneous Amendments etc.) (EU Exit) Regulations 2020.

There was a requirement in the legislation to review these enhanced import controls on food from Japan in 2021. Following the UK's exit from the EU, the responsibility to review the controls fell to ministers in England, Wales and Scotland based on advice from the FSA and FSS.

In December 2021, the FSA and FSS launched a public consultation as part of this review [193]. The consultation proposed removing the last of the remaining enhanced controls based on the outcome of the FSA and FSS risk assessment, which concluded that the removal of the 100Bq kg^{1} maximum level for radiocaesium in imported Japanese food would result in a negligible increase in dose and any associated risk to UK consumers [194]. Following the consultation, the FSA and FSS boards both agreed to make recommendations to ministers to remove the controls [195] [196]. Following agreement from ministers, legislation was laid to revoke retained EU Regulation 2016/6 which came into force on 25 June 2022 (in Scotland) [197] and 29 June 2022 (in England and Wales) [198] [199]. From these dates, the enhanced controls and requirements for testing these food products from Japan were removed for products entering Great Britain.

In Northern Ireland, European Regulations continue to apply under the terms of the UK's withdrawal agreement from the EU. In September 2021, the EU published Commission Implementing Regulation (EU) 2021/1533 [200] which replaced Regulation 2016/6 in the EU. The EU retained enhanced controls on any food where there is a single instance of exceeding the maximum level of 100Bq kg^{-1}, or similar. As a result, some controls will remain in place for food imported into the EU and Northern Ireland. The list of foods covered by the enhanced controls in the EU regulations is now very limited and includes wild mushrooms, foraged foods and some species of fish.

A full description of the legislation, requirements and procedures involved for imports are provided in earlier RIFE reports [24].

A percentage of Japanese imports into the EU were monitored in the UK and this work continued in 2021. Monitoring was carried out by local port health authorities (or local authorities in Scotland). Following changes to the regulations in 2016, the FSA and FSS ceased collating routine data on these samples and were 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 2021 were found to contain radioactivity exceeding the maximum permitted levels (100Bq kg^{-1} for the total of caesium-134 and caesium-137 in food). 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 2021, 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 [2]. Therefore, a programme of surveillance into the distribution of important 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 provided 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 to 2020), see Section 1.4.2 of this report for more details. The surveys also provide information that can be used to distinguish different sources of artificial radioactivity (for example, [201]) and to derive dispersion factors for nuclear licensed sites (for example, [202]). 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 2021 are given in Figure 7.4 to Figure 7.8.

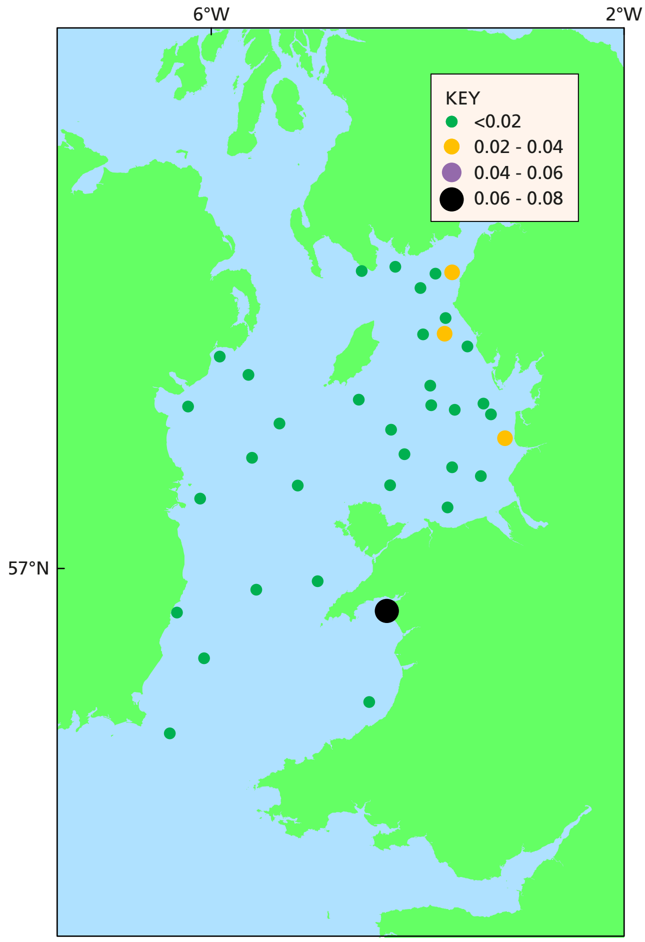


Figure 7.4 Concentrations (Bq l^{-1}) of caesium-137 in surface water from the Irish Sea, September–October 2021

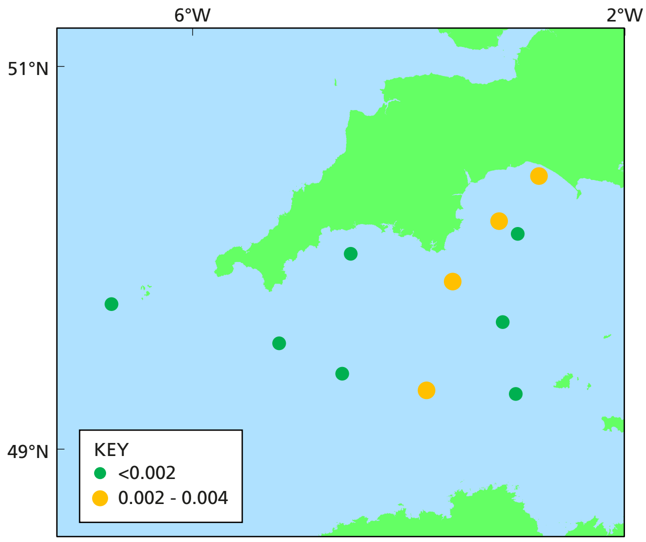


Figure 7.5 Concentrations (Bq l^{-1}) of caesium-137 in surface water from the English Channel, March 2021

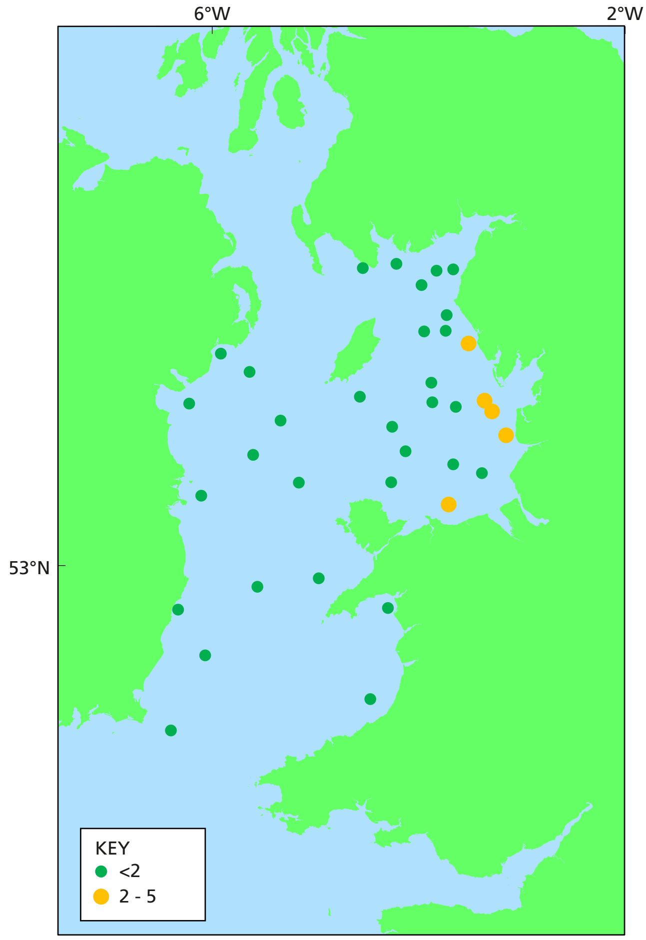


Figure 7.6 Concentrations (Bq l-1) of tritium in surface water from the Irish Sea, September 2021

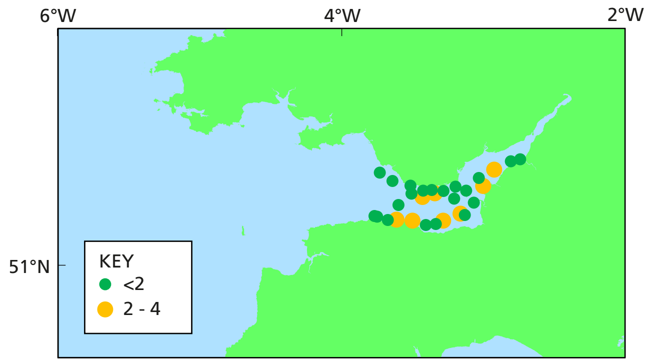


Figure 7.7 Concentrations (Bq l-1) of tritium in surface water from the Bristol Channel, September 2021

A seawater survey of the Irish Sea was carried out in 2021. 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 2021 survey recorded concentrations of up to 0.04Bq l^{-1} in the eastern Irish Sea (in comparison with 0.06Bq l^{-1} in the eastern Irish Sea in 2019) and up to 0.08Bq l^{-1} of the west coast of Wales. For the remainder of the Irish Sea, caesium-137 concentrations were reported as less than values (0.02Bq l^{-1}). Overall, concentrations were similar to those reported in the previous Irish Sea survey in 2019 [20]. Caesium-137 concentrations in the Irish Sea were only a very small percentage of those prevailing in the late 1970s, when discharges were substantially higher (typically up to 30Bq l^{-1}, [203]).

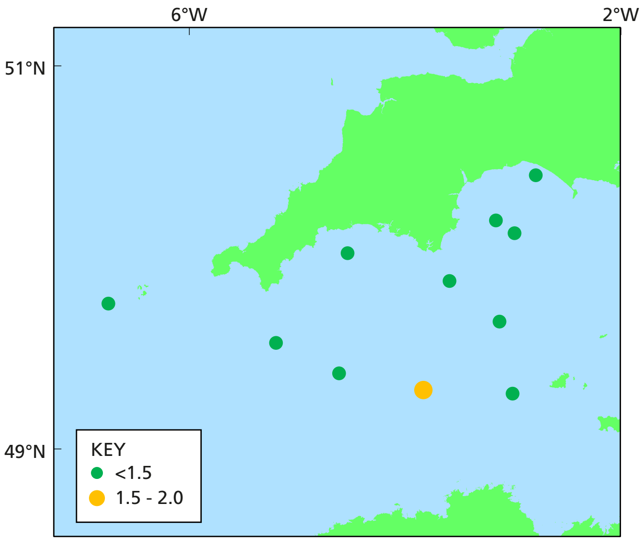


Figure 7.8 Concentrations (Bq l^{-1}) of tritium in surface water from the English Channel, March 2021

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 [204]. 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 over 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 several 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 [205]. 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 concentrations of caesium-137 of up to 0.5Bq l^{-1} in the North Sea surface waters in the late 1970s. Due to significantly decreasing discharges after 1978, remobilisation of caesium-137 from contaminated sediments in the Irish Sea was considered to be the dominant source of water contamination for most of the North Sea [206].

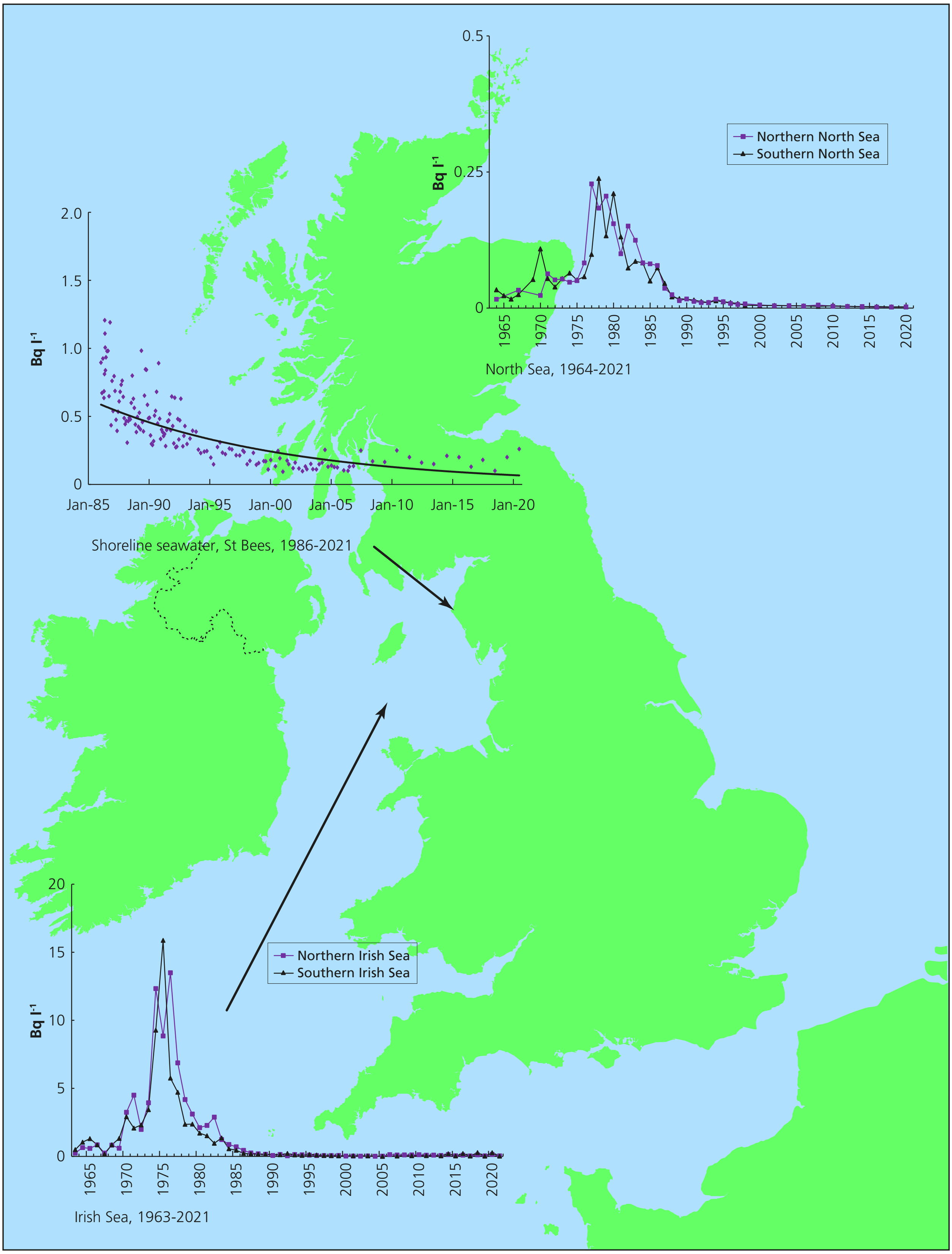


Figure 7.9 Concentration of caesium-137 in the Irish Sea, North Sea and in shoreline seawater close to Sellafield at St. Bees (Note different scales used for activity concentrations)

In 2020, very low concentrations (up to 0.004Bq l^{-1}) were found throughout most of the North Sea survey area [24]. The few positively detected values were only slightly above those observed for global fallout levels in surface seawaters (0.0001 – 0.0028Bq l^{-1}, [207]). 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 Skagerrak) 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 [208].

In 2021, 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).

A full assessment of historic long-term trends of caesium-137 in surface waters of Northern European seas is provided elsewhere [205].

Tritium concentrations in Irish Sea seawater in 2021 are shown in Figure 7.6. These are generally lower (by small amounts) than those observed in the North Sea in 2020 (Figure, 7.6, [24]) 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 the former GE Healthcare Limited facility at 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 2021. 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 the former GE Healthcare Limited facility at Cardiff, Berkeley, Oldbury and Hinkley Point. Tritium concentrations in the western English Channel were all reported as below the less than value (or close to the less than value) (Figure 7.8).

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 [206] [209] [210] [211] [212] and an estimate of the total inventory residing in the sub-tidal sediments of the Irish Sea has also been published [213]. Trends in plutonium and americium concentrations in seawater of the Irish Sea have also been published [214].

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 [215] [216] [217] [218]. The Fifth Periodic Evaluation covers both radioactive discharges from the nuclear and non-nuclear sectors and environmental concentrations and demonstrated that Contracting Parties successfully fulfilled the RSS objectives for the nuclear and non-nuclear sectors [53].

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 7.10. Most radionuclides are reported as less than values. Tritium and caesium-137 concentrations remote from site discharge points are consistent with those in Figure 7.4 to Figure 7.8.

Due to COVID-19 restrictions, collection and analysis of marine sediment and seawater samples from across Scotland was not performed in 2021. Results up to 2019 are included in earlier RIFE reports (for example, [20]).

Table 7.1 Concentrations of radionuclides in seafood and the environment near the Channel Islands, 2021

Location	Material	No. of sampling observations	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}					
			^{60}Co	^{90}Sr	^{99}Tc	^{106}Ru	^{137}Cs	^{155}Eu
Guernsey								
	Crabs	1	<0.08			<0.73	<0.08	<0.18
	Lobsters	1	<0.05			<0.44	<0.05	<0.15
	Limpets	1	<0.04			<0.46	<0.04	<0.14
	Ormers	1	<0.06			<0.55	<0.05	<0.14
	Scallops	1	<0.03			<0.28	<0.03	<0.07
St. Sampson's Harbour	Sand	1	<0.14			<1.5	0.43	<0.61
	Seawater	2					0.0015	
Jersey								
	Crabs	1	<0.10			<0.88	<0.09	<0.21
	Spiny spider crabs	1	<0.07			<0.65	<0.10	<0.15
	Lobsters	1	<0.04		0.11	<0.41	<0.08	<0.12
La Rocque	Oysters	1	<0.02			<0.19	<0.02	<0.05
Plemont Bay	Porphyra	2	<0.10			<0.75	<0.09	<0.17
La Rozel	Fucus vesiculosus	4	<0.06	<0.029	1.4	<0.48	<0.06	<0.13
Gorey	Ascophyllum nodosum	4	<0.10			<0.61	<0.07	<0.17

Location	Material	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 beta
Guernsey								
	Crabs	1	0.00036	0.0013	0.0020	*	0.00023	90
	Lobsters	1			<0.19			110
	Limpets	1			<0.18			89
	Ormers	1			<0.18			34
	Scallops	1	0.00053	0.0018	0.0011	*	0.00011	110
St. Sampson's Harbour	Sand	1	0.030	0.13	0.18	0.0025	0.010	580
	Seawater	2						
Jersey								
	Crabs	1	0.00014	0.00056	0.0024	*	0.00016	110
	Spiny spider crabs	1			<0.14			30
	Lobsters	1	0.000091	0.00043	0.0077	0.000033	0.00048	73
La Rocque	Oysters	1	0.00055	0.0019	0.0027	*	0.00015	50
Plemont Bay	Porphyra	2			<0.18			250
La Rozel	Fucus vesiculosus	4	0.0026	0.0068	0.0042	*	0.00044	230
Gorey	Ascophyllum nodosum	4			<0.18			300

* Not detected by the method used
[a] Except for seawater where units are Bq l^{-1}, and for sediment where dry concentrations apply

Table 7.2(a) Concentrations of radionuclides in seafood and the environment in Northern Ireland, 2021[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	29	<0.06		<0.12	<0.06	0.36
Plaice	Kilkeel	4		<0.04		<0.10	<0.04	0.22
Haddock	Kilkeel	4		<0.05		<0.11	<0.04	0.30
Herring	Ardglass	2		<0.09		<0.24	<0.12	0.26
Lesser spotted dogfish	North coast	4		<0.11		<0.23	<0.10	0.62
Skates / rays	Kilkeel	4		<0.07		<0.15	<0.08	0.99
Crabs	Kilkeel	4		<0.06		<0.15	<0.07	<0.09
Lobsters	Ballycastle	2		<0.06	7.0	<0.15	<0.10	0.12
Lobsters	Kilkeel	4		<0.06	6.5	<0.13	<0.08	<0.10
Nephrops	Kilkeel	4		<0.04	1.3	<0.10	<0.05	0.26
Dog whelk	Minerstown	1		<0.11		<0.20	<0.06	0.19
Winkles	Minerstown	1		<0.06		<0.14	<0.04	0.21
Mussels	Carlingford Lough	2		<0.10	2.1	<0.20	<0.11	0.25
Scallops	County Down	2		<0.05		<0.11	<0.03	0.11
Toothed winkles	Minerstown	2		<0.08		<0.18	<0.09	0.17
Fucus species	Carlingford Lough	3		<0.05	11	<0.10	<0.03	0.23
Ascophyllum nodosum	Carlingford Lough	1		<0.04		<0.08	<0.02	0.16
Fucus species	Portrush	4		<0.05		<0.10	<0.03	<0.05
Ascophyllum nodosum	Ardglass	1		<0.07		<0.14	<0.05	0.18
Fucus vesiculosus	Ardglass	3		<0.04	6.7	<0.09	<0.06	0.23
Rhodymenia species	Strangford Lough - Island Hill	4		<0.09	0.24	<0.18	<0.09	0.53
Mud	Carlingford Lough	2		<0.32		<0.86	<0.35	32
Sandy mud	Ballymacormick	2		<0.20		<0.53	<0.21	10
Mud	Dundrum Bay	1		<0.24		<0.51	<0.16	2.9
Sandy mud	Dundrum Bay	1		<0.17		<0.48	<0.29	3.4
Mud	Strangford Lough - Nicky's Point	2		<0.21		<0.53	<0.32	8.8
Clay	Oldmill Bay	1		<0.25		<0.62	<0.15	7.5
Sandy mud	Oldmill Bay	1		<0.21		<0.58	<0.16	7.8
Sand	Portrush	2		<0.13		<0.33	<0.16	0.32
Sandy mud	Carrichue	2		<0.19		<0.47	<0.21	1.7
Seawater	North of Larne	3			0.00055		*	0.0022

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	<0.13			<0.13		
Plaice	Kilkeel	4	<0.11			<0.17		
Haddock	Kilkeel	4	<0.11			<0.12		
Herring	Ardglass	2	<0.25			<0.25		
Lesser spotted dogfish	North coast	4	<0.22			<0.21		
Skates / rays	Kilkeel	4	<0.14			<0.13		
Crabs	Kilkeel	4	<0.17			<0.22		
Lobsters	Ballycastle	2	<0.18			<0.40		
Lobsters	Kilkeel	4	<0.14			<0.15		
Nephrops	Kilkeel	4	<0.11	0.00087	0.0059	0.021	*	*
Dog whelk	Minerstown	1	<0.17			0.14		
Winkles	Minerstown	1	<0.15	0.044	0.27	0.28	*	0.00060
Mussels	Carlingford Lough	2	<0.16			0.19		
Scallops	County Down	2	<0.11			<0.08		
Toothed winkles	Minerstown	2	<0.19			0.52		
Fucus species	Carlingford Lough	3	<0.16			<0.19		
Ascophyllum nodosum	Carlingford Lough	1	<0.16			<0.11		
Fucus species	Portrush	4	<0.10			<0.13		
Ascophyllum nodosum	Ardglass	1	<0.15			<0.17		
Fucus vesiculosus	Ardglass	3	<0.14			<0.18		
Rhodymenia species	Strangford Lough - Island Hill	4	<0.26	0.073	0.44	0.88	*	*
Mud	Carlingford Lough	2	<1.4	1.6	11	8.7	*	*
Sandy mud	Ballymacormick	2	<0.95			13		
Mud	Dundrum Bay	1	<1.0			1.9		
Sandy mud	Dundrum Bay	1	<1.5			2.5		
Mud	Strangford Lough - Nicky's Point	2	<1.2			3.6		
Clay	Oldmill Bay	1	<1.3			8.6		
Sandy mud	Oldmill Bay	1	<1.1			8.3		
Sand	Portrush	2	<0.46			1.1		
Sandy mud	Carrichue	2	<0.85	0.054	0.44	0.86	*	*
Seawater	North of Larne	3						

* 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, 2021[a]

Location	Ground type	No. of sampling observations	Mean gamma dose rate in air at 1m, $\mu Gy\ h^{-1}$
Lisahally	Mud	1	0.055
Donnybrewer	Shingle	1	0.047
Carrichue	Mud	1	0.064
Bellerena	Mud	1	0.054
Benone	Sand	1	0.052
Castlerock	Sand	1	0.055
Portstewart	Sand	1	0.053
Cushendun	Sand	1	0.056
Cushendall	Sand and stones	1	0.057
Red Bay	Sand	1	0.055
Carnlough	Sand	1	0.053
Glenarm	Sand	1	0.057
Half Way House	Sand	1	0.052
Ballygally	Sand	1	0.054
Drains Bay	Sand	1	0.052
Larne	Sand	1	0.055
Whitehead	Sand	1	0.056
Carrickfergus	Sand	1	0.053
Jordanstown	Sand	1	0.053
Helen's Bay	Sand	1	0.055
Groomsport	Sand	1	0.058
Millisle	Sand	1	0.071
Ballywalter	Sand	1	0.065
Ballyhalbert	Sand	1	0.065
Cloghy	Sand	1	0.062
Portaferry	Shingle and stones	1	0.083
Kircubbin	Sand	1	0.081
Greyabbey	Sand	1	0.081
Ards Maltings	Mud	1	0.078
Island Hill	Mud	1	0.069
Nicky's Point	Mud	1	0.077
Strangford	Shingle and stones	1	0.094
Kilclief	Sand	1	0.062
Ardglass	Mud	1	0.083
Killough	Mud	1	0.074
Ringmore Point	Sand	1	0.066
Tyrella	Sand	1	0.070
Dundrum	Sand	1	0.081
Newcastle	Sand	1	0.096
Annalong	Sand	1	0.098
Cranfield Bay	Sand	1	0.076
Mill Bay	Sand	1	0.097
Greencastle	Sand	1	0.076
Rostrevor	Sand	1	0.10
Narrow Water	Mud	1	0.082

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

Table 7.3 Concentrations of radionuclides in diet, 2021[a]

Region	No. of sampling observations	Mean radioactivity concentration (fresh), Bq kg^{-1}			
		^{14}C	^{40}K	^{90}Sr	^{137}Cs
Canteen meals					
England	7		96	<0.025	<0.06
Northern Ireland	4		120	<0.031	<0.09
Scotland	12	36	91	<0.018	<0.02
Wales	1		84	0.017	<0.10

Region		No. of sampling observations	Mean radioactivity concentration (fresh), Bq kg^{-1}			
			^{14}C	^{40}K	^{90}Sr	^{137}Cs
Mixed diet in Scotland						
Dumfriesshire	Dumfries	4		72	<0.10	<0.05
East Lothian	North Berwick	4		82	<0.10	<0.05
Renfrewshire	Paisley	4		79	<0.10	<0.05
Ross-shire	Dingwall	4		90	<0.10	<0.05

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

Table 7.4 Concentrations of radionuclides in milk remote from nuclear sites, 2021

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		28	<0.024	<0.05
	max				<0.028	<0.06
Buckinghamshire		1		15	<0.023	<0.04
Ceredigion		1			<0.032	<0.04
Clywd		1			<0.019	<0.04
Cornwall		1		18	<0.028	<0.03
Devon		1		40	<0.025	<0.04
Dorset		1		14	<0.019	<0.03
Co. Down		1			<0.024	<0.05
Dumfriesshire		1	<5.0	<15	<0.10	<0.05
Co. Fermanagh		1			<0.028	<0.04
Gloucestershire		1		17	<0.026	<0.03
Gwynedd		1		17	<0.024	<0.04
Humberside		1		17	<0.027	<0.03
Kent		1		19	<0.025	<0.04
Lanarkshire		1	<5.0	<15	<0.023	<0.03
Lancashire		1		21	<0.023	<0.03
Leicestershire		1		10	<0.024	<0.04
Londonderry		1			0.018	<0.06
Middlesex		1		24	<0.024	<0.03
Midlothian		1	<5.0	<15	<0.10	<0.05
Nairnshire		1	<5.0	<16	<0.10	<0.05
Norfolk		1		12	<0.023	<0.03
North Yorkshire		1		28	<0.024	<0.03
Renfrewshire		1	<5.0	<15	<0.14	<0.11
Shropshire		1		22	<0.030	<0.03
Suffolk		1		11	<0.024	<0.03
Co. Tyrone		2		22	<0.024	<0.05
	max				0.026	
Mean Values						
England				19	<0.025	<0.03
Northern Ireland				25	<0.024	<0.05
Wales				17	<0.025	<0.04
Scotland			<5.0	<15	<0.093	<0.06
United Kingdom			<5.0	<19	<0.037	<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, 2021

Location	Sample	No. of sampling observations	Mean radioactivity concentration[a]					
			^{3}H	^{7}Be	^{7}Be[d]	^{90}Sr	^{137}Cs	^{137}Cs[d]
Ceredigion								
Aberporth	Rainwater	4	<1.8	0.86			<0.0070	
	Air	4		0.0044			<7.3 10^{-7}	
Co. Down								
Conlig	Rainwater	4		0.71			<0.0092	
	Air	4		0.0023			<5.3 10^{-7}	
Dumfries and Galloway								
Eskdalemuir	Rainwater	12	<1.0	<1.0		<0.0062	<0.011	
	Air	12		0.0032			<1.0 10^{-5}	
Newton Stewart	Air	7		0.0023			<1.0 10^{-5}	
City of Edinburgh								
Edinburgh Silvan	Air	10		0.0032			<1.0 10^{-5}	
North Lanarkshire								
Holytown	Rainwater	12	<1.0	<0.94		<0.0095	<0.025	
	Air	2		0.0015			<1.0 10^{-5}	
North Yorkshire								
Dishforth/Leeming	Rainwater	4		0.62			<0.012	
	Air	4		0.0037			<6.8 10^{-7}	
Oxfordshire								
Chilton	Rainwater	4		1.3	0.49	<0.00045	<0.018	<0.00032
	Air	12		0.0029			<4.4 10^{-7}	
Shetland								
Lerwick	Rainwater	12	<1.0	2.0		<0.0064	<0.022	
	Air	12		0.0026			<1.0 10^{-5}	
Suffolk								
Orfordness	Rainwater	4	<1.8	1.2			<0.016	
	Air	4		0.0043			<5.5 10^{-7}	

Location	Sample	No. of sampling observations	Mean radioactivity concentration[a]				
			^{238}Pu[c]	^{239}Pu+ ^{240}Pu[c]	^{241}Am	Gross alpha	Gross beta
Ceredigion							
Aberporth	Rainwater	4	<3.2 10^{-6}	4.5 10^{-6}	3.3 10^{-6}		
	Air	4	<8.5 10^{-10}	2.0 10^{-9}	1.0 10^{-9}		
Dumfries and Galloway							
Eskdalemuir	Air	12					<0.00021
Newton Stewart	Air	7					<0.00020
City of Edinburgh							
Edinburgh Silvan	Air	10					<0.00021
North Lanarkshire							
Holytown	Air	2					<0.00020
Oxfordshire							
Chilton	Rainwater	4				0.030[d]	0.19
Shetland							
Lerwick	Air	12					<0.00020

a Bq l^{-1} for rainwater and Bq kg^{-1} for air. 1.2 kg air occupies $1m^3$ 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 Concentrations of radionuclides in sources of drinking water in Scotland, 2021

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
Annual Samples							
Angus	Loch Lee	4	<1.0	<0.0050	<0.010	<0.011	0.036
Argyll and Bute	Auchengaich	1	<1.1		<0.01	<0.010	0.043
Argyll and Bute	Helensburgh Reservoir	1	<1.0		0.04	<0.010	0.025
Argyll and Bute	Loch Ascog	1	<1.0		<0.01	<0.010	0.26
Argyll and Bute	Loch Eck	1	<1.0		<0.01	<0.010	0.044
Argyll and Bute	Lochan Ghlas Laoigh	1	<1.1		0.01	<0.010	0.095
Argyll and Bute	Loch Finlas	1	<1.0		<0.01	0.011	0.18
Clackmannanshire	Gartmorn Dam	1	<1.0		<0.01	<0.011	0.092
Dumfries and Galloway	Black Esk	1	<1.0		<0.01	<0.010	0.071
Dumfries and Galloway	Gullielands Burn	1	14		<0.01	0.019	0.19
Dumfries and Galloway	Purdomstone	1	<1.0		<0.01	<0.011	0.047
Dumfries and Galloway	Winterhope	1	<1.0		<0.01	<0.010	0.050
East Lothian	Hopes Reservoir	1	<1.0		<0.01	<0.010	0.016
East Lothian	Thorters Reservoir	1	<1.0		<0.01	<0.010	0.022
East Lothian	Whiteadder	1	<1.0		<0.01	<0.010	0.064
East Lothian	Thornton Loch Burn	1	<1.0		0.05	0.011	0.14
Fife	Holl Reservoir	1	<1.0		<0.01	0.011	0.076
Highland	Loch Baligill	1	<1.1		0.01	0.010	0.041
Highland	Loch Calder	1	<1.1		<0.01	0.011	0.054
Highland	Loch Glass	4	<1.0	<0.0050	<0.01	<0.011	0.028
Highland	Loch Shurrerey	1	<1.1		<0.01	0.011	0.049
North Ayrshire	Camphill	1	<1.0		<0.01	<0.010	0.043
North Ayrshire	Outerwards	1	<1.0		<0.01	<0.010	0.070
Orkney Islands	Heldale Water	1	<1.1		<0.01	0.011	0.040
Perth and Kinross	Castlehill Reservoir	1	<1.0		<0.01	<0.010	0.013
Scottish Borders	Knowesdean	4	<1.0	<0.0050	<0.01	<0.010	0.043
Stirling	Loch Katrine	12	<1.0	0.0017	<0.0017	<0.0094	0.029
West Dunbartonshire	Loch Lomond (Ross Priory)	1	<1.0		<0.01	<0.010	0.039
West Lothian	Morton No 2 Reservoir	1	<1.0		<0.01	<0.010	0.057

[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

Table 7.7 Concentrations of radionuclides in sources of drinking water in England and Wales, 2021

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										
Buckinghamshire	Bourne End, Groundwater	4	<3.7	0.025	<0.00087		<0.00077	<0.034	0.047	0.038
Cambridgeshire	Grafham Water	4	<3.8	0.27	<0.00087		<0.00082	<0.032	0.37	0.31
Cheshire	River Dee	4	<3.6	0.077	<0.00083	<0.0014	<0.00076	0.0025	0.095	0.076
Cornwall	River Fowey	4	<3.6	0.042	<0.00083	<0.0013	<0.00076	0.076	0.073	0.059
County Durham	Honey Hill Water Treatment Works, Consett	4	<3.7	0.031	<0.00082		<0.00097	0.017	0.047	0.039
County Durham	River Tees, Darlington	4	<3.6	<0.034	<0.00071	<0.0014	<0.00087	0.015	0.057	0.045
Cumbria	Ennerdale Lake	4	<3.7	<0.015	<0.00077		<0.00075	0.0084	0.020	0.016
Cumbria	Haweswater Reservoir	4	<3.5	<0.016	<0.0074		<0.00078	<0.0081	0.023	0.019
Derbyshire	Arnfield Water Treatment Plant[a]	4	<3.8	<0.019	<0.00075		<0.00074	0.14	0.12	0.026
Derbyshire	Matlock, Groundwater[b]	4	<3.7	0.038	<0.00068		<0.00065	0.14	0.12	0.097
Devon	River Exe, Exeter	4	<3.7	0.058	<0.00074	<0.0013	<0.00078	0.0083	0.078	0.064
Devon	Roadford Reservoir, Broadwoodwidger	4	<3.6	0.054	<0.00081		<0.00070	0.0042	0.079	0.065
Gloucestershire	River Severn, Tewkesbury	4	<3.7	0.18	<0.00072	<0.0013	<0.00083	0.0035	0.22	0.17
Greater London	River Lee, Walthamstow	4	<3.5	0.21	<0.00085	<0.0016	<0.00080	<0.034	0.30	0.25
Hampshire	River Avon, Christchurch	4	<3.6	0.073	<0.00091	<0.0013	<0.00081	0.024	0.080	0.066
Humberside	Littlecoates, Groundwater	3	<3.6	0.084	<0.00087		<0.00076	0.024	0.11	0.089
Kent	Sittingbourne, Deep Groundwater	4	<3.7	0.045	<0.00080		<0.00079	<0.027	0.048	0.039
Kent	Denge, Shallow Groundwater	4	<3.7	0.092	<0.00080		<0.00083	<0.012	0.12	0.098
Lancashire	Worsthorne, Groundwater	4	<3.7	<0.014	<0.00082		<0.00077	0.012	0.029	0.023
Norfolk	River Drove, Stoke Ferry	4	<3.7	0.10	<0.00092	<0.0012	<0.00069	0.034	0.15	0.12
Northumberland	Kielder Reservoir	4	<3.7	<0.016	<0.00074		<0.00078	0.013	0.030	0.024
Oxfordshire	River Thames, Oxford	4	<3.6	0.13	<0.00088	<0.0014	<0.00076	0.033	0.18	0.14
Somerset	Ashford Reservoir, Bridgwater	4	<3.6	0.061	<0.00075		<0.00082	<0.026	0.083	0.065
Somerset	Chew Valley Lake Reservoir, Bristol	4	<3.5	0.12	<0.00096		<0.00080	0.025	0.16	0.13
Surrey	River Thames, Chertsey	4	<3.6	0.19	<0.00091	<0.0014	<0.00081	<0.039	0.23	0.18
Surrey	River Thames, Walton	4	<3.7	0.19	<0.00094	<0.0016	<0.00079	<0.029	0.23	0.18
Yorkshire	Chellow Heights, Bradford	4	<3.6	<0.016	<0.0010		<0.00080	0.016	0.033	0.027
Yorkshire	Washburn Valley Reservoirs, Leeds	4	<3.7	0.056	<0.00085		<0.00076	0.012	0.070	0.057
Wales										
Gwynedd	Cwm Ystradllyn Treatment Works	4	<3.6	<0.017	<0.00092		<0.00087	0.0091	0.019	0.016
Mid-Glamorgan	Llwyn-on Reservoir	4	<3.6	<0.027	<0.00078		<0.00078	0.0088	0.024	0.018
Powys	Elan Valley Reservoir	4	<3.6	<0.018	<0.0011		<0.00083	0.0091	0.018	0.015

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 <0.0023, 0.00094, <0.00082, <0.00069 and <0.00081 Bq l^{-1} respectively
b The concentrations of ^{210}Po, ^{226}Ra, ^{234}U, ^{235}U and ^{238}U were <0.0037, 0.016, 0.044, <0.0011 and 0.024 Bq l^{-1} respectively

Table 7.8 Concentrations of radionuclides in sources of drinking water in Northern Ireland, 2021

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	2	<7.9	0.0014	<0.0029	<0.0010	<0.06	<0.010	<0.010	<0.010	<0.03	<0.13
Co. Antrim	Lough Neagh	2	<7.9	0.00095	<0.0031	<0.0010	<0.06	<0.010	<0.010	<0.010	<0.10	0.017
Co. Down	Silent Valley	2	<7.9	0.0027	0.0020	0.0030	<0.03	<0.010	<0.010	<0.010	<0.10	0.017

Table 7.9 Doses from radionuclides in drinking water, 2021[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	0.010	0.010	Matlock, Groundwater, Derbyshire	0.015
Wales[d]	<0.001			Llwyn-on Reservoir Mid-Glamorgan	<0.001[d]
Northern Ireland[d]	<0.001	0.017	0.018	R Faughan, Co. Londonderry	0.019
Scotland[d]	<0.001			Gullielands Burn, Dumfries and Galloway	<0.001[d]
UK	<0.001	0.015	0.015	R Faughan, Co. Londonderry	0.019

[a] Assessments of dose are based on some concentration results at limits of detection. Exposures due to potassium-40 content of water are not included here because they do not vary according to the potassium-40 content of water. Levels of potassium are homeostatically controlled
[b] Average of the doses to the most exposed age group at each location
[c] Including tritium
[d] Analysis of naturally occurring radionuclides was not undertaken

Table 7.10 Concentrations of radionuclides in seawater, 2021

Location	No. of sampling observations	Mean radioactivity concentration, Bq l^{-1}							
		^{3}H	^{14}C	^{60}Co	^{90}Sr	^{99}Tc	^{106}Ru	^{110m}Ag	^{129}I
Dounreay (Sandside Bay)	2[S]	<1.0		<0.10			<0.34	<0.10	
Dounreay (Brims Ness)	2[S]	<1.0		<0.10			<0.25	<0.10	
Rosyth	2[S]	<1.0		<0.10			<0.18	<0.10	
Torness[a]	2[S]	<3.9		<0.10			<0.33	<0.10	
Hartlepool (North Gare)[b]	2	<4.3		<0.30			<2.0	<0.31	
Sizewell	2	<3.8	<5.4	<0.35			<2.3	<0.38	
Bradwell (Beach pipeline)	2	<3.6		<0.24			<1.9	<0.29	
Dungeness south	2	<3.6		<0.32			<2.1	<0.34	
Winfrith (Lulworth Cove)	1			<0.25			<1.8	<0.27	
Devonport (Millbrook Lake)	1	<3.2	10	<0.23					
Devonport (Tor Point South)	1	<3.4	<11	<0.30					
Hinkley	1	<3.7		<0.24	<0.031		<1.6	<0.29	
Berkeley and Oldbury	2	<3.6		<0.23			<1.8	<0.27	
Wylfa (Cemaes Bay)	2	<3.5		<0.33			<2.3	<0.38	
Heysham[c]	2	9.5		<0.31			<2.2	<0.37	
Seascale (Particulate)[d]	2			<0.02	<0.013		<0.18	<0.03	<0.025
Seascale (Filtrate)	2	<4.0	<5.5	<0.16	<0.037	<0.068	<1.3	<0.22	<0.34
St. Bees (Particulate)[e]	2			<0.02	<0.013		<0.18	<0.03	<0.025
St. Bees (Filtrate)	2	<3.6	<4.9	<0.16	<0.042	<0.045	<1.3	<0.20	<0.69
Seafield (near Chapelcross)	1[S]	<1.0		<0.10			<0.19	<0.10	
Southerness	2[S]	<1.0		<0.10			<0.32	<0.10	
Auchencairn	2[S]	<1.0		<0.10			<0.26	<0.10	
Port Patrick	2[S]	<1.0		<0.10			<0.30	<0.10	
Knock Bay	1[B]	<1.5							
Hunterston[f]	2[S]	210		<0.10			<0.38	<0.10	
North of Larne	3[N]					0.00055			
Faslane (Carnban)	2[S]	<1.0		<0.10			<0.31	<0.10	

Table 7.10 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)	2S	<0.10	<0.10	<0.20		<0.10		
Dounreay (Brims Ness)	2S	<0.10	<0.10	<0.17		<0.10		
Rosyth	2S	<0.10	<0.10	<0.11		<0.10		
Torness[a]	2S	<0.10	<0.10	<0.20		<0.10		
Hartlepool (North Gare)[b]	2	<0.27	<0.23	<1.1		<0.34	<3.2	14
Sizewell	2	<0.33	<0.26	<1.2		<0.34	<2.6	13
Bradwell (Beach pipeline)	2	<0.26	<0.21	<1.2		<0.35	<2.4	14
Dungeness south	2	<0.29	<0.23	<1.2		<0.34	<3.8	14
Winfrith (Lulworth Cove)	1	<0.26	<0.21	<1.1		<0.35	<2.6	15
Guernsey	2C	*	0.0015					
Hinkley	1	<0.24	<0.18	<0.83		<0.24	<2.1	13
Berkeley and Oldbury	2	<0.24	<0.20	<0.92		<0.30	<1.3	5.3
Holyhead	1B	*	<0.0017					
Wylfa (Cemaes Bay)	2	<0.35	<0.26	<0.97		<0.31	<3.7	13
Llandudno	1B	*	0.0043					
Prestatyn	1B	*	0.0095					
New Brighton	1B	*	0.0053					
Rossall	1B	*	0.020					
Heysham[c]	2	<0.31	<0.26	<0.97		<0.29	<1.9	14
Half Moon Bay	1B	*	0.028					
Silecroft	1B	*	0.016					
Seascale (Particulate)[d]	2	<0.02	<0.02	<0.08	<0.0025	<0.030	0.074	0.06
Seascale (Filtrate)	2	<0.18	<0.14	<0.87	<0.13	<0.25	<1.6	8.3
St. Bees (Particulate)[e]	2	<0.02	<0.02	<0.08	<0.0024	0.099	0.23	0.099
St. Bees (Filtrate)	2	<0.18	<0.14	<0.82	<0.13	<0.37	<3.1	11
Whitehaven	1B	*	0.019					
Maryport	1B	*	0.017					
Silloth	1B	*	0.029					
Seafield (near Chapelcross)	1S	<0.10	<0.10	<0.10		<0.10		
Southerness	2S	<0.10	<0.10	<0.18		<0.10		
Auchencairn	2S	<0.10	<0.12	<0.15		<0.10		
Ross Bay	1B	*	0.0094					
Isle of Whithorn	1B	*	0.0046					
Drummore	1B	*	0.0048					
Port Patrick	2S	<0.10	<0.10	<0.17		<0.10		
Knock Bay	1B	*	0.0060					
Hunterston[f]	2S	<0.10	<0.10	<0.21		<0.10		
North of Larne	3N	*	0.0022					
Faslane (Carnban)	2S	<0.10	<0.10	<0.18		<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 <0.38 Bq l^{-1}
c The concentration of ^{35}S was <1.1Bq l^{-1}
d The concentrations of ^{238}Pu, $^{239/40}Pu$ and ^{241}Pu were <0.00086, 0.0091 and <0.11 Bq l^{-1} respectively
e The concentrations of ^{238}Pu, $^{239/40}Pu$ and ^{241}Pu were 0.0034, 0.025 and 0.18 Bq l^{-1} respectively
f The concentration of ^{35}S was <0.61 Bq l^{-1}
Results are made on behalf of the Environment Agency unless indicated otherwise
B Measurements labelled "B" are made on behalf of the Department of Business, Energy and Industrial Strategy (BEIS)
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

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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/radioactivity-reports.

Appendix 2. Disposals of radioactive waste

Table A2.1 Principal discharges of gaseous radioactive wastes from nuclear establishments in the United Kingdom, 2021*

Establishment	Radioactivity	Discharge limit (annual equivalent)[a],	Discharges during 2021	
		Bq	Bq[b]	% of annual limit[c]
Nuclear fuel production and reprocessing				
Capenhurst (Urenco	Uranium	1.00E+07	Nil	Nil
Nuclear Stewardship Ltd)	Alpha	1.00E+07	6.00E+00	<1
	Beta	5.00E+07	Nil	Nil
Capenhurst (Urenco UK Ltd)	Uranium	7.50E+06	3.41E+05	4.5
	Other alpha	2.40E+06	Nil	Nil
	Technetium-99	1.00E+08	Nil	Nil
	Others	2.25E+09	Nil	Nil
Capenhurst (UCP)	Uranium	7.50E+06	1.23E+04	<1
	Other alpha	2.40E+06	Nil	Nil
	Technetium-99	1.00E+08	Nil	Nil
	Other radionuclides	7.50E+06	Nil	Nil
Sellafield[d]	Alpha[1]	6.60E+08	6.72E+07	10
	Beta[1]	3.20E+10	6.65E+08	2.1
	Tritium[2]	3.70E+14	3.87E+13	10
	Carbon-14[2]	2.30E+12	6.89E+10	3.0
	Krypton-85[2]	7.00E+16	4.33E+15	6.2
	Strontium-90[1]	5.00E+08	3.65E+06	<1
	Ruthenium-106	2.80E+09	5.53E+08	20
	Antimony-125[2]	3.00E+10	5.31E+08	1.8
	Iodine-129[2]	4.20E+10	1.84E+09	4.4
	Caesium-137[1]	4.80E+09	4.67E+07	<1
	Plutonium alpha[1]	1.30E+08	9.09E+06	7.0
	Americium-241 and curium-242[1]	8.40E+07	8.89E+06	11
Springfields	Uranium	5.30E+09	1.17E+07	<1
Springfields	Tritium	1.00E+08	5.86E+05	<1
(National Nuclear Laboratory)	Carbon-14	1.00E+07	6.47E+03	<1
	Krypton-85	7.20E+11	Nil	Nil
	Other alpha radionuclides	1.00E+06	Nil	Nil
	Other beta radionuclides	1.00E+07	4.68E+02	<1
Research establishments				
Dounreay[e]	Alpha[f]	3.1E+07	6.8E+04	<1
	Non-alpha[g]	1.7E+09	9.3E+05	<1
	Tritium	1.72E+13	2.3E+10	<1
	Krypton-85[h]	5.69E+14	1.1E+10	<1
	Iodine-129	1.08E+08	1.3E+07	12
Harwell (Magnox)	Alpha	8.00E+05	2.00E+04	2.5
	Beta	2.00E+07	7.00E+05	3.5
	Tritium	1.50E+13	1.20E+11	<1
	Krypton-85	2.00E+12	Nil	Nil
	Radon-220	1.00E+14	4.80E+12	4.8
	Radon-222	3.00E+12	2.40E+11	8.0
	Iodines	1.00E+10	Nil	Nil
	Other radionuclides	1.00E+11	Nil	Nil

Table A2.1 continued

Establishment	Radioactivity	Discharge limit (annual equivalent)[a],	Discharges during 2021	
		Bq	Bq[b]	% of annual limit[c]
Winfrith (Inutec)	Alpha	1.00E+05	8.10E+01	<1
	Tritium	1.95E+13	7.93E+10	<1
	Carbon-14	3.00E+10	1.53E+02	<1
	Other	1.00E+05	3.60E+02	<1
Winfrith (Magnox)	Alpha	2.00E+06	1.35E+03	<1
	Tritium	4.95E+13	2.65E+10	<1
	Carbon-14	5.90E+09	1.80E+08	3.1
	Other	5.00E+06	9.43E+03	<1
Minor sites				
Imperial College Reactor Centre	Tritium	3.00E+08	Nil	Nil
Ascot	Argon-41	1.70E+12	Nil	Nil
Nuclear power stations				
Berkeley[i]	Beta	2.00E+07	5.23E+05	2.6
	Tritium[3]	1.00E+12	3.97E+09	<1
	Carbon-14	5.00E+09	4.70E+08	9.4
Bradwell[4]	Beta	2.00E+07	1.70E+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	2.11E+13	2.8
	All other nuclides	2.50E+09	1.46E+09	58
Dungeness A Station	Beta[i]	5.00E+08	7.63E+05	<1
	Tritium	2.60E+12	5.26E+10	2.0
	Carbon-14	5.00E+12	3.92E+08	<1
Dungeness B Station	Tritium	1.20E+13	1.22E+11	1.0
	Carbon-14	3.70E+12	1.15E+10	<1
	Sulphur-35	3.00E+11	4.71E+08	<1
	Argon-41	7.50E+13	Nil	Nil
	Cobalt-60[j]	1.00E+08	2.59E+06	2.6
	Iodine-131	1.50E+09	2.50E+07	1.7
Hartlepool	Tritium	1.00E+13	5.22E+11	5.2
	Carbon-14	4.50E+12	1.89E+12	42
	Sulphur-35	2.30E+11	1.77E+10	7.7
	Argon-41	1.50E+14	2.67E+12	1.8
	Cobalt-60[j]	1.00E+08	2.68E+07	27
	Iodine-131	1.50E+09	1.58E+08	11
Heysham Station 1	Tritium	1.00E+13	8.31E+11	8.3
	Carbon-14	4.50E+12	1.32E+12	29
	Sulphur-35	2.00E+11	2.67E+10	13
	Argon-41	1.50E+14	6.56E+12	4.4
	Cobalt-60[j]	1.00E+08	7.37E+06	7.4
	Iodine-131	1.50E+09	5.52E+07	3.7
Heysham Station 2	Tritium	1.00E+13	9.24E+11	9.2
	Carbon-14	3.70E+12	1.53E+12	41
	Sulphur-35	2.30E+11	1.05E+10	4.6
	Argon-41	7.50E+13	2.28E+12	3.0
	Cobalt-60[j]	1.00E+08	1.04E+07	10
	Iodine-131	1.50E+09	8.00E+07	5.3
Hinkley Point A Station	Beta	5.00E+07	2.20E+05	<1
	Tritium	7.50E+11	1.40E+10	1.9
	Carbon-14	5.00E+10	5.20E+08	1.0
Hinkley Point B Station	Tritium	1.20E+13	1.10E+12	9.2
	Carbon-14	3.70E+12	1.21E+12	33
	Sulphur-35	3.50E+11	4.02E+10	11
	Argon-41	1.00E+14	7.19E+12	7.2
	Cobalt-60[j]	1.00E+08	9.68E+06	9.7
	Iodine-131	1.50E+09	3.60E+06	<1

Table A2.1 continued

Establishment	Radioactivity	Discharge limit (annual equivalent)[a],	Discharges during 2021	
		Bq	Bq[b]	% of annual limit[c]
Hunterston A Station	Tritium	2.00E+10	4.69E+08	2.3
	Carbon-14	2.00E+09	5.60E+07	2.8
	All other radionuclides	3.00E+06	3.83E+05	13
Hunterston B Station[e]	Particulate beta	5.00E+08	7.97E+07	16
	Tritium	1.50E+13	1.19E+12	7.9
	Carbon-14	4.50E+12	1.96E+12	44
	Sulphur-35	5.00E+11	6.31E+10	13
	Argon-41	1.50E+14	6.74E+12	4.5
	Iodine-131	2.00E+09	Nil	Nil
Oldbury	Beta	1.00E+08	1.44E+05	<1
	Tritium	9.00E+12	2.97E+10	<1
	Carbon-14	4.00E+12	2.29E+09	<1
Sizewell A Station	Beta	8.50E+08	2.76E+04	<1
	Tritium	3.50E+12	1.74E+10	<1
	Carbon-14	1.00E+11	6.46E+08	<1
Sizewell B Station	Noble gases	3.00E+13	2.72E+12	9.1
	Particulate Beta	1.00E+08	3.00E+06	3.0
	Tritium	3.00E+12	3.65E+11	12
	Carbon-14[5]	6.00E+11	3.49E+11	58
	Iodine-131	5.00E+08	7.00E+06	1.4
Torness	Particulate beta	4.00E+08	1.03E+07	2.6
	Tritium	1.10E+13	1.33E+12	12
	Carbon-14	4.50E+12	1.48E+12	33
	Sulphur-35	3.00E+11	3.67E+10	12
	Argon-41	7.50E+13	5.10E+12	6.8
	Iodine-131	2.00E+09	2.12E+06	<1
Trawsfynydd	Particulate Beta	5.00E+07	1.92E+05	<1
	Tritium	3.75E+11	1.90E+10	5.1
	Carbon-14	1.00E+10	1.16E+09	12
Wylfa[6]	Particulate Beta	7.00E+08	2.07E+06	<1
	Tritium	1.80E+13	4.00E+10	<1
	Carbon-14	2.30E+12	8.80E+08	<1
Defence establishments				
Aldermaston[k]	Alpha	1.65E+05	2.27E+04	13.8
	Particulate Beta	6.00E+05	1.63E+04	2.7
	Tritium	3.90E+13	3.01E+12	7.7
	Carbon-14	6.00E+06	Nil	Nil
	Activation products[l]	BAT	3.00E+07	NA
	Volatile beta	1.00E+08	3.20E+05	<1
Barrow[l]	Tritium	3.20E+06	Nil	Nil
	Argon-41	4.80E+10	Nil	Nil
Burghfield[k]	Tritium	9.00E+09	Nil	Nil
	Alpha	5.00E+03	2.16E+03	43
Coulport	Tritium	5.00E+10	3.04E+09	6.1
Derby[j,n]	Alpha[o]	3.00E+06	7.96E+05	27
	Alpha[p,q]	2.40E+04	8.90E+00	<1
	Beta[p,q]	1.80E+06	4.02E+04	2.2
Devonport[r]	Beta[j]	3.00E+05	1.38E+04	4.6
	Tritium	4.00E+09	1.00E+08	2.5
	Carbon-14	6.60E+10	1.70E+08	<1
	Argon-41	1.50E+10	2.43E+06	<1
Dounreay[e] (Vulcan)	All other radionuclides	5.10E+06	1.05E+06	21
	Noble gases	5.00E+09	Nil	Nil
Rosyth[e,s]	Tritium	1.00E+07	1.83E+05	1.8
	Carbon-14	5.00E+07	3.45E+05	<1
	Other radionuclides	1.00E+05	4.34E+04	43

Table A2.1 continued

Establishment	Radioactivity	Discharge limit (annual equivalent)[a],	Discharges during 2021	
		Bq	Bq[b]	% of annual limit[c]
Radiochemical production				
Amersham (GE Healthcare)	Other Alpha emitting radionuclides	2.25E+06	1.30E+04	<1
	Radionuclides T1/2<2hr[t]	7.50E+11	Nil	Nil
	Tritium	2.00E+12	1.55E+11	7.8
	Radon-222	1.00E+13	1.28E+12	12.8
	All other radionuclides	1.60E+10	9.98E+08	6.2
Industrial and landfill sites				
LLWR	Alpha	BAT	1.21E+03	NA
	Beta	BAT	1.16E+04	NA
Lillyhall (Cyclife UK Limited)	Alpha (particulate)	5.00E+05	4.02E+03	<1
	Beta (particulate)	5.00E+05	1.96E+04	3.9

* As reported to SEPA and the Environment Agency

a These are the limits in force at end of the calendar year, unless otherwise stated. There may be changes in limits during the year (see notes for each nuclear site). In some cases permits/authorisations 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 3 significant figures, except where fewer significant figures are provided in source documents

c Data quoted to 2 significant figures except where values are <1%. Where permit/authorisation limits have changed during the year, this will not necessarily reflect the compliance position

d Revised discharge permit limits came into force with effect 1 October 2020. The new permit allows for upper limits to be in force for completion of Magnox reprocessing; until completion of active commissioning of HEPA filtration in the Magnox Swarf Storage Silo stack; and specific remediation activities, subject to a best available techniques case. See EPR/KP3690SX/V011 for more details. Lower limits are in effect unless otherwise specified

e Some discharges are upper estimates because they include 'less than' data derived from analyses of effluents at limits of detection

f All alpha emitting nuclides taken together

g All non-alpha emitting radionuclides, not specifically listed, taken together

h Krypton-85 discharges are calculated

i Combined data for Berkeley Power Station and Berkeley Centre

j Particulate activity

k Discharges were made by AWE plc

l Argon-41 is reported under the Activation products total and the limit is the demonstration of Best Available Technique

m Discharges from Barrow are included with those from MoD sites because they are related to submarine activities. Discharges were made by BAE Systems Marine Ltd

n Discharges were made by Rolls Royce Submarines Ltd

o Discharge limit is for the Nuclear Fuel Production Plant Site

p Annual limits on beta and alpha derived from monthly and weekly notification levels

q Discharge limit is for the Neptune Reactor Raynesway Site

r Discharges were made by Devonport Royal Dockyard Ltd

s Discharges were made by Rosyth Royal Dockyard Ltd

t Denotes radionuclides with a half-life of less than 2 hours

1 Upper limit in force until completion of the active commissioning of HEPA filters in the MSSS stack. See Section 2.3 for further details

2 Upper limit in force during Magnox reprocessing operations. See Section 2.3 for further details

3 Discharge permit revised with effect 1 May 2021

4 Discharge permit revised with effect 1 May 2019

5 Discharge permit revised with effect 1 September 2021

6 Discharge permit revised with effect 1 November 2019, the discharge limits for sulphur-35 and argon-41 were removed

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, 2021

Establishment	Radioactivity	Discharge limit (annual equivalent)[a], Bq	Discharges during 2021	
			Bq[b]	% of annual limit[c]
Nuclear fuel production and reprocessing				
Capenhurst (Urenco UK Ltd)	Uranium	7.50E+08	1.77E+06	<1
	Uranium daughters	1.36E+09	3.64E+06	<1
	Non-uranic alpha	2.20E+08	8.08E+06	3.7
	Technetium-99	1.00E+09	1.93E+06	<1
Sellafield[c]	Alpha	3.40E+11	8.78E+10	26
	Beta	6.30E+13	7.41E+12	12
	Tritium[1]	3.00E+15	1.85E+14	6.2
	Carbon-14[1]	1.30E+13	1.28E+12	9.8
	Cobalt-60	2.50E+12	1.33E+10	<1
	Strontium-90	1.40E+13	2.35E+12	17
	Technetium-99[1]	7.50E+12	4.80E+11	6.4
	Ruthenium-106	3.10E+12	1.70E+11	5.5
	Iodine-129	3.20E+11	2.17E+10	6.8
	Caesium-137	1.70E+13	1.40E+12	8.2
	Uranium alpha	2.00E+10	4.56E+09	23
	Plutonium alpha	2.90E+11	7.63E+10	26
	Plutonium-241	6.00E+12	8.29E+11	14
	Americium-241	1.40E+11	1.05E+10	7.5
Springfields	Alpha	1.00E+11	8.67E+09	8.7
	Beta	2.00E+13	4.78E+10	<1
	Technetium-99	6.00E+11	2.20E+08	<1
	Thorium-230	2.00E+10	1.08E+08	<1
	Thorium-232[e]	1.50E+10	1.60E+07	<1
	Neptunium-237	4.00E+10	2.90E+07	<1
	Other transuranic radionuclides	2.00E+10	1.55E+08	<1
	Uranium	4.00E+10	8.12E+09	20
Research establishments				
Dounreay[e]	Alpha[f]	3.4E+09	2.0E+08	5.9
	Non-alpha[g]	4.8E+10	9.6E+09	20
	Tritium	6.9E+12	1.6E+10	<1
	Strontium-90	1.77E+11	4.8E+10	27
	Caesium-137	6.29E+11	3.0E+09	<1
Harwell (Lydebank Brook)	Alpha	3.00E+07	6.10E+06	20
	Beta	3.00E+08	1.28E+07	4.3
	Tritium	2.00E+10	2.30E+08	1.2
Harwell (sewer)	Alpha	1.00E+07	1.80E+04	<1
	Beta	6.00E+08	1.15E+05	<1
	Tritium	1.00E+11	3.35E+08	<1
	Cobalt-60	5.00E+06	2.53E+05	5.1
	Caesium-137	2.00E+08	1.68E+05	<1
Winfrith (inner pipeline)[h]	Alpha	1.40E+10	7.10E+05	<1
	Tritium	4.00E+13	1.52E+09	<1
	Caesium-137	1.98E+12	1.01E+08	<1
	Other radionuclides	9.80E+11	1.93E+07	<1
Winfrith (outer pipeline)	Alpha	2.00E+09	8.07E+05	<1
	Tritium	1.50E+11	8.58E+07	<1
	Other radionuclides	1.00E+09	3.33E+06	<1
Minor sites				
Imperial College Reactor Centre	Tritium	4.00E+07	Nil	Nil
Ascot	Other radioactivity	1.00E+07	Nil	Nil

Table A2.2 continued

Establishment	Radioactivity	Discharge limit (annual equivalent)[a], Bq	Discharges during 2021	
			Bq[b]	% of annual limit[c]
Nuclear power stations				
Berkeley	Tritium	1.00E+12	7.80E+07	<1
	Caesium-137	2.00E+11	3.17E+08	<1
	Other radionuclides	2.00E+11	1.56E+08	<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	2.16E+06	<1
	Non-alpha[i]	1.00E+12	1.27E+09	<1
	Tritium	6.50E+12	5.68E+08	<1
Dungeness A Station	Tritium	8.00E+12	1.91E+09	<1
	Caesium-137	1.10E+12	1.50E+10	1.4
	Other radionuclides	8.00E+11	3.17E+10	4.0
Dungeness B Station	Tritium	6.50E+14	2.37E+12	<1
	Sulphur-35	2.00E+12	4.82E+07	<1
	Cobalt-60	1.00E+10	7.49E+07	<1
	Caesium-137	1.00E+11	2.39E+08	<1
	Other radionuclides	8.00E+10	7.96E+08	<1
Hartlepool	Tritium	6.50E+14	2.54E+14	39
	Sulphur-35	3.60E+12	5.15E+11	14
	Cobalt-60	1.00E+10	2.60E+08	2.6
	Caesium-137	1.00E+11	2.08E+09	2.1
	Other radionuclides	8.00E+10	2.28E+09	2.9
Heysham Station 1	Tritium	6.50E+14	2.44E+14	3.8
	Sulphur-35	2.00E+12	3.22E+11	16
	Cobalt-60	1.00E+10	2.22E+08	2.2
	Caesium-137	1.00E+11	4.93E+08	<1
	Other radionuclides	8.00E+10	4.47E+09	5.6
Heysham Station 2	Tritium	6.50E+14	2.29E+14	35
	Sulphur-35	2.00E+12	1.57E+11	7.9
	Cobalt-60	1.00E+10	6.59E+07	<1
	Caesium-137	1.00E+11	4.60E+08	<1
	Other radionuclides	8.00E+10	7.27E+09	9.1
Hinkley Point A Station	Tritium	1.00E+12	1.92E+09	<1
	Caesium-137	1.00E+12	7.40E+07	<1
	Other radionuclides	7.00E+11	1.06E+08	<1
Hinkley Point B Station	Tritium	6.50E+14	1.65E+14	25
	Sulphur-35	2.00E+12	1.64E+11	8.2
	Cobalt-60	1.00E+10	4.84E+07	<1
	Caesium-137	1.00E+11	4.25E+08	<1
	Other radionuclides	8.00E+10	2.00E+09	2.5
Hunterston A Station	Alpha	2.00E+09	3.00E+06	<1
	All other non-alpha[j]	6.00E+10	5.40E+07	<1
	Tritium	3.00E+10	1.00E+07	<1
	Caesium-137	1.60E+11	5.60E+07	<1
	Plutonium-241	2.00E+09	3.00E+06	<1
Hunterston B Station	Alpha	1.00E+09	1.72E+07	1.7
	All other non-alpha	1.50E+11	5.00E+09	3.3
	Tritium	7.00E+14	2.04E+14	29
	Sulphur-35	6.00E+12	4.10E+11	6.8
	Cobalt-60	1.00E+10	3.20E+08	3.2
Oldbury	Tritium	1.00E+12	5.93E+08	<1
	Caesium-137	7.00E+11	2.73E+08	<1
	Other radionuclides	7.00E+11	3.06E+08	<1
Sizewell A Station	Tritium	5.00E+12	7.70E+08	<1
	Caesium-137	1.00E+12	1.67E+09	<1
	Other radionuclides	7.00E+11	2.09E+09	<1

Table A2.2 continued

Establishment	Radioactivity	Discharge limit (annual equivalent)[a], Bq	Discharges during 2021	
			Bq[b]	% of annual limit[c]
Sizewell B Station	Tritium	8.00E+13	1.87E+13	23
	Caesium-137	2.00E+10	2.00E+08	1.0
	Other radionuclides	1.30E+11	9.10E+09	7.0
Torness	Alpha	5.00E+08	6.91E+06	1.4
	All other non-alpha	1.50E+11	3.46E+09	2.3
	Tritium	7.00E+14	2.86E+14	41
	Sulphur-35	3.00E+12	1.27E+11	4.2
	Cobalt-60	1.00E+10	1.70E+08	1.7
Trawsfynydd	Tritium	3.00E+11	1.23E+09	<1
	Caesium-137	1.50E+10	2.36E+08	1.6
	Other radionuclides[k]	3.00E+10	4.55E+08	1.5
Wylfa	Tritium	1.50E+13	6.82E+08	<1
	Other radionuclides	1.10E+11	1.91E+08	<1
Defence establishments				
Aldermaston (Silchester)[l]	Alpha	1.00E+07	1.55E+06	16
	Other beta emitting radionuclides	2.00E+07	7.88E+06	39
	Tritium	2.50E+10	1.40E+08	<1
Aldermaston (to Stream)[l, m]	Tritium	NA	2.10E+08	NA
Barrow[n]	Tritium	1.20E+10	1.14E+06	<1
	Carbon-14	2.95E+08	1.65E+05	<1
	Cobalt-60	1.34E+07	1.98E+04	<1
	Other beta-gamma emitting radionuclides	3.50E+06	1.75E+04	<1
Burghfield (Sewer)	Alpha[o]	NA	1.15E+03	NA
Derby[p]	Alpha[q]	2.00E+09	3.42E+07	1.7
	Alpha[r]	3.00E+05	2.17E+03	<1
	Beta[r]	3.00E+08	1.21E+05	<1
Devonport (sewer)[s]	Tritium	2.00E+09	7.80E+06	<1
	Cobalt-60	3.50E+08	1.33E+06	<1
	Other radionuclides	6.50E+08	3.20E+07	4.9
Devonport (estuary)[s]	Tritium	7.00E+11	1.14E+10	1.6
	Carbon-14	1.70E+09	2.74E+07	1.6
	Cobalt-60	8.00E+08	1.29E+06	<1
	Other radionuclides	3.00E+08	2.95E+06	<1
Faslane	Alpha	2.00E+08	6.00E+04	<1
	Beta[i,s]	5.00E+08	1.05E+06	<1
	Tritium	1.00E+12	1.34E+10	1.3
	Cobalt-60	5.00E+08	2.80E+05	<1
Rosyth[e, t]	Tritium	3.00E+08	2.12E+07	7.1
	Cobalt-60	1.00E+08	1.35E+06	1.4
	Other radionuclides	1.00E+08	3.35E+06	3.4
Radiochemical production				
Amersham (GE Healthcare)[t]	Alpha	3.00E+08	2.42E+06	<1
	Tritium	1.41E+11	1.00E+06	<1
	Other radionuclides	6.50E+10	9.15E+07	<1
Industrial and landfill sites				
LLWR	Alpha	BAT	8.76E+07	NA
	Beta	BAT	7.94E+08	NA
	Tritium	BAT	5.86E+10	NA
Lillyhall (Cyclife UK limited)	Alpha	5.00E+05	6.30E+02	<1
	Other radionuclides	5.00E+05	1.18E+04	2.4

Table A2.2 continued

[a] These are the limits in force at end of the calendar year, unless otherwise stated. There may be changes in limits during the year (see notes for each nuclear site). In some cases permits/authorisations 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 3 significant figures, except where fewer significant figures are provided in source documents
[c] Data quoted to 2 significant figures except where values are <1%. Where permit/authorisation limits have changed during the year, this will not necessarily reflect the compliance position
[d] Includes discharges made via the sea pipelines, factory sewer and Calder interceptor sewer. Revised discharge permit limits came into force with effect 1 October 2020. The new permit allows for upper limits to be in force for completion of Magnox reprocessing; and specific remediation activities, subject to a best available techniques case. See EPR/KP3690SX/V011 for more details. Lower limits are in effect unless otherwise specified
[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. There was no overall change in the 2018 discharge limits at the Winfrith site due to the Maxnox and Inutec discharge permits
[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
[p] Discharges were made by Rolls Royce Submarines Ltd
[q] Discharge limit is for Nuclear Fuel Production Plant
[r] Discharge limit is for Neptune Reactor Raynesway Site
[s] Discharges were made by Devonport Royal Dockyard Ltd
[t] Excluding cobalt-60
[u] Discharges were made by Rosyth Royal Dockyard Ltd
[v] A quarterly notification level of 5.00E+03 is in effect
[1] Upper limit in force during Magnox reprocessing operations. See Section 2.3 for further details
[2] Discharge permit revised with effect 1 May 2019
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 2021/22

Radionuclide or group of radionuclides	Total vault disposed[a] waste FY21/22 (Bq)	Cumulative total vault disposed[a,b] waste (Bq)
Tritium	1.14E+10	2.79E+13
Carbon-14	9.03E+09	5.11E+11
Chlorine-36	1.58E+07	7.15E+11
Calcium-41	Nil	1.20E+10
Selenium-79	Nil	4.90E+02
Molybdenum-93	Nil	1.40E+06
Zirconium-93	Nil	3.83E+10
Niobium-94	2.60E+03	6.94E+09
Technetium-99	5.60E+08	3.04E+12
Silver-108m	2.82E+03	1.33E+10
Iodine-129	2.09E+07	3.36E+09
Caesium-135	Nil	5.25E+08
Radium-226	1.68E+07	7.38E+10
Thorium-229	Nil	5.38E+05
Thorium-230	1.09E+06	7.05E+09
Thorium-232	4.01E+05	3.57E+10
Protactinium-231	Nil	2.44E+09
Uranium-233	9.62E+06	5.69E+10
Uranium-234	1.05E+09	4.68E+11
Uranium-235	2.82E+07	3.19E+10
Uranium-236	1.43E+08	2.80E+10
Uranium-238	8.66E+08	5.29E+11
Neptunium-237	5.65E+07	4.31E+10
Plutonium-238	1.50E+09	2.29E+11
Plutonium-239	3.95E+09	5.20E+11
Plutonium-240	3.40E+09	3.36E+11
Plutonium-241	4.04E+10	9.93E+12
Plutonium-242	1.23E+07	1.01E+09
Americium-241	1.13E+10	1.42E+12
Americium-242m	Nil	5.87E+10
Americium-243	5.30E+07	6.17E+08
Curium-243	1.53E+06	3.37E+09
Curium-244	1.15E+08	2.07E+10
Curium-245	1.04E+05	5.73E+06
Curium-246	9.87E+03	2.06E+06
Curium-248	Nil	4.98E+07
OTHRT**	2.95E+06	1.20E+09
PUALD**	Nil	1.01E+11
UALD**	Nil	1.13E+10
URRM**	Nil	2.38E+10
Others*	7.51E+11	6.60E+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
2020/21	4.36E+02	2.52E+05	2.78E+04	5.06E+05
2021/22	5.33E+02	2.53E+05	2.53E+04	5.31E+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, 2021*

Establishment Transfer from	Volume m^3	Total Activity Bq	Alpha Bq	Beta/Gamma Bq
Research establishments				
Dounreay	7.36E-02		1.01E+05	7.18E+05
Nuclear Power Stations				
Chapelcross[a]	2.19E+02	2.68E+09		
Hunterston A	7.89E+01	1.40E+09		
Hunterston B	7.22E+01	1.03E+09	3.98E+06	1.03E+09
Torness	4.49E+01		1.58E+06	8.76E+09
Defence establishments				
Coulport	Nil	Nil	Nil	Nil
Dounreay (Vulcan)	Nil	Nil	Nil	Nil
Faslane[b]	7.70E+06		6.40E+06	2.00E+03
Rosyth	1.50E+01	7.25E+07	Nil	Nil

* As reported by site operators to SEPA
[a] Reported as total activity only
[b] Transfers of cobalt-60 tritium were 1.15E+06Bq and 5.93E+06Bq, respectively

Table A2.5 Summary of unintended leakages, spillages, emissions or unusual findings of radioactive substances from nuclear licensed sites in the UK in 2021

Site	Month/Year	Summary of incident	Consequences and action taken
Dounreay	February 2022	In February 2022 SEPA issued an Information Notice to DSRL to obtain details of DSRL's options assessment for the non-active drainage system at Dounreay. This follows the identification of very low levels of radioactivity in samples taken from the non-active drainage system which is not an authorised disposal route for radioactive waste.	Although the concentrations of radionuclides measured in the samples do not give rise to concern in relation to public health, DSRL are required to address its EASR permit compliance requirements in relation to liquid discharges to the marine environment from the non-active drainage system.
Sellafield	October 2019	Sellafield Limited identified a leak of contaminated water from a redundant open-air concrete settling tank on the Sellafield site.	This is an update to an event that commenced in October 2019 (see Table A2.5, RIFE 25). Sellafield Limited has now completed work to retrieve the inventory (solid and sludge) and seal the tank with grout. The Environment Agency issued a warning letter to Sellafield Limited for breaches of permit conditions and placed actions to ensure that Sellafield Limited develop its plans to update its contaminated land and groundwater risk assessment for the site and that it included the leak from this facility in its annual update of the site land and groundwater conceptual model. The environmental impact of this event was considered to be minor.
Sellafield	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 update to an on-going event that commenced in 2019 (see Table A2.5, RIFE 25). Based on current understanding of groundwater movement in the area of the MSSS, the majority of radioactive liquid that leaks to the ground is expected to remain in the soil immediately around the facility and does not represent a risk to public health. However, risk of faster groundwater migration, or migration via alternative pathways, cannot be ruled out, and the consequences for future clean-up could well be significant. In 2021 the Environment Agency amended Sellafield Limited's Environmental Permit for the Sellafield site, so it now includes Improvement Requirements for Sellafield Limited to assess options to stop, or mitigate, the leak at the MSSS facility. The Environment Agency has also now completed its investigation of the circumstances surrounding the start of the leak and decided that a warning letter, in addition to these requirements, provided an appropriate enforcement response. In July 2022, Sellafield Limited submitted proposals to the Environment Agency and Office for Nuclear Regulation to prevent, minimise or mitigate the leak and its consequences. Both regulators are now assessing these proposals.
Sellafield	November 2020	The Environment Agency were notified of a leak of radioactively contaminated condensate to ground as a result of corrosion of the cell ventilation duct condensate drain line.	The Environment Agency determined that there were breaches of the permit as a result of failures in planning, undertaking maintenance and inspection and failure to act on previous findings. Sellafield Limited subsequently replaced the length of corroded pipework. The enforcement response was to provide advice and guidance to the site operator. The Environment Agency required Sellafield Limited to complete the actions outlined within its Basic Cause Investigation, ensuring an asset management inspection of all the ventilation condensate drains within the Magnox Reprocessing facility was to be undertaken. In addition, Sellafield Limited is required to provide a written report to the Environment Agency which sets out the inspection findings and an action plan to address the identified deficiencies within these systems.
Sellafield	December 2020	The Environment Agency were notified that very low-level radioactive waste had been mis-consigned to a transfer station not permitted to accept radioactive waste.	The Environment Agency determined that there were breaches of the permit as a result of failures to follow procedures for the storage of radioactive waste. The Environment Agency's response was to provide advice and guidance. It was considered that the corrective actions proposed would ensure future compliance by reinforcing staff awareness of their duties.

Table A2.5 continued

Site	Month/Year	Summary of incident	Consequences and action taken
Sellafield	May 2021	During the replacement of its radionuclide fingerprint database, Sellafield Limited identified that trace radionuclides, which are required to be reported to the Low-level Waste Repository (LLWR) as part of waste acceptance criteria (WAC), had been underestimated by a factor of one hundred.	The Environment Agency determined that there were breaches of the permit as a result of failures to supply accurate information and to effectively communicate significant changes to LLWR's processes and procedures. The Environment Agency's enforcement response was to provide advice and guidance and review the outstanding actions from the resulting Management Investigation to help prevent re-occurrence.

Appendix 3. Abbreviations and glossary

ABL	AWE plc, Babcock and Lockheed Martin UK
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
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 Power Corporation
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
Defra	Department for Environment, Food and Rural Affairs
DPE	Designated Point of Entry
DPAG	Dounreay Particles Advisory Group
DSRL	Dounreay Site Restoration Limited
Euratom	European Atomic Energy Community
EASR18	Environmental Authorisations (Scotland) Regulations 2018
EARP	Enhanced Actinide Removal Plant
EC	European Commission
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 19	Environmental Permitting (England and Wales) Regulations 2019
EPR™	European Pressurised Reactor™
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
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	His Majesty’s Inspectorate of Pollution
HMNB	His Majesty’s Naval Base
HPA	Health Protection Agency
HSE	Health and 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
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
MAFF	Ministry of Agriculture, Fisheries & Food
MMO	Marine Management Organisation
MOD	Ministry of Defence
MRF	Metals Recycling Facility
MRL	Minimum Reporting Level
ND	Not Detected
NDA	Nuclear Decommissioning Authority
NDAWG	National Dose Assessment Working Group
NIEA	Northern Ireland Environment Agency
NNB GenCo	NNB Generation Company Limited
NORM	Naturally Occurring Radioactive Material
NRPB	National Radiological Protection Board
NRW	Natural Resources Wales

NRTE	Naval Reactor Test Establishment
NWS	Nuclear Waste Services
OBT	Organically Bound Tritium
OECD	Organisation for Economic Co-operation and Development
ONR	Office for Nuclear Regulation
OSPAR	Oslo and Paris Convention for the Protection of the marine environment of the North-East Atlantic
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
RIFE	Radioactivity in Food and the Environment
RRDL	Rosyth Royal Dockyard Limited
RNAS	Royal Naval Air Station
RRSL	Rolls-Royce Submarines Limited
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 Effluent Plant
STW	Sewage Treatment Works
THORP	Thermal Oxide Reprocessing Plant
TENORM	Technologically Enhanced Naturally Occurring Radioactive Material
TRAMP	Terrestrial Radioactivity Monitoring Programme
UCP	Urenco ChemPlants Limited
UKAEA	United Kingdom Atomic Energy Authority
UKAS	UK Accreditation Service
UKHSA	UK Health Security Agency
UKNWM	UK Nuclear Waste Management Limited
UOC	Uranium Ore Concentrate
UNS	Urenco Nuclear Stewardship Limited
UUK	Urenco UK Limited
VLLW	Very Low-Level Waste

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}.
Artificial radionuclides	These are radioactive isotopes that are not found readily in nature. They are generally produced during nuclear power generation, nuclear fuel reprocessing, from nuclear weapons testing or in specialist devices by neutron bombardment.
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 1mSv 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	Shortened form of ‘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 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.
Source specific dose	An assessment of dose that focuses on specific sources on sites (for example, liquid or gaseous discharges) and their associated pathways (for example, external exposure over shoreline areas). See Section 1.1, Appendix 1 (Annex 3) for more information on these dose calculations. In some cases, assessments may include the impacts from multiple sites. For example, the source specific assessment of the Dumfries and Galloway coast includes the impacts of discharges from Chapelcross and Sellafield.
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 take 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, to ensure that dose assessment calculations reflect the real-world situation
- 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, 2021
Offshore Dose Assessment Model	N/A	S	Q1 2023
Thorium Transfer Work	N/A	S	In press[1]
NORM Biota Project	N/A	S	In press[1]
PhD research project - Assessing the hazard from radioactive particles in the environment	N/A	S	2022
Background monitoring in urban environments	N/A	S	Complete
Clyde Estuary Assessment	N/A	S	Q2 2023
Covid-19 Habits Survey	N/A	S	October 2022
Soil and herbage follow-up	N/A	S	Q1 2023
City Monitoring	N/A	S	Q3 2022
Coastal Monitoring	N/A	S	Q1 2023
WWTW Monitoring	N/A	S	Q2 2022

Notes
E Environment Agency
S Scotland and Northern Ireland Forum for Environmental Research or SEPA
[1] The work is complete and the intent is to publish on the SEPA website, however the cyber attack has delayed publication

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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