Summary of Radioactivity in Food and the Environment (2004–2016)

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This report was prepared, as part of the submission to the Radioactive Substances Committee (RSC) of the OSPAR Commission, for the UK statement on the implementation of PARCOM Recommendation 91/4 on Radioactive Substances.
https://www.ospar.org/documents?v=38933

Summary of Radioactivity in Food and the Environment in the UK (2004-2016)

Preface

The environmental monitoring programmes in this report were organised by the environment agencies, FSA and FSS and are independent of the industries discharging radioactive wastes. The programmes include monitoring on behalf of the Scottish Government, Channel Island States, the Department of Agriculture Environment and Rural Affairs (DAERA), the Department of Business, Energy and Industrial Strategy (BEIS), Department for Environment, Food and Rural Affairs (Defra), Natural Resources Wales (NRW) and the Welsh Government.

As partner agencies for environment and food protection, the joint findings are published in an annual report, 'Radioactivity in Food and the Environment' (RIFE) which brings together the results of the radiological monitoring and provides an overall detailed assessment of radioactivity for the UK. The report is a compilation of the evaluations made on the public's exposure to ionising radiation from authorised discharges, to show that exposure is within EU and UK limits.

Building on the information derived from the previous RIFE reports (RIFE 10-22), this review has been prepared to give an overview of recent trends in data from 2004-2016. The report primarily focuses on trends associated with:

- Radiation exposure (doses) to people living around nuclear sites.
- Disposals of radioactive waste (discharges) to air and water.
- Radionuclide activity (concentrations) in samples collected around nuclear sites.

This report shows that for all 39 nuclear licensed sites, the overall amount of radiation the public was exposed to was less than the UK and European limit of 1 mSv per year, in each year over the review period. A key observation is that radionuclide concentrations were very low at many sites, indeed so low they could not be detected with the sensitive methods used. In many cases there is a correlation between lower environmental concentrations and reducing discharges to the environment, showing that the efforts of regulators and the industry to progressively reduce discharges is having a beneficial effect.

At several nuclear sites, trends in *total doses* were dominated by direct radiation (radiation arising from processes or operations on the premises), with the largest *total dose* over the period reported at Dungeness. However, this direct radiation reduced after 2006 when the first generation Magnox reactors at Dungeness A ceased power generation. Radiation exposure around Sellafield and Whitehaven was the second largest *total dose*, with trends broadly reflecting a combination of changes in shellfish consumption rates, and the concentrations of naturally occurring radionuclides arising as a result of past discharges from the former phosphate works at Whitehaven, in these shellfish.

The cessation, decommissioning and defuelling of the majority of first generation nuclear power stations and reduction in reprocessing over the review period has clearly had a significant impact in reducing discharges and radiation doses to the public.

For nuclear power station sites with only Magnox reactors, the most significant trends were an overall decline in the gaseous and liquid discharges over the period 2004-2016. The most pronounced effects were at Chapelcross where discharges reduced significantly after the site stopped generating electricity. For the same reason, Sizewell A and Dungeness A both showed significant declines in discharges after 2006. For the sites with AGR or PWR reactors, the overall trend was a decline in gaseous and liquid discharges over the period. Discharges from other sites were generally similar over the period, with fluctuations between years. Most of the apparent variations can be associated with changes in power output.

Discharges of man-made radionuclides over the last two decades have shown large and sustained reductions of the most important radionuclides. This is particularly true of the nuclear fuel reprocessing sector where investment, for example in new treatment plants, has had a significant effect. Concentrations of radionuclides in food and the environment have also declined over a similar time-frame. In addition, reductions in discharges and doses have occurred from older Magnox power stations where the reactors have been shut down and ended electricity production. Therefore, in comparison to earlier decades, some downward trends in environmental concentrations have become less significant. Where there have been radionuclide fluctuations in recent years, this has been mostly at low concentrations in the environment, due to normal year to year variation. In some cases, no clear trend is apparent and variation or ‘noise’ is a key feature of the monitoring data.

It is important to note that this is a summary of trends over the period 2004-2016 and is not a detailed technical report. Anyone wanting to understand the in-depth background to the methodologies applied in the specific yearly assessments should consult the relevant annual RIFE report.

Introduction

This report provides a summary of the public's exposure (doses) to radiation, between 2004 and 2016, to people living around nuclear sites. It also gives more detail of time trends on discharges of radioactivity to the environment and concentrations of radionuclides in food and the environment over the same time period for each of the nuclear industry sectors (e.g. nuclear fuel production and processing). The information in this report is taken from more detailed data published in the annual Radioactivity in Food and the Environment (RIFE) reports. The RIFE reports give analytical results from independent monitoring carried out by the Food Standards Agency (FSA), Environment Agency, Scottish Environment Protection Agency (SEPA), Food Standards Scotland (FSS), Natural Resources Wales (NRW) and the Northern Ireland Environment Agency (NIEA).

The data are presented to indicate the overall trends in doses (impacts), discharges and concentrations. These data allow a broad interpretation of the picture with time, to whether the trends are generally increasing, decreasing, largely staying the same or not showing a trend.

The report provides information that can be considered in its own right and in relation to a strategic view of the UK approach to managing the impact of radioactive discharges over recent years. In particular it allows the radioactivity concentrations and public radiation doses to be considered in relation to the 1998 Ministerial OSPAR agreement and the UK's commitments under its national Radioactive Discharge Strategy. The OSPAR Radioactive Substances Strategy was agreed by Ministers in 1998. Its strategic objective is to prevent pollution of the OSPAR maritime area (marine environment of the North-East Atlantic) from ionising radiation through progressive and substantial reductions in radioactive discharges, emissions and losses. This has the ultimate aim of concentrations in the environment near background values for naturally occurring radioactive substances and close to zero for artificial radioactive substances. This strategy will be implemented so that by the year 2020 any releases of radioactive substances are low enough so that any increase in the levels, above historic levels, in the marine environment from these discharges will be close to zero.

The UK Strategy for Radioactive Discharges presents Key Marine Environmental Indicators (KMEIs) at a number of locations around the coast of the UK. This helps evaluate progress against the OSPAR targets and are included in the OSPAR Periodic Report Series. The KMEIs include seaweed at all the locations. At some locations KMEIs include marine foods and seawater. All of the KMEI data are from monitoring carried out by the FSA, Environment Agency, SEPA, FSS, NRW and NIEA. Selected KMEI data have been presented in this report.

1. Overview of *total dose* and environmental indicators near the UK's nuclear sites

Key points

- All *total doses* were less than the UK and European dose limit.
- *Total dose* and their trends were dominated by direct radiation at many sites.
- *Total dose* trend at Sellafield was influenced by changes in natural radioactivity from non-nuclear industry activity.
- *Total dose* declined when electricity generation ended at several older Magnox power stations.
- Trends in Key Marine Environmental Indicators around the UK show decreasing concentrations over the period.

This section considers the time trends of *total dose*[1] summed over all sources at each site in the UK. It also considers Key Marine Environmental Indicators (KMEIs) around the UK that have been used to evaluate the UK Strategy for Radioactive Discharges.

1.1 *Total dose* assessment

Figure 1.1 provides time trends of *total doses* from 2004-2016, due to the combined effects of authorised/permitted waste discharges and direct radiation, to those people (representative person[2]), most exposed to radiation near all major nuclear licensed sites in the UK.

The *total doses* from radiation at all sites were all less than the annual national (UK) and the European limit for members of the public of 1 mSv per year, in each year over the period. An additional comparison can be made with the exposure from natural radioactivity. The estimated dose for each person (per caput) in the UK population (in 2010) from natural radiation is approximately 2.3 mSv per year (Oatway *et al*., 2016).

Changes in direct radiation dominated the inter-annual variation at most of the power station sites, and small fluctuations in external dose rates had relatively large effects at some sites where high rates of intertidal occupancy were recorded.

Figure 1.1 shows the annual *total dose* was highest at Dungeness in Kent, ranging between 0.014 and 0.63 mSv, over the period. *Total doses* at Dungeness were

[1] *Total dose* is an assessment that uses a defined method that takes account of all exposure pathways in combination e.g. radionuclides in food, the environment and direct radiation.

[2] The 'representative person' concept is considered equivalent to the previously used 'critical group' (Environment Agency, FSA, FSS, NIEA, NRW and SEPA, 2016).

dominated by direct radiation, and following 2006, this dose has declined due to the end of power generation from the first generation Magnox reactors.

The second highest annual *total dose* was in the vicinity of Sellafield (Sellafield, LLWR (near Drigg) and Whitehaven) in Cumbria, ranging between 0.076 and 0.58 mSv over the period. This trend broadly reflected a combination of changes in the amount of shellfish eaten and of naturally occurring radionuclides from the non-nuclear industry in these shellfish.

The larger step changes in *total dose* in the vicinity of Sellafield (from 2004-2005, 2008-2009 and 2012-2013) were due to variations in naturally occurring radionuclides (mainly polonium-210). The changes in *total dose* in the intervening years from 2005-2007 were mainly a result of changes in seafood consumption rates. The decrease in 2010 was due to both reductions in naturally occurring radionuclides concentrations (polonium-210) and consumption rates, whilst the variation in the radionuclide contributors in 2011 (from previous years) resulted from a change in the representative person (from a consumer of molluscan shellfish to locally harvested marine plants).

The largest proportion of the *total dose* in the vicinity of Sellafield, up till 2008 and again from 2011-2012 and 2014-2016, was mostly due to enhanced naturally occurring radionuclides from the historical discharges at Whitehaven and a smaller contribution from the historical discharges from Sellafield.

In 2013, the highest *total dose* (relating to the effects of Sellafield) was entirely due to external radiation from sediments. The change was due to both decreases in naturally occurring radionuclides concentrations (polonium-210) and a revision of habits information, resulting in a change in the representative person. In 2014, the increase in *total dose* was due to a change in the habits information from the most recent survey. In the following year (2015), the relative increase in dose were largely due to an increase in polonium-210 concentrations (from the non-nuclear industry) in locally caught lobsters and crabs.

The third highest exposure was at Amersham in Buckinghamshire, where annual *total doses* ranged from 0.14 and 0.24 mSv over the period. This trend remained broadly similar with time and was dominated by direct radiation. The lower value in 2014 (and subsequently thereafter) was due to changes in working practices (for distribution activities, products spend less time in the dispatch yard) and the construction of a shield wall on the western side of a building that contains legacy radioactive wastes.

Other notable observations in *total dose* included increased exposure at Capenhurst in Cheshire. Any changes in *total doses* with time are attributable to changes in the estimates of direct radiation from the Capenhurst site. The small increases in *total dose* at Bradwell and Winfrith (both in 2015 and 2016) were also mostly due to higher estimates of direct radiation from the individual sites. At Springfields the *total dose* decreased over time, although there was an increase in 2008 (compared with 2007). Thereafter, the trend at this site was primarily due to variations in gamma dose rates over sediment, and improvements in the methods used for dose assessments for houseboat dwellers, resulting in an overall decline in dose over the period.

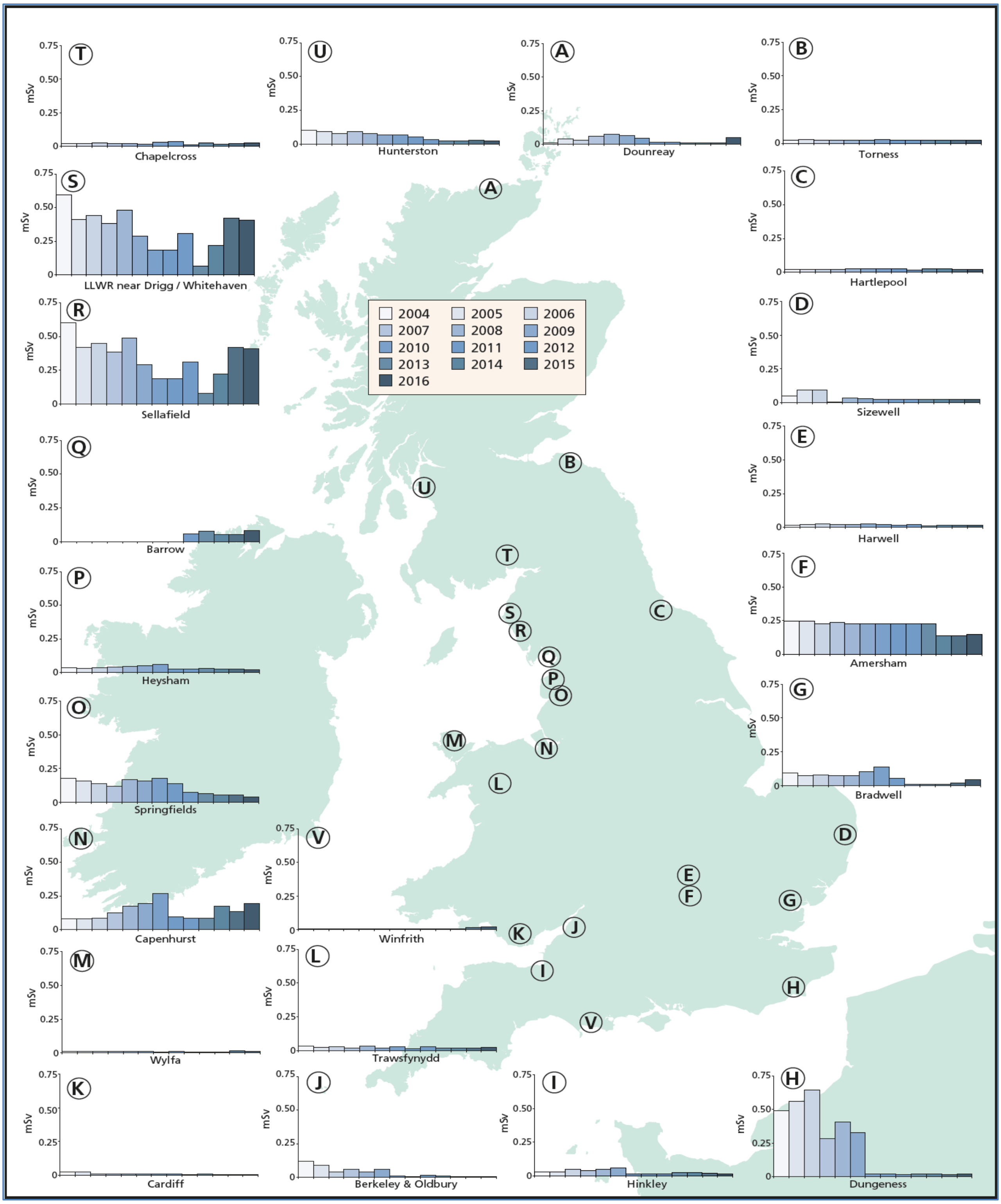

Figure 1.1 Total radiation exposures around the UK's nuclear sites due to radioactive waste discharges and direct radiation (2004-2016). (Exposures at Sellafield/Whitehaven receive a significant contribution to the dose from technologically enhanced naturally occurring radionuclides from previous non-nuclear industrial operations)

At Sizewell, the *total dose* has reduced by a factor of three since Sizewell A ceased generation in 2006. The *total dose* declined at the end of 2006, following the closure of the Magnox reactors at Sizewell A, thereafter any variations were due to the change in the contribution from direct radiation from the site. A habits survey was undertaken in 2012 at Barrow, allowing a full dose assessment to be introduced, making use of the marine data. Virtually all of this dose was due to the effects of Sellafield discharges.

Total doses at all the remaining locations in Figure 1.1 were low. Any variations in *total dose*s with time at these sites were primarily due to changes in direct radiation or variations in gamma dose rates from environmental variability.

1.2 Environmental indicators close to and away from nuclear sites

Monitoring carried out on behalf of the Environment Agency, FSA, FSS, NIEA, NRW and SEPA includes data that are used as part of the KMEIs. These are used to show how the UK is meeting its OSPAR obligations. The KMEI include concentrations of radionuclides in fish and shellfish, seaweed and seawater. Seaweed data are available for a wide range of locations around the UK (as indicators for Sellafield-derived technetium-99) and are shown in Figure 1.2. The data show that activity concentrations have declined around the Irish Sea (Chapelcross, Heysham, Northern Ireland, Sellafield and Wylfa). Further afield, the data also show a decrease for long distance transport of technetium-99 (Dounreay, Hartlepool and Torness) over the period.

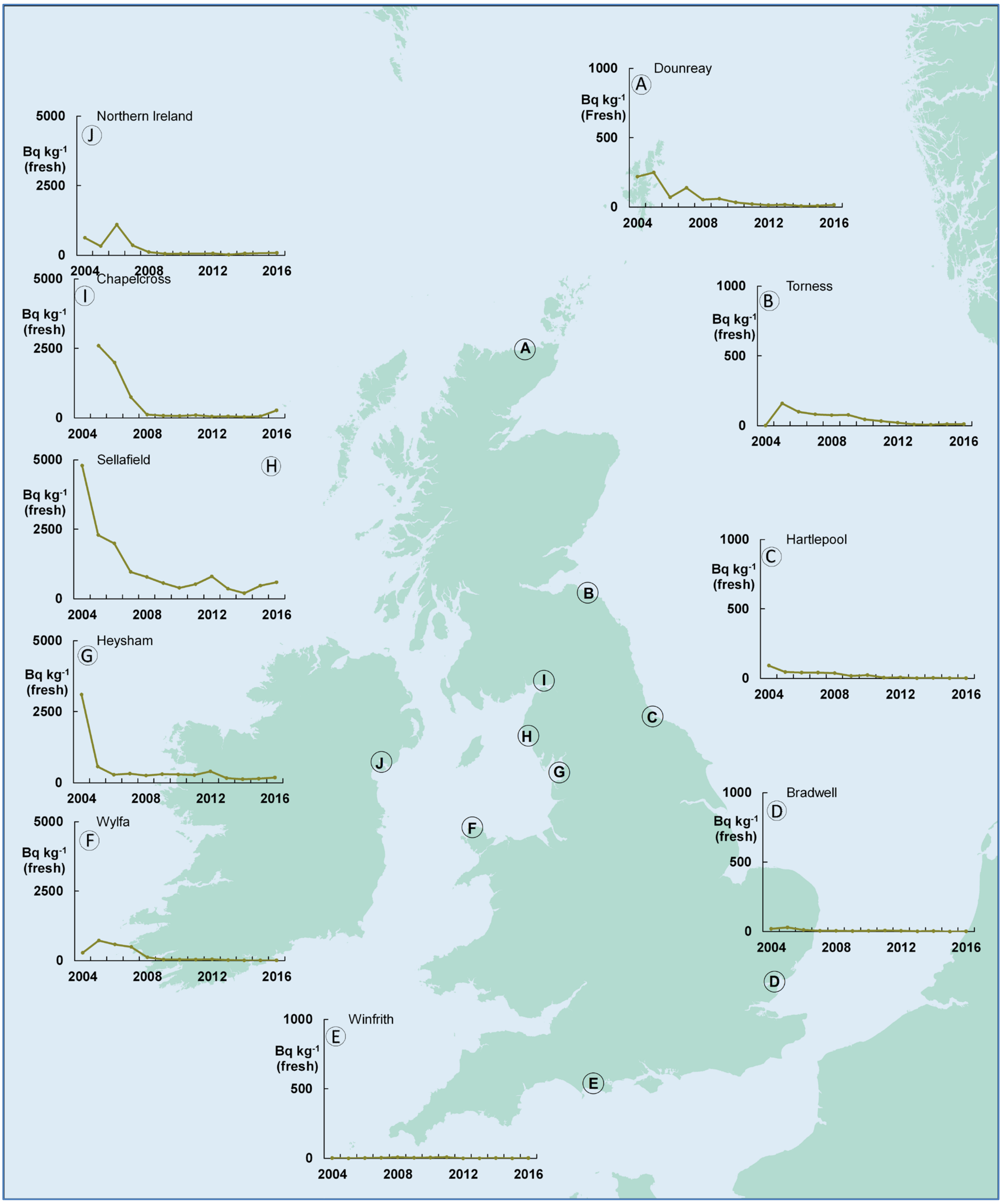

Figure 1.2 Technetium-99 concentrations in seaweed around the UK (2004-2016)

1.3 Doses to the public away from nuclear sites

The mean annual dose from consumers drinking water was assessed in the UK. Available data are presented in Table 1.1. This gives an indication of the range of doses to the public away from nuclear sites between 2005 and 2016.

Table 1.1 Ranges of estimated dose from radionuclides in drinking water between 2005-2016*

Country	Mean exposure mSv/y		
	Man-made radionuclides	Naturally occurring radionuclides	All radionuclides
England	< 0.001	0.026 - 0.051	0.026 - 0.051
Wales	< 0.001	0.027 - 0.029	0.027 - 0.029
Northern Ireland	< 0.001- 0.001	0.017 - 0.062	0.017 - 0.063
Scotland	< 0.001	0.002 - 0.003#	0.002 - 0.003#
UK	< 0.001	0.017 - 0.054	0.017 - 0.054

* No data available in 2004
# Data only available in 2014-2016, inclusive (for K-40 only)

2. Nuclear fuel production and reprocessing

Key points

- All doses were significantly less than the dose limit for members of the public of 1 mSv per year.
- Highest annual dose (from artificial radionuclides) was 0.24 mSv at Sellafield.
- Overall trend was a reduction in gaseous and liquid discharges, with all authorised discharges below authorised limits.
- Doses from historic non-nuclear industry activity (naturally occurring radionuclides) were significant near Sellafield.

This section looks at the time trends between 2004 and 2016 from the UK's nuclear fuel production and reprocessing sites. The time trends show the public's exposure, discharges of radioactive waste and concentrations of radionuclides in food and the environment. The public's exposure[3] (dose) from radioactive waste discharges is assessed using radionuclide concentrations and gamma dose rates in the environment. The public's exposure from naturally occurring radionuclides is also considered near Sellafield.

There are three sites in the UK involved with production and reprocessing of nuclear fuel. At Capenhurst, near Ellesmere Port (Cheshire), uranium enrichment is carried out together with the management of uranic materials and undertaking of decommissioning activities. At Springfields, near Preston (Lancashire), and Sellafield (Cumbria) the main commercial activities are the manufacture of fuel elements for nuclear reactors and fuel reprocessing from nuclear power stations, respectively.

2.1 Public's exposure to radiation due to discharges of radioactive waste

Figure 2.1 provides time trends, between 2004 and 2016, of doses for those groups most exposed to radiation due to the effects of gaseous and liquid waste discharges from the UK's nuclear fuel production and reprocessing sites. At all locations, the doses from radioactive waste discharges were significantly below the UK and European limit for members of the public of 1 mSv per year.

Figure 2.1 shows that the highest annual dose from artificial radionuclides (shown in blue) was 0.24 mSv in 2007 near Sellafield. The Sellafield annual doses ranged from 0.083 to 0.24 mSv. The maximum value is less than a quarter of the dose limit and the contribution to dose from artificial radionuclides has generally declined over the time period. The dose was determined for people who ate seafood, and was mostly due to the accumulation of radionuclides including caesium-137, plutonium isotopes

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[3] The monitoring results are interpreted in terms of radiation exposures of the public, commonly termed 'doses'. These people are a group, who generally eat large quantities of locally grown food (high-rate consumers) or who spend long periods of time in the locations being assessed. This dose, referred to in Sections 2-6, is an exposure that uses a different assessment method to that of *total dose* in Section 1.

and americium-241 in seafood and the environment. These doses were attributable to historic liquid discharges from Sellafield which were at their highest during the 1970s and 1980s. Between 2004 and 2007, habits surveys indicated an increase in the amount of fish and shellfish eaten, which led to a slight rise in doses during this time. In 2008 consumption went down again leading to a reduction in doses, together with a reduction in dose from artificial radionuclides. Since 2008, Sellafield annual doses have declined due to the reduced accumulation of artificial radionuclides in seafood. The small increase in 2013 was due to the revision of habits information.

Figure 2.1 also shows the trend of doses to people who ate seafood near Sellafield resulting from the historic discharges of naturally occurring radionuclides from the former phosphate works (non-nuclear industry) at Whitehaven (shown in green). The data show that the doses from naturally occurring radionuclides were significantly larger than for artificial radionuclides. The variations in dose for naturally occurring radionuclides were due to changes to both concentrations (polonium-210) in sea food and consumption rates (of fish and shellfish).

Exposure of communities associated with fisheries was also assessed in other parts of the Irish Sea. These were Whitehaven, Dumfries and Galloway, Morecambe Bay, Fleetwood (2004-2013), Northern Ireland, North Wales and the Isle of Man (2004-2013). The assessments show that exposures in these areas were lower than to people local to Sellafield. This was due to the lower concentrations and dose rates further away from Sellafield. There were small changes in the reported doses in each area over the time period. These were caused by variations in gamma dose rates over sediment, new information on people’s eating habits and fluctuations in radionuclide concentrations (mainly americium-241 in some shellfish). Doses to fisheries communities generally declined over the time period.

The annual doses received by people at Sellafield, who were exposed to gaseous discharges from the site, ranged between 0.012 and 0.036 mSv over the time period. The dose was from inhaling gases, from radiation emitted from the gas and from eating food grown on land around the site. Before 2008, this trend was generally declining because of the permanent shut down of Calder Hall power station on the Sellafield site which ended gaseous discharges of argon-41 and sulphur-35. In 2008, the assessment method changed slightly to include cobalt-60 results (which were at the limits of analytical detection) which increased the dose over previous years.

The next group most affected by artificial radionuclide discharges was in the Ribble Estuary near the Springfields site. For those people living on houseboats in the Ribble Estuary, there was an apparent increase in annual dose, which ranged between 0.037 and 0.16 mSv over the time period. However, the trend over time included improvements in the methods used for dose assessments. The increase in doses from 2006 was due to updated information and additional measurements concerning the exact location of houseboats. The further increase in 2008 was due to a combination of increased gamma dose rates and the time spent on the houseboats. Thereafter, the decline was due a change in the method for dose assessment, due to measurements on a houseboat being available from the habits survey in 2012.

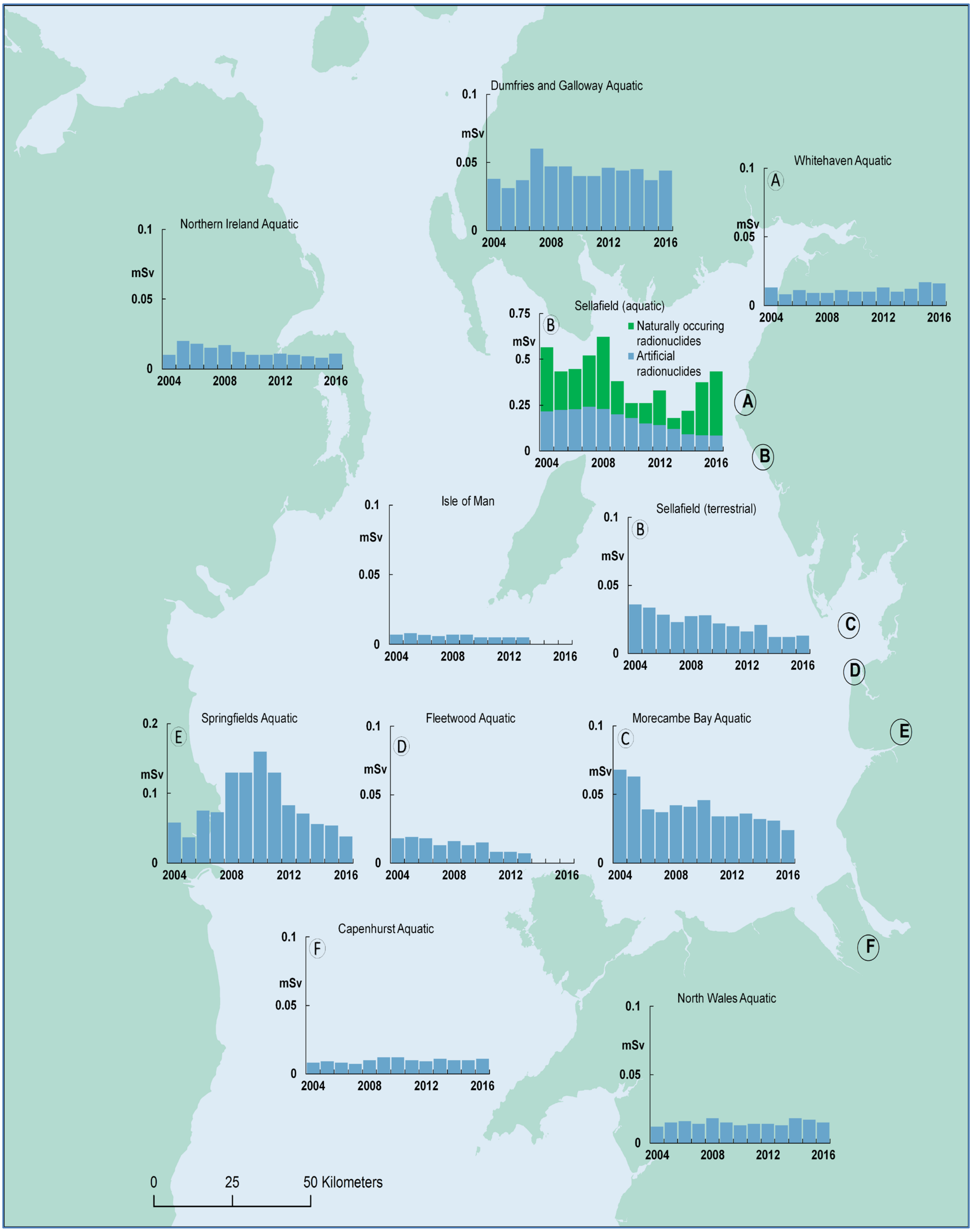

Figure 2.1 Individual radiation exposures to most exposed groups from artificial radionuclides, Irish Sea (2004-2016)
(includes exposures from naturally occurring radionuclides near Whitehaven)

At Capenhurst, children playing in and around Rivacre Brook received the highest annual dose. This ranged between 0.007 and 0.012 mSv over the time period. The doses were estimated using gamma dose rates, assuming children spent time on the banks of the brook and swallowed some water and sediment. The changes in dose over time were due to variations in gamma dose rates over sediment.

2.2 Sellafield, Cumbria

2.2.1 Discharges of radioactive waste

Permitted discharges of gaseous and liquid waste are released into the atmosphere and into the Irish Sea, from a wide variety of facilities and sources.

Figure 2.2 shows the trends of discharges over time (2004-2016) for a number of the permitted radionuclides.

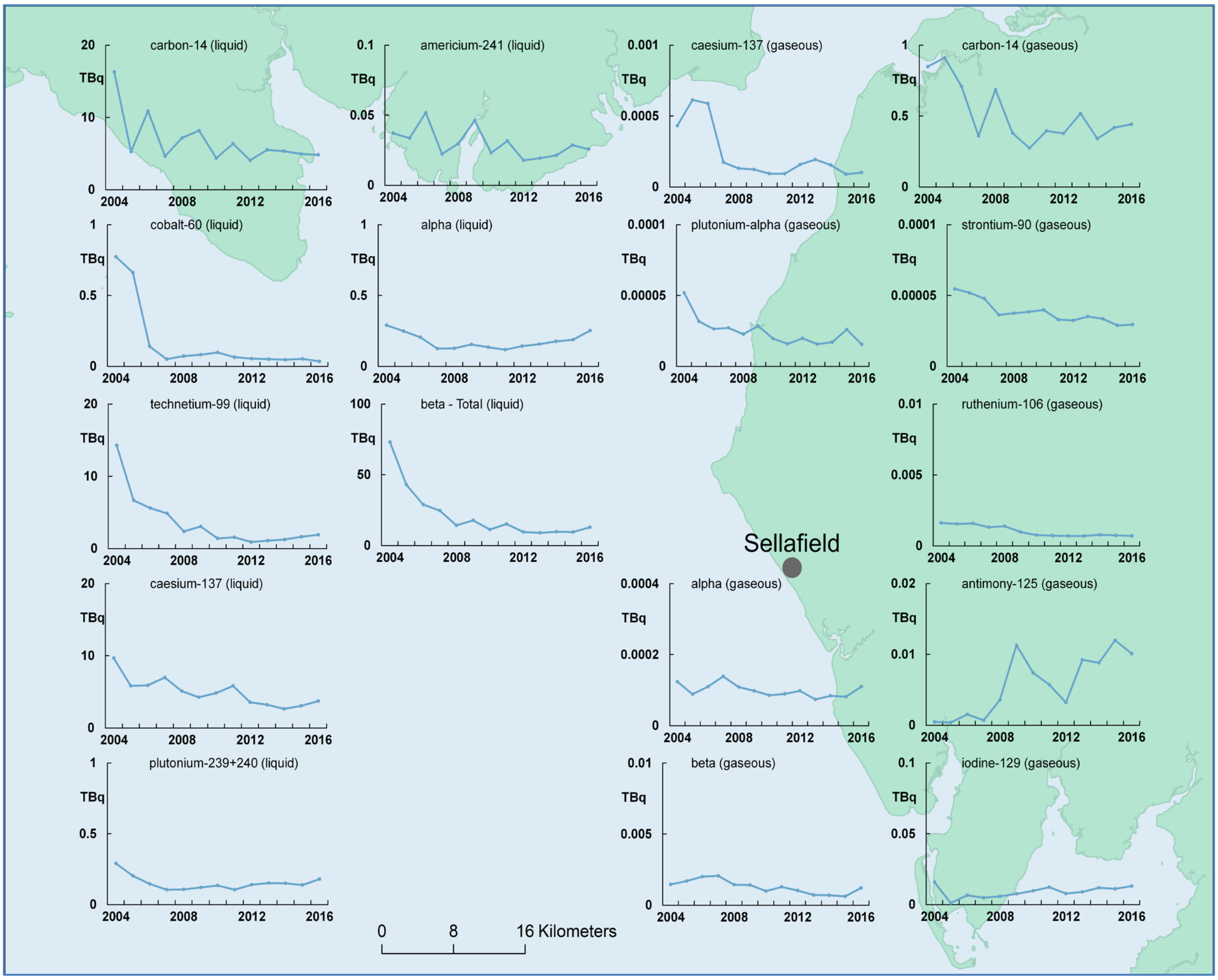

Figure 2.2 Permitted discharges of gaseous and liquid wastes, Sellafield (2004-2016)

Since 2004, the overall trend was a reduction of gaseous and liquid discharges with time. In 2010, a new permit, with a higher limit for gaseous antimony-125 was introduced to reflect increased discharges of this radionuclide as a result of reprocessing Magnox spent fuel. Between 2004 and 2016, all liquid discharges generally followed a pattern of overall reduction.

2.2.2 Concentrations of radionuclides in food and the environment

The food and environment monitoring programmes around Sellafield are the most extensive in the UK; this includes monitoring for the effects from Sellafield in other parts of the Irish Sea. The monitoring reflects the range and concentrations of radionuclides that have been discharged from Sellafield over a considerable number of years.

Figure 2.3 shows the trends of radionuclide concentrations in food (winkles, lobsters, plaice and milk) and the environment (seawater and sediment) near Sellafield between 2004 and 2016. All radionuclide concentrations in the environment from gaseous discharges were very low. Over the time period, caesium-137 and strontium-90 concentrations in milk declined over time, whilst carbon-14 concentrations in milk were relatively constant.

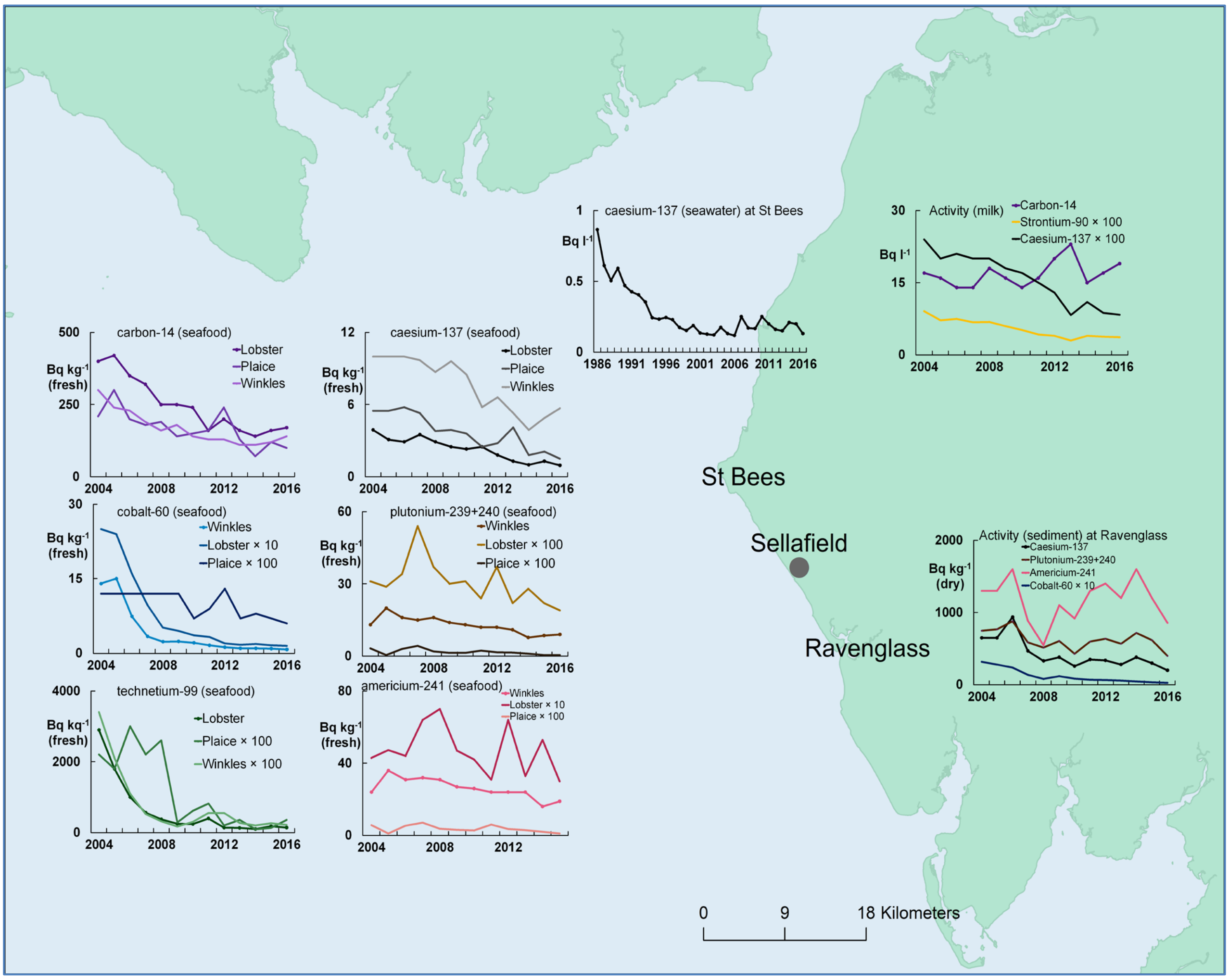

Figure 2.3 Monitoring of the environment from discharges of radioactive wastes, Sellafield (2004-2016)

Concentrations of radionuclides in seafood generally continued to reflect changes in liquid discharges over time. The majority of trends for carbon-14 and cobalt-60 concentrations showed large decreases directly associated with a fall in discharges since 2004, with smaller decreases in concentrations over the last decade. Overall, concentrations of technetium-99 in fish and shellfish have shown a continued reduction, from the relatively elevated levels shown at the beginning of the period, but were generally similar (with minor variations) over most recent years. Between 2004 and 2016, concentrations of caesium-137 in seafood generally declined at a constant rate, with some variations between years (due to natural variation in the environment). Caesium-137 concentrations in seafood may be affected by the release of this radionuclide from seabed and estuary sediment. For americium-241 and plutonium-239+240, the long-term trends of reductions in concentrations from earlier decades continued, but appear to be slowing. Over the last decade, despite generally decreasing discharges, concentrations of americium-241 and plutonium-239+240 in some shellfish have shown some variations from year to year. Over the last five years, concentrations of plutonium-239+240 and americium-241 in seafood were relatively constant, with a few slightly elevated concentrations in shellfish in the most recent years.

Figure 2.3 also shows the trends of caesium-137 in seawater (2014-2016) at St Bees and sediment activity concentrations from Ravenglass. For caesium-137 in seawater, the data show (as the rate of decrease is slower, relative to the reduction rate of discharges, over the longer period) that the current sources are liquid discharges from the site and the release of caesium from sediments (from earlier discharges in earlier decades) into the water column. In more recent years, the rate of decline of caesium-137 concentrations with time has been decreasing at St Bees. The concentrations of radionuclides in sediments from Ravenglass have remained relatively constant or decreased over the period, responding to decreases in discharges. Discharges of cobalt-60 have reduced over the last decade, as reflected in the sediment concentrations, with some evidence of a lag time between discharge and sediment concentration.

There is a suggestion of small progressive increases in caesium-137, plutonium-239+240 and americium-241 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.

2.3 Capenhurst –

Discharges of radioactive waste and concentrations of radionuclides in food and the environment

Uranium is the main radioactive constituent of gaseous discharges from Capenhurst, with small amounts of other radionuclides present in discharges by Capenhurst Nuclear Services Limited (previously Sellafield Limited). The UUK permit for the Capenhurst site allows liquid waste discharges to the Rivacre Brook for uranium and uranium daughters, technetium-99 and non-uranium alpha (mainly neptunium-237).

Figure 2.4 shows the trends of discharges over time (2004-2016) for a number of the permitted radionuclides.

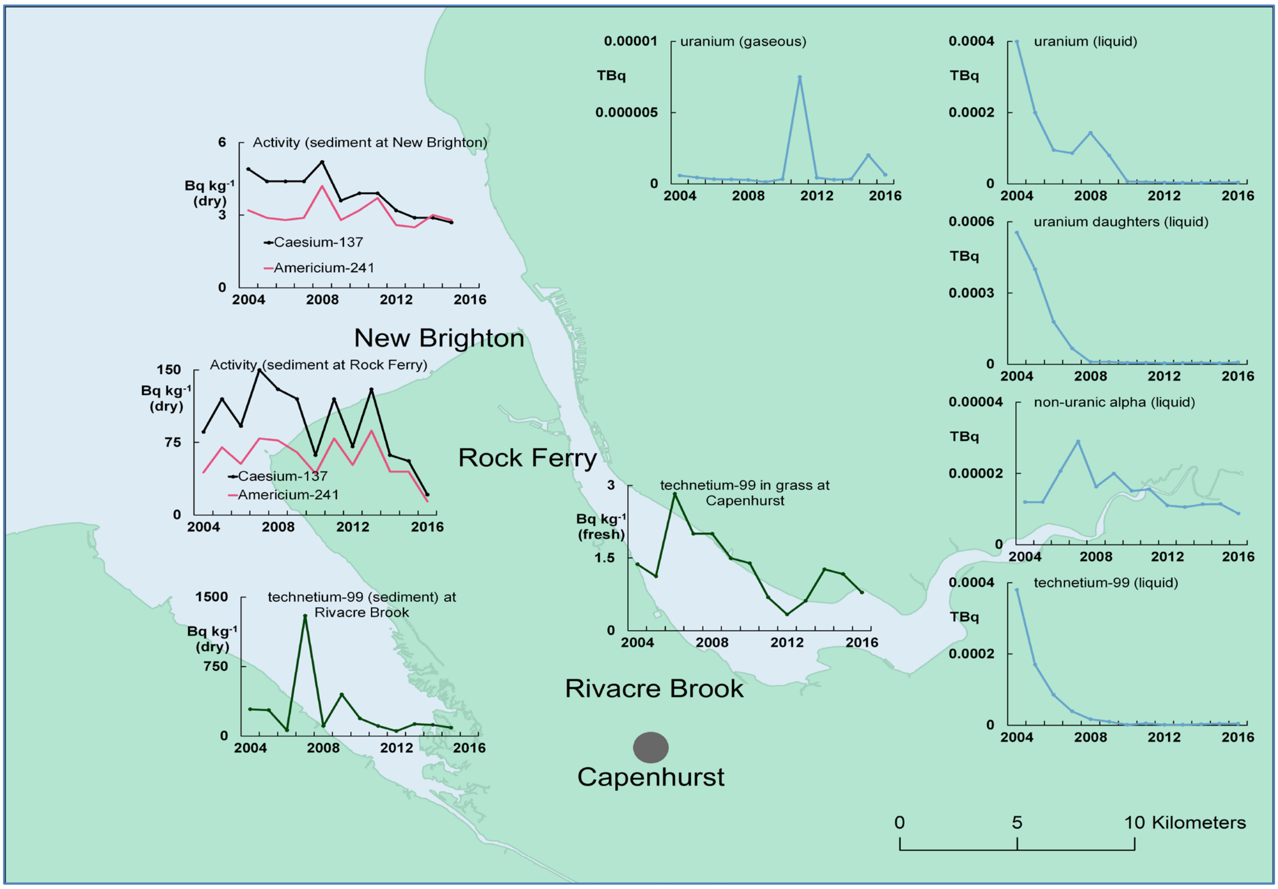

Figure 2.4 Discharges of gaseous and liquid radioactive wastes and monitoring of the environment, Capenhurst (2004-2016)

Since 2004, the overall trend was a reduction of gaseous and liquid discharges over time. Most of the reductions were attributed to progress in decommissioning some of the older plant and equipment. The decline in liquid technetium-99 discharges over time is reflected in the reduction of recycled uranium.

Figure 2.4 also provides selected monitoring trends to assess the impact on the surrounding environment. The concentrations of technetium-99 in grass were relatively low. The overall trend reflects the reductions in discharges of technetium-99 from recycled uranium. Concentrations of uranium radionuclides in the environment (and food) were very low. Concentrations of technetium-99 in sediment (Rivacre Brook) from liquid discharges were detectable close to the discharge point. The increase in 2007 was probably due to the discharge occurring at the same time as environmental sampling. Thereafter, sediment samples collected downstream from the Rivacre Brook contained very low but measurable concentrations of uranium (enhanced above natural levels) and technetium-99. Concentrations of caesium-137 and americium-241 in sediments at Rock Ferry and New Brighton on the Irish Sea coast were from past discharges from Sellafield carried into the area by tides and currents. The concentrations were generally similar over most of the time period and any fluctuations were most likely due to normal changes in the environment. The lowest activity concentrations were reported in 2016 at both locations.

2.4 Springfields – Discharges of radioactive waste and concentrations of radionuclides in food and the environment

The main radioactive constituent of gaseous discharges from Springfields is uranium with small amounts of other radionuclides from research and development facilities. Permitted discharges of liquid waste are made from the Springfields site to the Ribble Estuary by two pipelines. The largest discharge for a number of years was of short half-life beta emitting radionuclides (mainly thorium-234).

Figure 2.5 shows the trends of discharges over time (2004-2016) for a number of the permitted radionuclides.

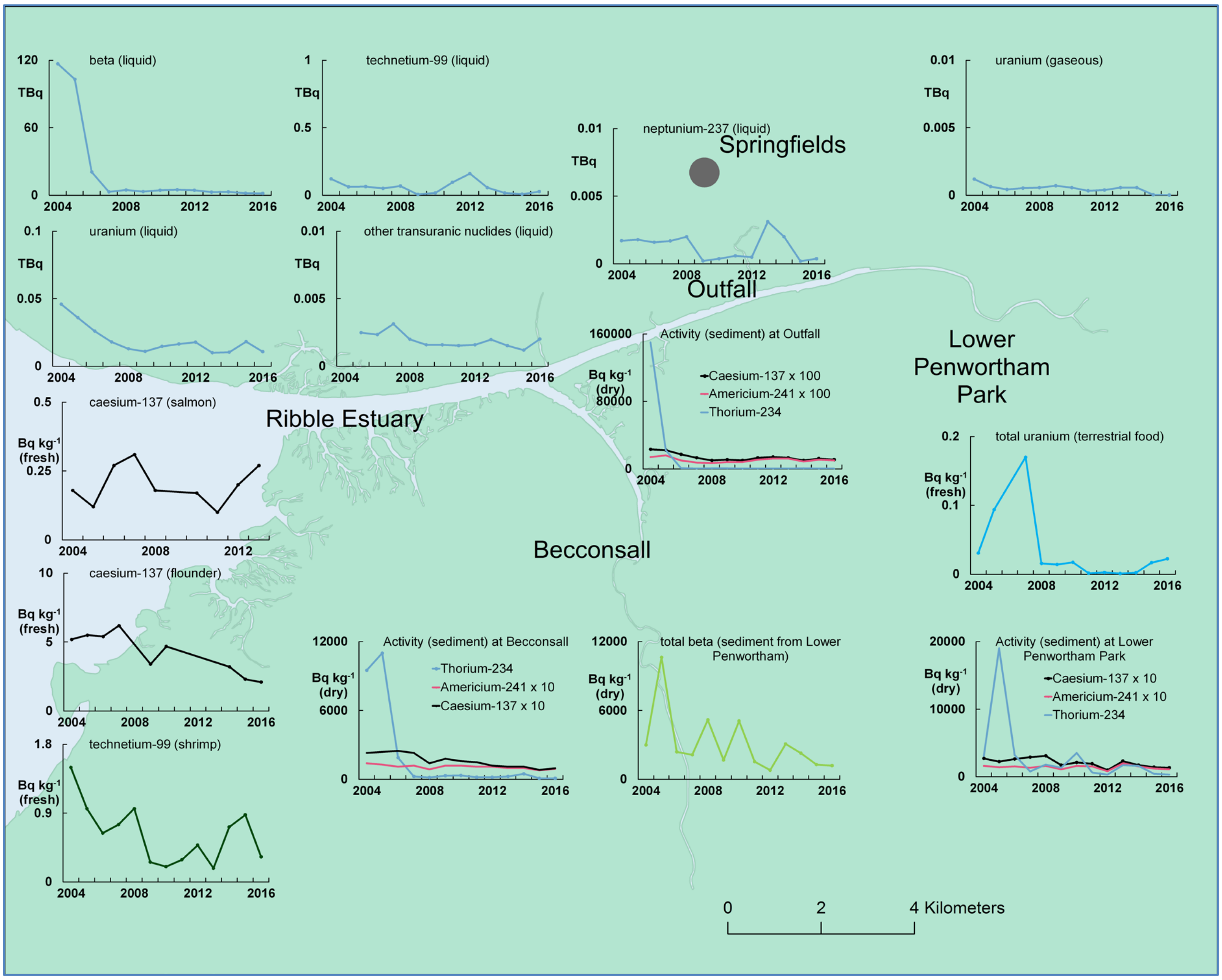

Figure 2.5 Discharges of gaseous and liquid radioactive wastes and monitoring of the environment, Springfields (2004-2016)

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 Uranium Ore Concentrate purification process ended in 2006. Liquid discharges of uranium radionuclides decreased over time, whilst other discharges were relatively constant.

Figure 2.5 also shows the trends of radionuclide concentrations in food (cabbage, shrimps, flounders and salmon) and the environment (sediment) near Springfields.

The concentrations of radionuclides from gaseous discharges were very low. Over the time period, concentrations of uranium were found in soil around the site, but the isotopic ratio showed they were naturally occurring. Total uranium in cabbage samples was also detected during the period (no data in 2006), but the apparent peak in 2007 was very low and significantly less, when compared to concentrations in slightly elevated soil samples.

Concentrations of technetium-99 and caesium-137 were present in flounder, shrimps and salmon around Springfields. These were due to past liquid discharges from Sellafield, carried from the waters off West Cumbria into the Ribble Estuary by sea currents and adsorbed on fine-grained mud. The change in concentrations was due to natural changes in the environment, together with some evidence of declining concentrations over time (e.g. caesium-137 in flounder).

The trends of concentrations in sediments over time from liquid discharges are shown in Figure 2.5 and were dominated by the reduction of thorium-234. Total beta activity in sediment generally declined over the whole period. Other activity concentrations (and including thorium-234) in sediments from liquid discharges were generally similar (with minor variations), or declining by small amounts, over the most recent years.

2.5 Summary

The information presented in Table 2.1 gives an overview of trends associated with doses, discharges and environmental concentrations described in Section 2.

Table 2.1 Summary of trend data for nuclear fuel production and reprocessing sector (2004-2016)*

Trend data	Downwards	No change	Upwards	Overall
Gaseous discharges	7	3	1	Majority downward trend
Liquid discharges	16	1	0	Majority downward trend
Overall discharges	23	4	1	Majority downward trend
Environmental concentrations	10	0	0	Downward trend
Food concentrations	10	1	0	Majority downward trend
Food and the environment overall	20	1	0	Majority downward trend
Overall doses from gaseous and liquid discharges	6	5	0	Majority Downward trend
All doses were below the dose limit				

***** Taken from the number of trend graphs for this sector presented in this report. This is a visual evaluation only.

3. Research and development

Key points

- All doses were less than the dose limit for members of the public of 1 mSv per year.
- Highest annual dose (from artificial radionuclides) was 0.047 mSv at Dounreay.
- All discharges were well below the authorised/permitted limits.
- Overall, gaseous and liquid discharges were low.
- Concentrations in the marine and terrestrial environment and food continued to be very low.

This section looks at the time trends between 2004 and 2016 from the UK's research establishments that hold nuclear site licences. The time trends show the public's exposure, discharges of radioactive waste and concentrations of radionuclides in food and the environment. The public's exposure[4] (dose) from radioactive waste discharges is assessed using radionuclide concentrations and gamma dose rates in the environment.

There are six sites associated with research reactors that are currently authorised/permitted to discharge radioactive waste in the UK. The main sites are Dounreay in Highland, Harwell in Oxfordshire and Winfrith in Dorset. Other smaller research sites include Culham (Oxfordshire), the Imperial College Reactor Centre (Berkshire) and Windscale (Cumbria) which is on the Sellafield site. These latter smaller sites make small discharges overall, and are not considered here.

3.1 Public's exposure to radiation due to discharges of radioactive waste

Figure 3.1 shows the time trends of doses between 2004 and 2016, due to the effects of gaseous and liquid waste discharges at the main research sites. All doses were much less than the UK and European limit of 1 mSv per year for members of the public.

Figure 3.1 shows that the highest annual dose was at Dounreay from consuming food produced on land around the site. This ranged between 0.008 and 0.047 mSv over the time period. The sudden increase in dose in 2005 (and subsequent doses until 2008) was due to dose estimates being more conservative. Doses were more conservative because higher analytical limits of detection were used in the assessments. Between 2008 and 2012, reduced doses were mostly due to lower caesium-137 concentrations in game meat and the type of game sampled. A change in doses between 2013 and 2015 was mostly due to the contribution of goats' milk not being included in the assessment (which has been assessed prior to 2013), as

[4] The monitoring results are interpreted in terms of radiation exposures of the public, commonly termed 'doses'. These people are a group, who generally eat large quantities of locally grown food (high-rate consumers) or who spend long periods of time in the locations being assessed. This dose, referred to in Sections 2-6, is an exposure that uses a different assessment method to that of *total dose* in Section 1.

milk samples have not been available in most recent years. An increase in dose in 2016 was mostly due to the inclusion of the caesium-137 concentration in game, the activity most likely from historical releases.

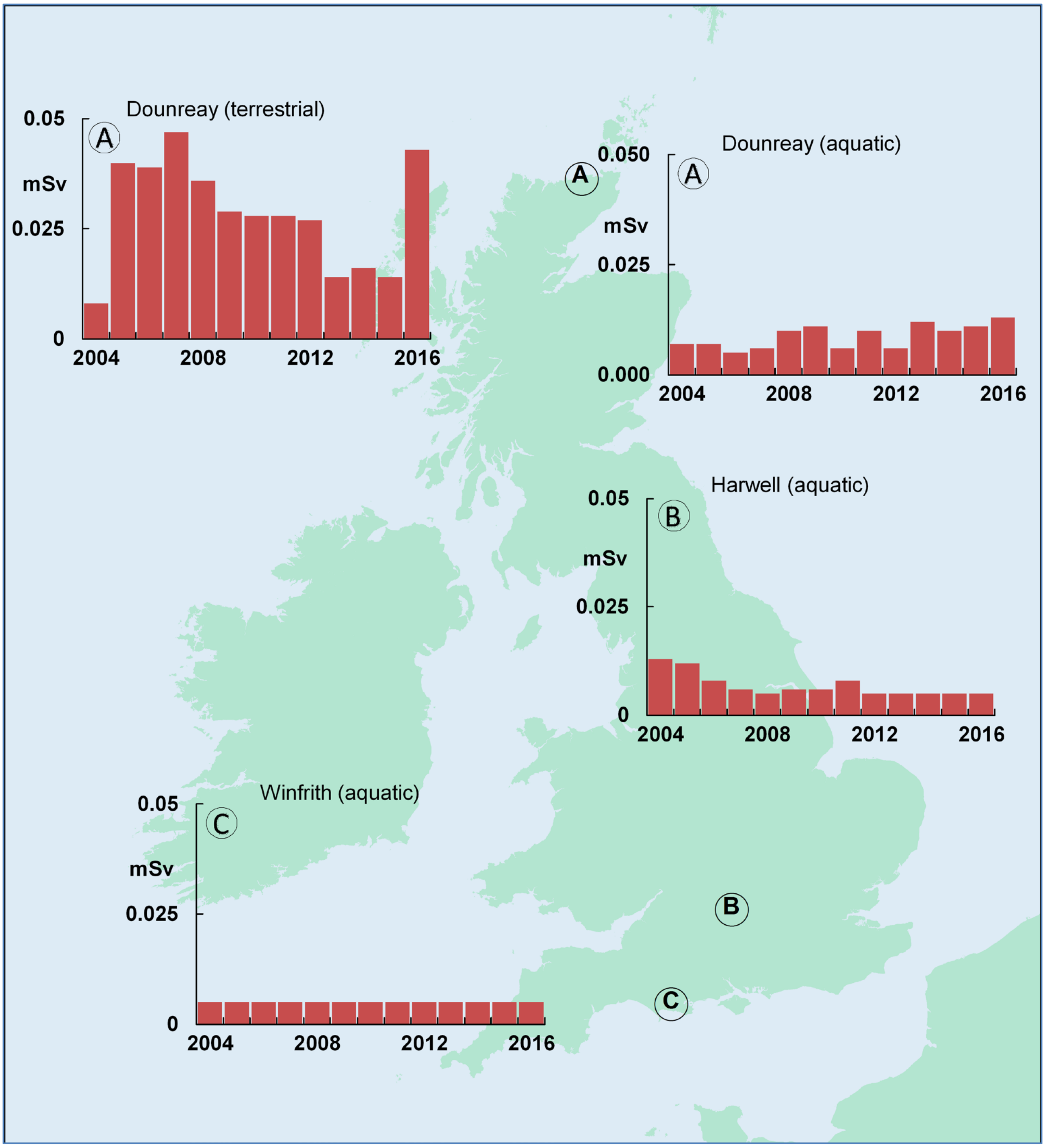

Figure 3.1 Individual radiation exposures to most exposed groups from artificial radionuclides, Dounreay, Harwell and Winfrith (2004-2016)
(Small doses less than or equal to 0.005mSv are recorded as being 0.005mSv)

The annual dose from seafood consumption and external exposure over local beaches at Dounreay ranged from less than 0.005 to 0.013 mSv over the time period. Between 2004 and 2007, the variations in dose were mostly likely due to normal changes in the environment. Between 2008 and 2016, variations in dose were mostly due to changes in gamma dose rates over winkle beds and sand. Additionally, the apparent increase in dose in 2013 was due to increased occupancy rates from new habits information.

At Harwell, the group of people most affected by radioactive waste discharges were anglers on the River Thames, with annual doses from less than 0.005 to 0.013 mSv over the time period. The variations in aquatic dose with time were mainly due to changes in gamma dose rates (in 2006 and 2011) and revised occupancy rates on the river bank (in 2007). There is an overall decline in aquatic doses over the time period.

At Winfrith (and all the other smaller sites), all assessed doses were well below 0.005 mSv, which is less than 0.5 per cent of the dose limit for members of the public.

3.2 Dounreay –

Discharges of radioactive waste and concentrations of radionuclides in food and the environment

Gaseous and liquid discharges are released into the atmosphere and into the sea (Pentland Firth) by a pipeline terminating 600 metres offshore at a depth of about 24 metres.

Figure 3.2 shows the trends of discharges over time (2004-2016) for a number of the authorised radionuclides. The overall trend was a reduction in both gaseous and liquid discharges (2004-2016).

Figure 3.2 also provides selected monitoring trends to assess the impact on the surrounding environment. The majority of measurements of radionuclide concentrations in food and the environment were at or below the analytical limits of detection, which made it difficult to produce valuable trend monitoring data that may correspond to discharge data. Nevertheless, concentrations of technetium-99 from Sellafield found in seaweed taken from Sandside Bay, Kinlochbervie and Burwick Pier showed an overall decline over the period. Variations in technetium-99 concentrations (mostly demonstrated in the earlier years) were most likely due to the complexity of how radionuclides move around in the Irish Sea, with technetium-99 being dispersed in varying amounts before arriving at distant locations. Concentrations of caesium-137 in sediments at Sandside Bay, Rennibister and Oigins Geo were likely to include a contribution from Sellafield discharges. The concentrations were generally unchanged over the time period with any fluctuations most likely due to normal variations in the environment.

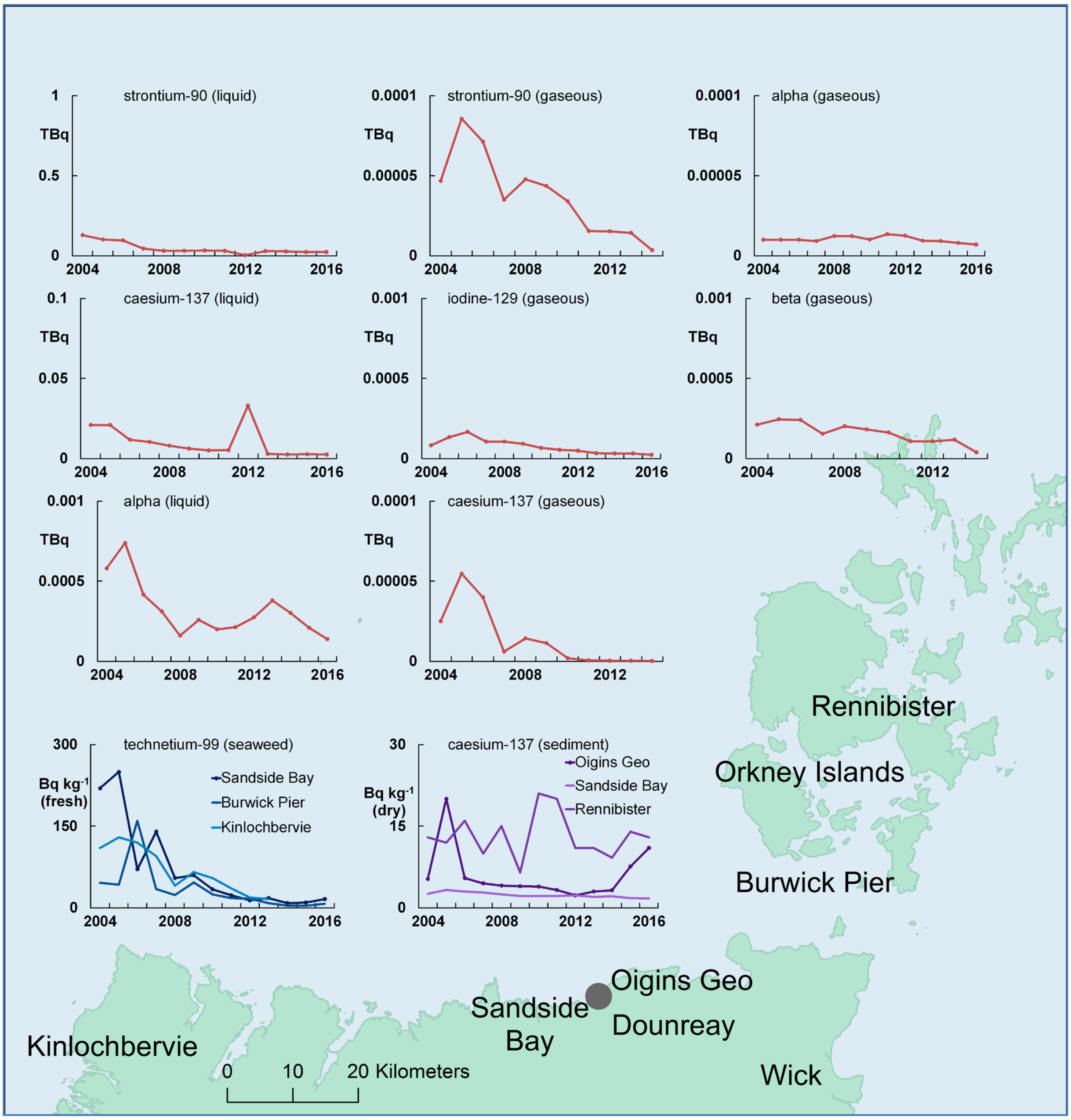

Figure 3.2 Discharges of gaseous and liquid radioactive wastes and monitoring of the environment, Dounreay (2004-2016)

3.3 Harwell –

Discharges of radioactive waste and concentrations of radionuclides in food and the environment

Gaseous releases from Harwell are discharged into the atmosphere. Liquid releases are discharged to sewers serving the Didcot Sewage Treatment Works; treated effluent subsequently enters the River Thames at Long Wittenham. Discharges to the River Thames at Sutton Courtenay ceased in 2013, thereafter the decommissioning of the treated waste effluent discharge point was completed in 2014 by Research Sites Restoration Limited. Discharges of surface water effluent from the Harwell site are made via the Lydebank Brook, north of the site, which is a permitted route.

Figure 3.3 shows trends of discharges over time (2004-2016) for a number of the permitted radionuclides.

The gaseous discharges were low and generally similar over the time period. There was an overall reduction in liquid discharges, particularly for cobalt-60. Liquid discharges of caesium-137 were the lowest release for many years.

Figure 3.3 also provides monitoring trends from four locations (Harwell outfall, Appleford, Day's Lock and Lydebank Brook) to assess the impact on the surrounding environment. Concentrations of caesium-137 in sediments from the Appleford, and Lydebank Brook were generally declining due to reduced liquid caesium-137 discharges. As expected, the biggest difference in concentrations was observed near the Harwell discharge point (outfall), although discharges have declined since the peak value in 2013. Prior to 2013, discharges from Harwell to the Thames were not continuous but occurred in batches when tanks were emptied. The peaks in some years (and including the peak at Lydebank Brook in 2014) were probably due to the discharge occurring at the same time as environmental sampling.

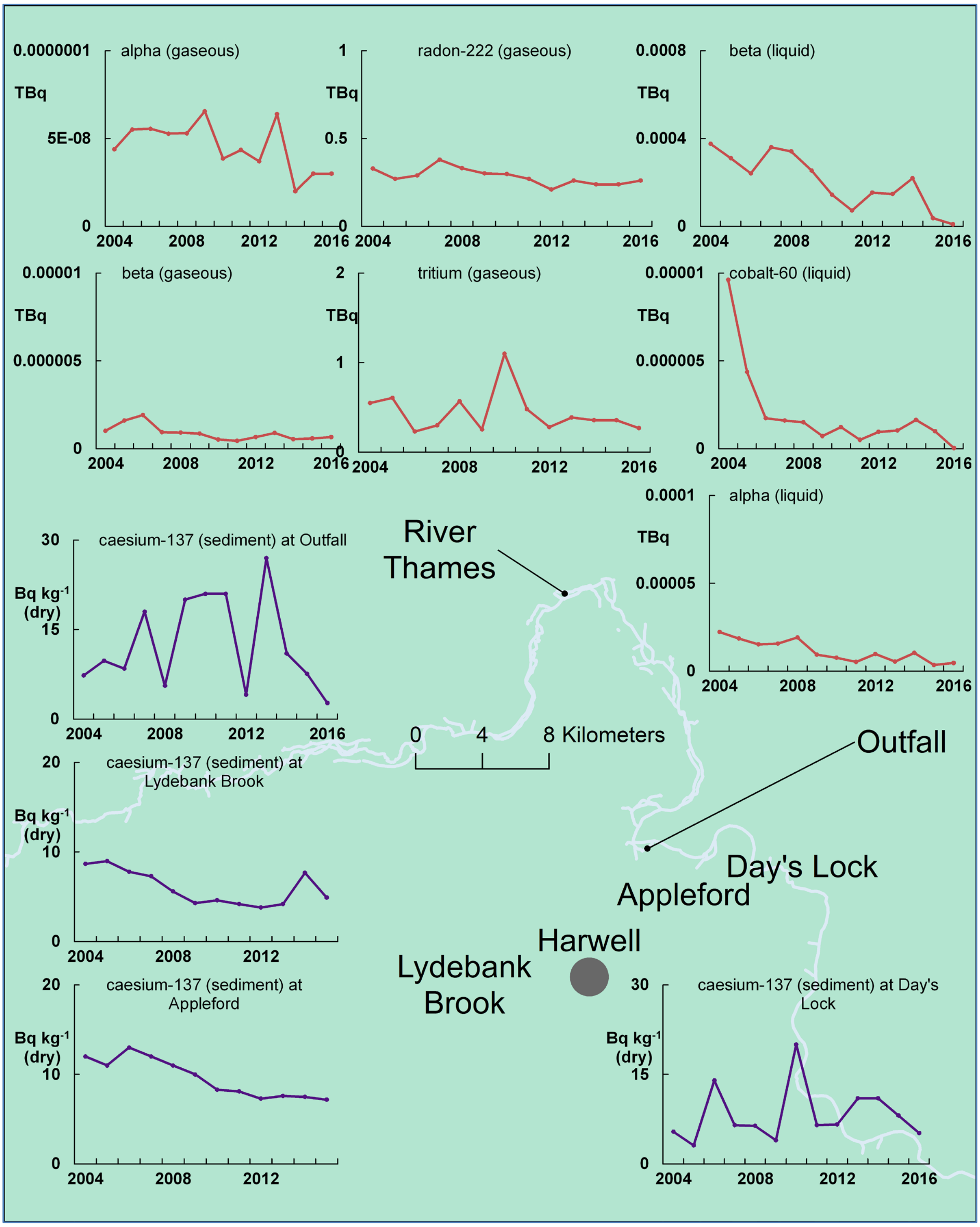

Figure 3.3 Discharges of gaseous and liquid radioactive wastes and monitoring of the environment, Harwell (2004-2016)

3.4 Winfrith –

Discharges of radioactive waste and concentrations of radionuclides in food and the environment

Gaseous emissions from Winfrith are discharged into the atmosphere, and liquids to deep water in Weymouth Bay and to the River Frome.

Figure 3.4 shows the trends of discharges over time (2004-2016) for a number of the permitted radionuclides. Gaseous and liquid discharges generally remained at low rates over the period. Gaseous discharges of tritium peaked in 2006 and this coincided with a revised permit to increase tritium discharges from the site, for the processing of wastes. Gaseous tritium discharges increased again in 2012 due to operations of a tenant on the site (Tradebe Inutec, formerly Inutec). Gaseous discharges of carbon-14 declined since the peak value in 2007. Liquid tritium discharges have varied between years, with periodic peaks in releases, due to operations at Tradebe Inutec. Over the period, liquid discharges of alpha-emitting radionuclides have generally decreased (although discharges peaked in 2013) and were less than 1 per cent of the annual limit in most recent years.

Figure 3.4 also provides radionuclide concentrations from four locations, to assess the impact on the surrounding environment. Tritium concentrations in a stream north of the site showed enhanced levels that slightly increased following the revision of the permit in 2006. These concentrations were still relatively low and were less than 10 per cent of the World Health Organisation’s screening levels for drinking water. Since 2006, tritium concentrations have generally declined over time. Plutonium radionuclides and americium-241 concentrations in seafood from Lulworth Ledges, Lulworth Banks and Poole Bay were very low over the time period, albeit with some relatively small enhancement in activity concentrations in more recent years. Over the time period there have been some changes in the concentrations of these radionuclides between years, most likely attributable to environmental variability.

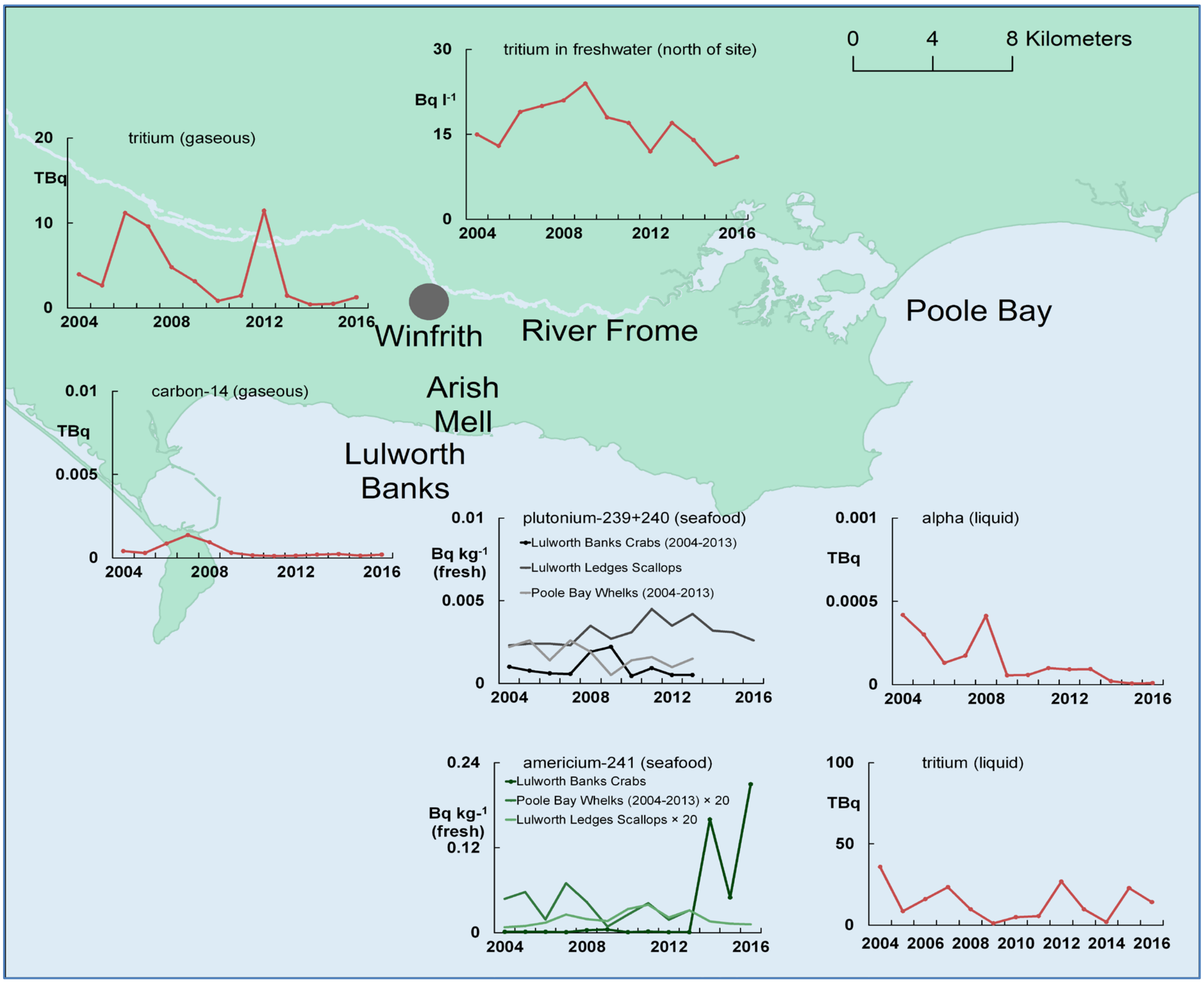

Figure 3.4 Discharges of gaseous and liquid radioactive wastes and monitoring of the environment, Winfrith (2004-2016)

3.5 Summary

The information presented in Table 3.1 gives an overview of trends associated with doses, discharges and environmental concentrations described in Section 3.

Table 3.1 Summary of trend data for research sector (2004-2016)*

Trend data	Downwards	No change	Upwards	Overall
Gaseous discharges	8	3	1	Majority downward trend
Liquid discharges	7	1	0	Majority downward trend
Overall discharges	15	4	0	Majority downward trend
Food and the environment overall	3	6	0	Minority downward trend
Overall doses from gaseous and liquid discharges	2	2	0	Minority downward trend
All doses were below the dose limit				

* Taken from the number of trend graphs for this sector presented in this report. This is a visual evaluation only.

4. Nuclear power generation

Key points

- All doses were less than the dose limit for members of the public of 1 mSv per year.
- Highest annual dose (from artificial radionuclides) was 0.068 mSv at Heysham.
- Most changes in dose between years resulted from natural changes in the environment.
- Overall decline in gaseous and liquid discharges, with all permitted/authorised discharges well below the limits.
- Some Magnox sites remained operational during the period, stopping electricity generation in; 2004 (Chapelcross), 2006 (Dungeness and Sizewell), 2012 (Oldbury), 2015 (Wylfa).
- Concentrations on the land continued to be very low and concentrations in the sea were affected by natural changes in the environment and/or influenced by other sources.

This section looks at the time trends between 2004 and 2016 from the UK's nuclear power stations. The time trends show the public's exposure, discharges of radioactive waste and concentrations of radionuclides in food and the environment. The public's exposure[5] (dose) from radioactive waste discharges is assessed using radionuclide concentrations and gamma dose rates in the environment.

There is a total of 19 nuclear power stations at 14 locations, nine in England (Berkeley, Oldbury, Bradwell, Calder Hall, Dungeness, Hartlepool, Heysham, Hinkley Point and Sizewell), three in Scotland (Chapelcross, Hunterston and Torness) and two in Wales (Trawsfynydd and Wylfa). Eleven of the 19 nuclear power stations are first generation Magnox power stations, seven are more recent advanced gas-cooled reactor (AGR) power stations and one is a pressurised water reactor (PWR) power station. Five out of the original 11 first generation Magnox Power stations were operating in 2004. Over the period of this report all the remaining stations stopped operating.

4.1 Public's exposure to radiation due to discharges of radioactive waste

Figure 4.1 shows the time trends of doses between 2004 and 2016 due to the effects of liquid waste discharges at the power stations.

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[5] The monitoring results are interpreted in terms of radiation exposures of the public, commonly termed 'doses'. These people are a group, who generally eat large quantities of locally grown food (high-rate consumers) or who spend long periods of time in the locations being assessed. This dose, referred to in Sections 2-6, is an exposure that uses a different assessment method to that of *total dose* in Section 1.

The dose is made up from consuming seafood and external exposure over intertidal areas. External dose from intertidal areas can be important contributor to dose where people spend a lot of time on beach area. At all locations, around these sites, the doses were all less than the UK and European limit for members of the public of 1 mSv per year.

Figure 4.1 shows the annual dose was highest to a group of local fishermen at Heysham. This ranged between 0.024 and 0.068 mSv over the period, and with the highest value in 2004, and generally declined over the period. The doses were affected by past discharges from Sellafield, where radionuclides have travelled with currents around to the area. The decrease in dose after 2004 and 2011 was due to a reduction in the amount of shellfish eaten (containing americium-241 from past discharges from Sellafield) and a reduction in the occupancy rates, respectively. Most of the dose to this group was affected by external radiation measured above beaches and tidal areas and variations in the trend reflected changes between years in measured gamma dose rates.

The next group of people most affected by radioactive waste discharges was at Hinkley Point. This was a group of local fishermen, with annual doses ranging between 0.017 and 0.046 mSv over the period. The doses were from external radiation measured above beach sediment and a conservative estimate from tritium and carbon-14 in fish. Carbon-14 and tritium were likely due to discharges from the GE Healthcare facility at Cardiff. The trend graph shows apparent increases in doses during the period (in 2006, 2009 and 2013). The increase was due to slightly enhanced external dose rates above sediments. Variations in these measurements have contributed to the trend in recent years. There was no site related reason to account for the trend in dose rates, and the changes between years was most likely due to variations in natural radiation.

People living near Berkeley and Oldbury, including seafood consumers and houseboat dwellers, received annual doses between 0.006 and 0.031 mSv. This included external radiation, and a conservative estimate due to the tritium from Cardiff. The apparent increase in dose in 2008 was due to a higher gamma dose rate measured in a different type of sediment. Before 2008, the changes in dose were likely due to normal changes in the environment. Between 2009 and 2013, changes in doses in were due to variations in dose rates. The dose increased in 2014 due to a revision in the habits information and a new conservative assessment for houseboat dwellers. Thereafter, changes in dose were due to variation in dose rates.

Local fisherman and wildfowl consumers at Chapelcross received annual doses ranging from less than 0.005 to 0.027 mSv over the period. The changes in doses were mostly attributed to variations in gamma dose rate measurements over sediments. The dose declined in 2010 due to a revision in the habits information. The discharges from Chapelcross contributed a very small fraction of the dose to the local population. Most of the dose was attributed to historic Sellafield discharges.

At Bradwell, the annual dose ranged from less than 0.005 to 0.017 mSv. The highest dose was in 2007. In 2007, new habits information became available including about occupancy of boats at the main mooring locations. These data were included in the assessment of dose and lead to an increase in the dose calculated for the group. Before 2007, the changes were mainly due to normal changes in the environment. In

2008, a decrease was observed in dose rate above beaches and this lead to a decrease in doses to the group for the remainder of the period.

At Dungeness, the annual dose to a group of local bait diggers or a group of people living on houseboats ranged between 0.005 and 0.019 mSv. The changes in dose were mainly due to the normal variations in concentrations and dose rates in the environment.

At Hartlepool, between 2004 and 2007, the annual dose to a group of local fishermen was assessed to be less than 0.005 mSv. The apparent increase in 2008 was due to the identification and assessment of a new pathway, for the external exposure of a group of sea coal collectors. Variations in dose (and group) between 2009 and 2013 were due to changes in dose rates. In 2014, the two groups were combined and assessed, due to a revision in the habits information. Small changes in doses in 2015 and 2016 were due to variations in dose rates.

At Hunterston, the annual dose ranged from less than 0.005 to 0.012 mSv. This included a contribution from technetium-99 in shellfish, the activity having been discharged from Sellafield. Over the period, the overall trend was due to differences in measured gamma dose rates from normal changes in the environment.

At Sizewell, the assessed doses (between 2004 and 2011) for seafood consumers and houseboat dwellers were much less than 0.005 mSv. In 2012 and 2013, the dose for houseboat dwellers increased due to higher dose rates.

At Trawsfynydd, the annual dose ranged between less than 0.005 and 0.013 mSv over the period. The assessed dose was for a group of anglers using the lake for fishing. Part of their dose was from external exposure. It has proved difficult to obtain a reliable dose rate from artificial radionuclides by measurement, because of uncertainty in the dose rate from natural radionuclides. So, for this assessment, external dose was calculated from radionuclide concentrations (in particular caesium-137) using an external dose rate model. Caesium-137 concentrations in sediments have declined over the period so the model predicts a reduction in dose rate. The decrease in dose in 2016 was due to the contribution from caesium-137 in brown trout not being included in the assessment (sample not collected in 2016).

At Wylfa, the annual dose to a group of people who ate a large amount of fish and shellfish ranges from less than 0.005 to 0.010 mSv. The reduction in dose in 2004 at Wylfa was due to new estimates of consumption and occupancy rates. Thereafter, changes in doses were mostly due to variations in dose rates. The dose declined in 2013 due to a revision in the habits information.

All assessed doses were much less than 0.005 mSv at Torness, over the period, with no significant variation in doses to seafood consumers.

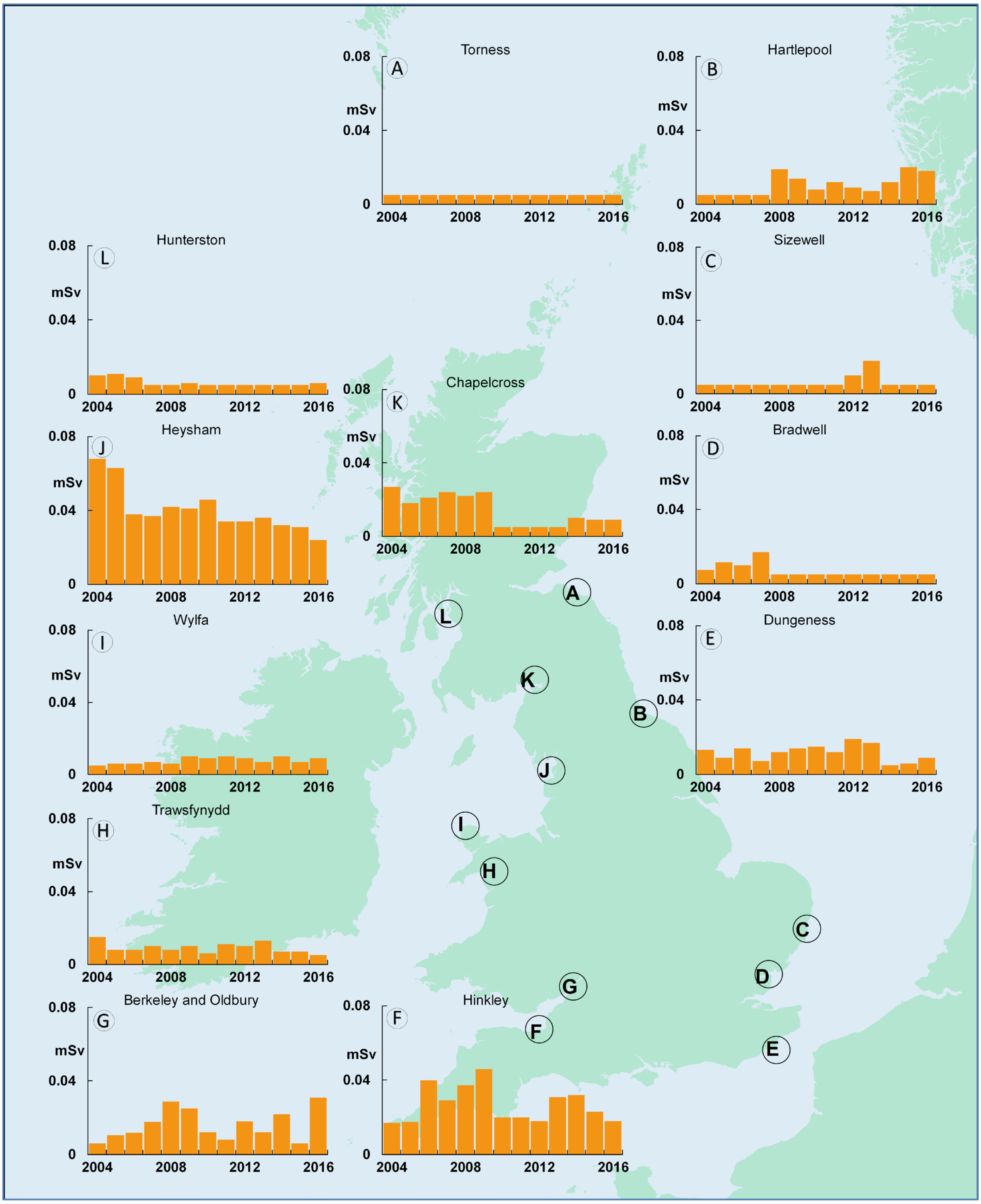

Figure 4.1 Individual radiation exposures around nuclear power stations from aquatic pathways for artificial radionuclides (2004-2016) (Small doses less than or equal to 0.005mSv are recorded as being 0.005mSv)

4.2 Discharges of radioactive waste from nuclear power stations

Permitted/authorised discharges of gaseous and liquid waste are made to the atmosphere and into the sea (except at Trawsfynydd where liquid discharges are released into Lake Trawsfynydd – see Section 4.4 for discharges). Figures 4.2 and 4.3, respectively, show the trends of gaseous and liquid discharges over time (2004-2016) for a number of radionuclides.

For Magnox stations, radionuclide permits/authorisations include tritium and carbon-14 (gaseous), and tritium and caesium-137 (liquid). For operating Magnox stations discharges of argon-41 and sulphur-35 gases are made. For AGR and PWR stations, these include tritium, carbon-14, sulphur-35 and argon-41 (for gaseous discharges), and tritium, sulphur-35, cobalt-60 and caesium-137 (for liquid discharges).

For the sites with only Magnox reactors (excluding Trawsfynydd – see section 4.4), the most significant trends over the period were an overall decline in the gaseous discharges of tritium and carbon-14 and liquid discharges of tritium and caesium-137. There was a pronounced decrease in the discharge of gaseous and liquid tritium from Chapelcross. This is because Chapelcross stopped generating electricity in 2004. Sizewell A and Dungeness A both showed significant declines in gaseous discharges of argon-41 and sulphur-35 after 2006. This was the year that they were shut down permanently. Gaseous and liquid tritium discharges from Berkeley and Oldbury also declined with time. Gaseous tritium and carbon-14 discharges at Bradwell were low. However, a small increase in tritium and gaseous carbon-14 discharges occurred in 2014 and 2015 due to the dissolution of Fuel Element Debris on the Bradwell site.

For the sites with AGR or PWR reactors, the trend was an overall decline in gaseous and liquid discharges over the period 2004-2016, at Dungeness, Hartlepool (gaseous), Hinkley Point, Hunterston and Sizewell. Discharges from other sites were generally similar over the period, with fluctuations between years. Most of the apparent variations can be associated with changes in power output (including shutdowns for maintenance operations). The most pronounced observation was the decreases of gaseous and liquid discharges in 2008 at Hartlepool. This is because both reactors at Hartlepool were shut down in 2008. In 2007, liquid tritium discharges declined due to the shut down of Heysham 1 and liquid tritium discharges decreased in 2011 from reduced power output at Dungeness B.

4.3 Concentrations of radionuclides in food and the environment

Monitoring of food and the environment is carried out around each of the power stations in the UK. The majority of measurements of radionuclide concentrations were at or below the analytical limits of detection. This meant that it was only possible to establish trends for a few radionuclides in environmental samples. Figure 4.4 shows monitoring trends of caesium-137 in sediments from marine locations to help assess the overall impact on the surrounding environment. Furthermore, it is difficult to differentiate the low concentrations of activity in marine material between site discharge and other factors such as liquid discharges of nearby sites, fallout from weapons testing and Chernobyl, and long-distance contributions (including past discharges) from nuclear reprocessing plants at Sellafield and Cap de la Hague (France).

Overall, the concentrations of caesium-137 in UK sediments were low over time at all locations. Data in Figure 4.4 show that, although there were minor changes between years for individual sites, the general trends were for activity concentrations to decrease or remain relatively constant over the period. The declining trend was most pronounced at Chapelcross and Heysham; the two power station sites (near the Irish Sea) most influenced by Sellafield. Further afield, the effects of Sellafield were less noticeable, partly due to the influence of releases from other sources and environmental variability. The apparent increase of caesium-137 at Dungeness in 2010 was due to the inclusion of a less than value (< 5.8 Bq kg^{-1}).

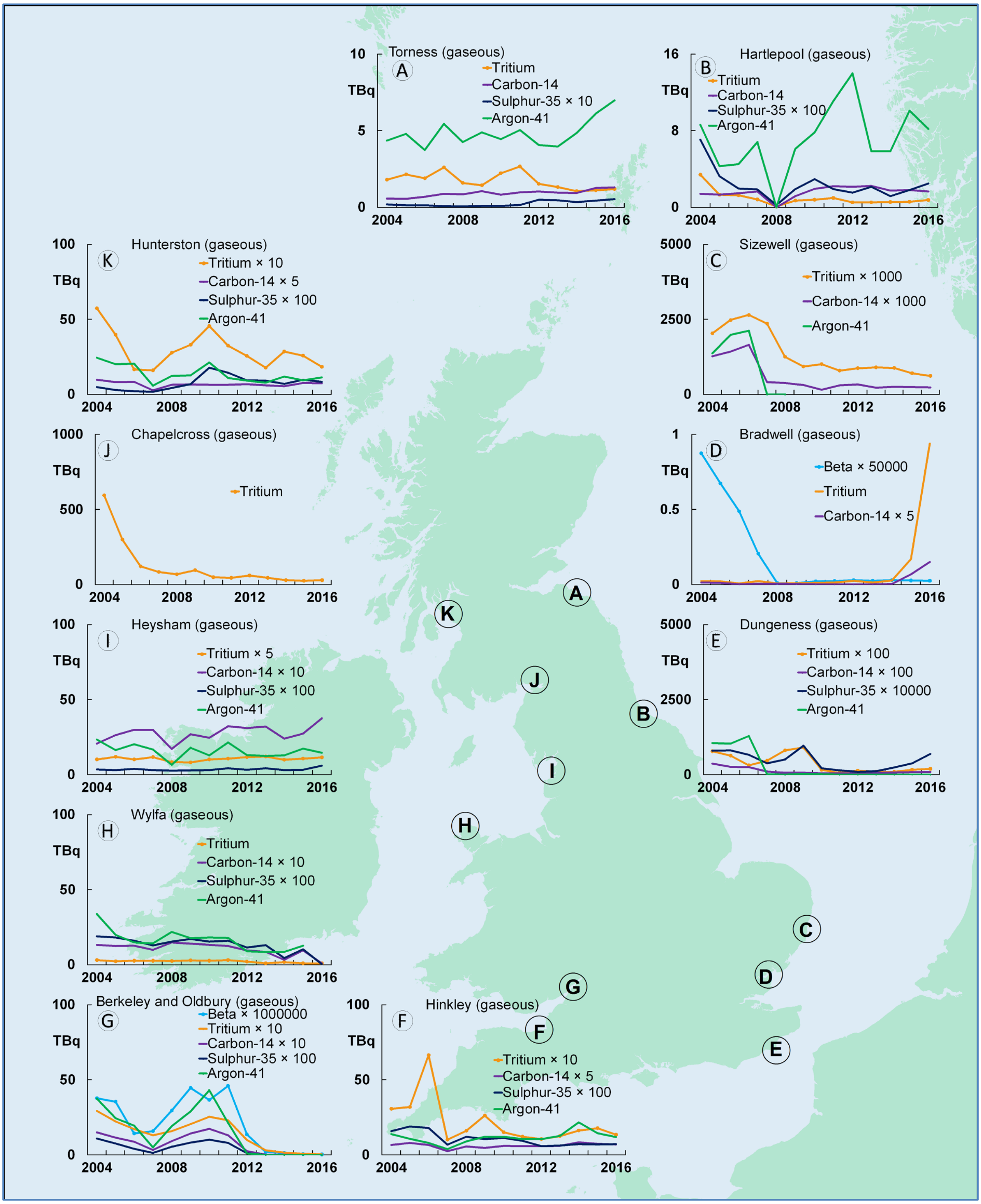

Figure 4.2 Permitted/authorised discharges of gaseous wastes from nuclear power stations (2004-2016)

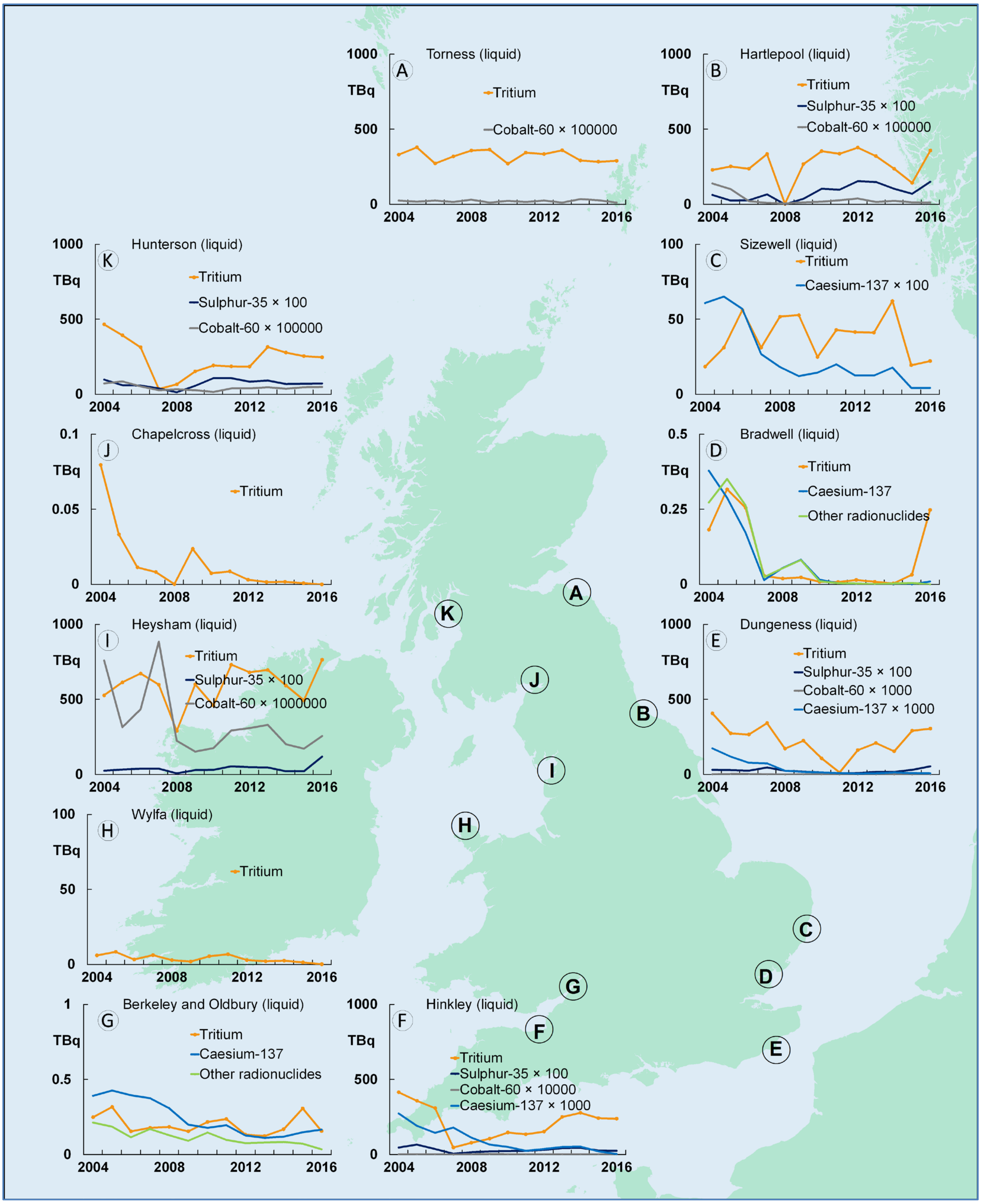

Figure 4.3 Permitted/authorised discharges of liquid wastes from nuclear power stations (2004-2016)

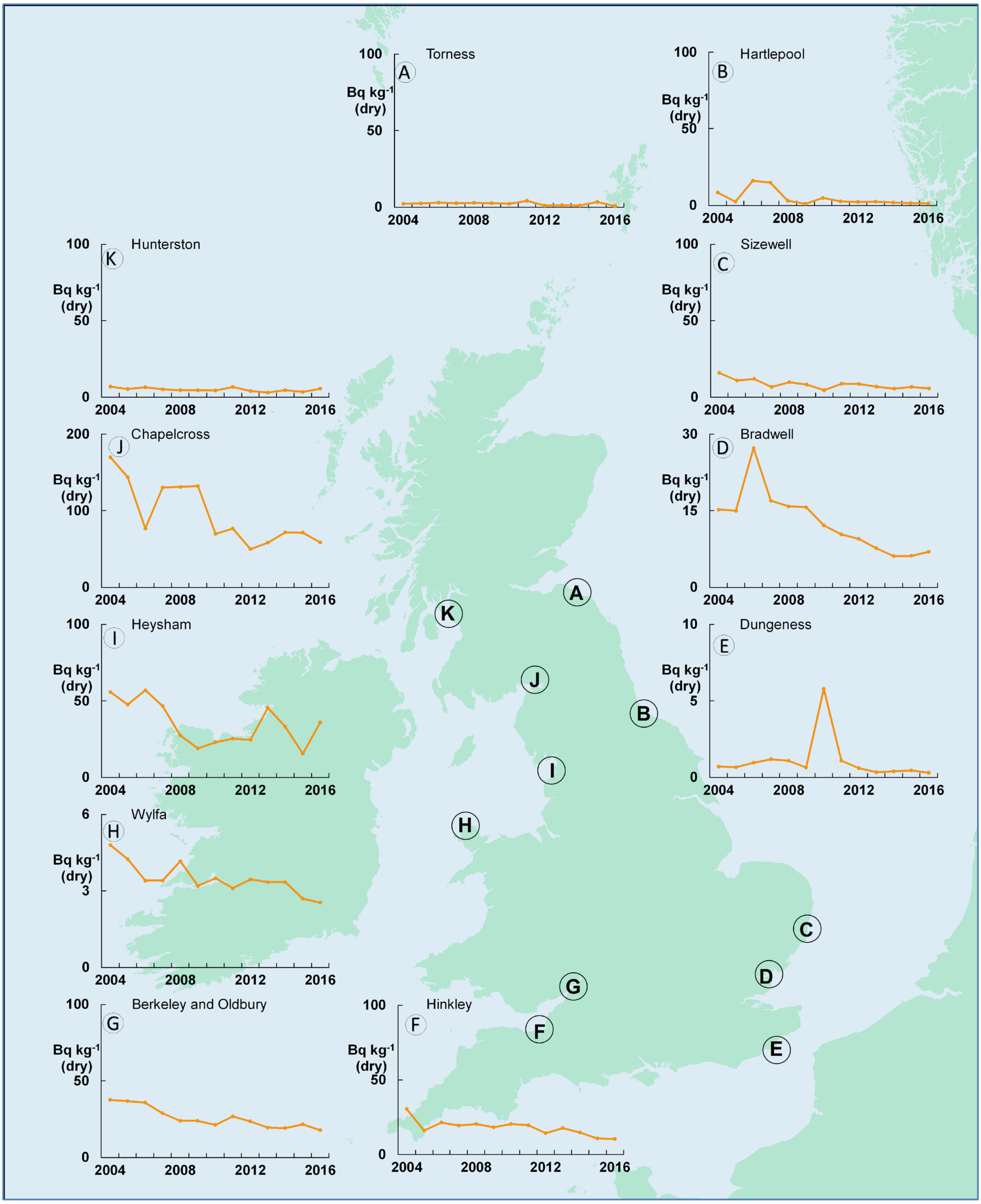

Figure 4.4 Caesium-137 concentrations in marine sediments near nuclear power stations (2004-2016)

4.4 Trawsfynydd –

Discharges of radioactive waste and concentrations of radionuclides in the environment

Trawsfynydd power station is permitted to discharge low levels of liquid waste to Lake Trawsfynydd. All the other power stations make liquid discharges to the coastal environment. Figure 4.5 shows the trends of gaseous and liquid discharges over time (2004-2016) for a number of the permitted radionuclides. Gaseous tritium discharges from Trawsfynydd peaked in 2011 but generally declined over the whole period, with low releases in most recent years. From 2006, liquid tritium discharges were generally low, but peaked in 2014, before returning to previous levels.

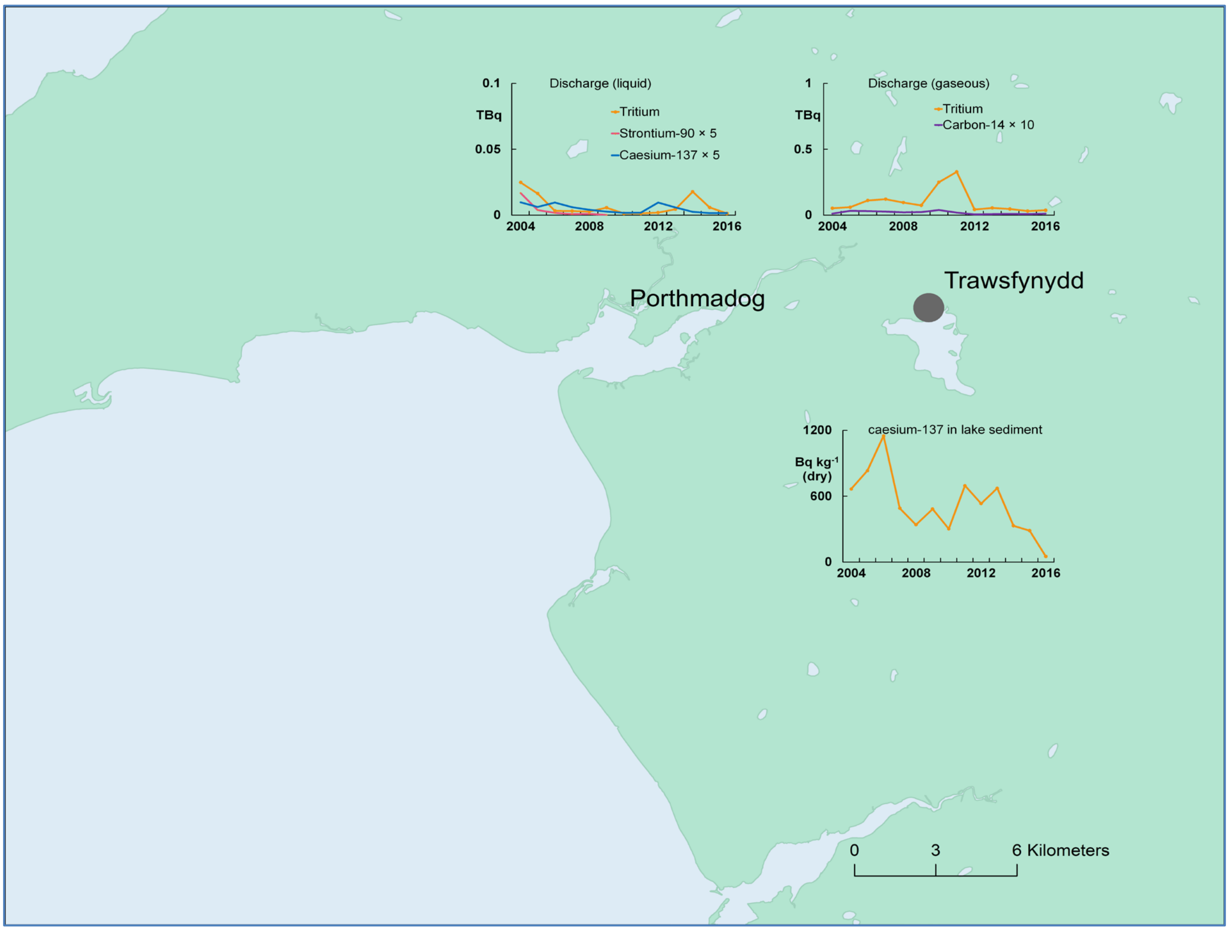

Figure 4.5 Permitted discharges of gaseous and liquid radioactive wastes and monitoring of the environment, Trawsfynydd (2004-2016)

Figure 4.5 also shows trends of caesium-137 in lake sediments from Trawsfynydd to help assess the overall impact on the surrounding environment. In the lake itself, there remains clear evidence of the effects of caesium-137 discharges from the power station, particularly in sediment. A substantial decline in environmental radionuclide concentrations was observed in the late 1990s in line with reducing discharges. Over the period reported here, there was an overall decline in concentrations, although some variability is shown from year to year including movement of activity on sediments from beneath the sediment surface. Nevertheless, the lowest caesium-137 concentrations in sediments were observed in 2016.

4.5 Summary

The information presented in Table 4.1 gives an overview of trends associated with doses, discharges and environmental concentrations described in Section 4.

Table 4.1 Summary of trend data for nuclear power sector (2004-2016)*

Trend data	Downwards	No change	Upwards	Overall
Gaseous discharges	8	3	1	Majority downward trend
Liquid discharges	8	4	1	Majority downward trend
Overall discharges	16	7	1	Majority downward trend
Environment overall	11	1	0	Majority downward trend
Overall doses from gaseous and liquid discharges	6	4	2#	Majority downward trend
All doses were below the dose limit				

* Taken from the number of trend graphs for this sector presented in this report. This is a visual evaluation only

Increase mostly due to revised habits data

5. Defence

Key points

- All doses were significantly less than the dose limit for members of the public of 1 mSv per year.
- Highest annual dose (from artificial radionuclides) was 0.017 mSv at Rosyth.
- All discharges were well below the authorised/permitted limits.
- Overall, gaseous and liquid discharges were low.
- Concentrations around the sites continued to be very low.

This section looks at the time trends between 2004 and 2016 from the UK's defence establishments. The trends show the public's exposure, discharges of radioactive waste and concentrations of radionuclides in food and the environment. The public's exposure[6] (dose) from radioactive waste discharges is assessed using radionuclide concentrations and gamma dose rates in the environment.

There are nine defence-related establishments that are currently authorised/permitted to discharge radioactive waste in the UK. The main sites are Aldermaston (and Burghfield) in Berkshire, Devonport in Devon, Faslane and Coulport in Argyll and Bute, and Rosyth in Fife. Other minor defence sites include Barrow (Cumbria), Derby (Derbyshire), Holy Loch (Argyll and Bute) and Vulcan (Highland). These latter smaller sites make small discharges overall, and are not considered here.

5.1 Public's exposure to radiation due to discharges of radioactive waste

Figure 5.1 shows the time trends of doses between 2004 and 2016, due to the effects of gaseous and liquid waste discharges. All doses were much less than the national UK and European limit for members of the public of 1 mSv per year.

At Aldermaston and Devonport, the doses were all less than 0.005 mSv over the entire period. The increase in dose at Faslane and Coulport in 2016 was mostly due to the increase of the fish consumption rate and occupancy time over sand from the revised habits data. The increase in doses at Rosyth was mostly due to a revision of habits information and higher gamma dose rates over sand in 2015 and 2016, respectively.

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[6] The monitoring results are interpreted in terms of radiation exposures of the public, commonly termed 'doses'. These people are a group, who generally eat large quantities of locally grown food (high-rate consumers) or who spend long periods of time in areas in the locations being assessed. This dose, referred to in Sections 2-6, is an exposure that uses a different assessment method to that of *total dose* in Section 1.

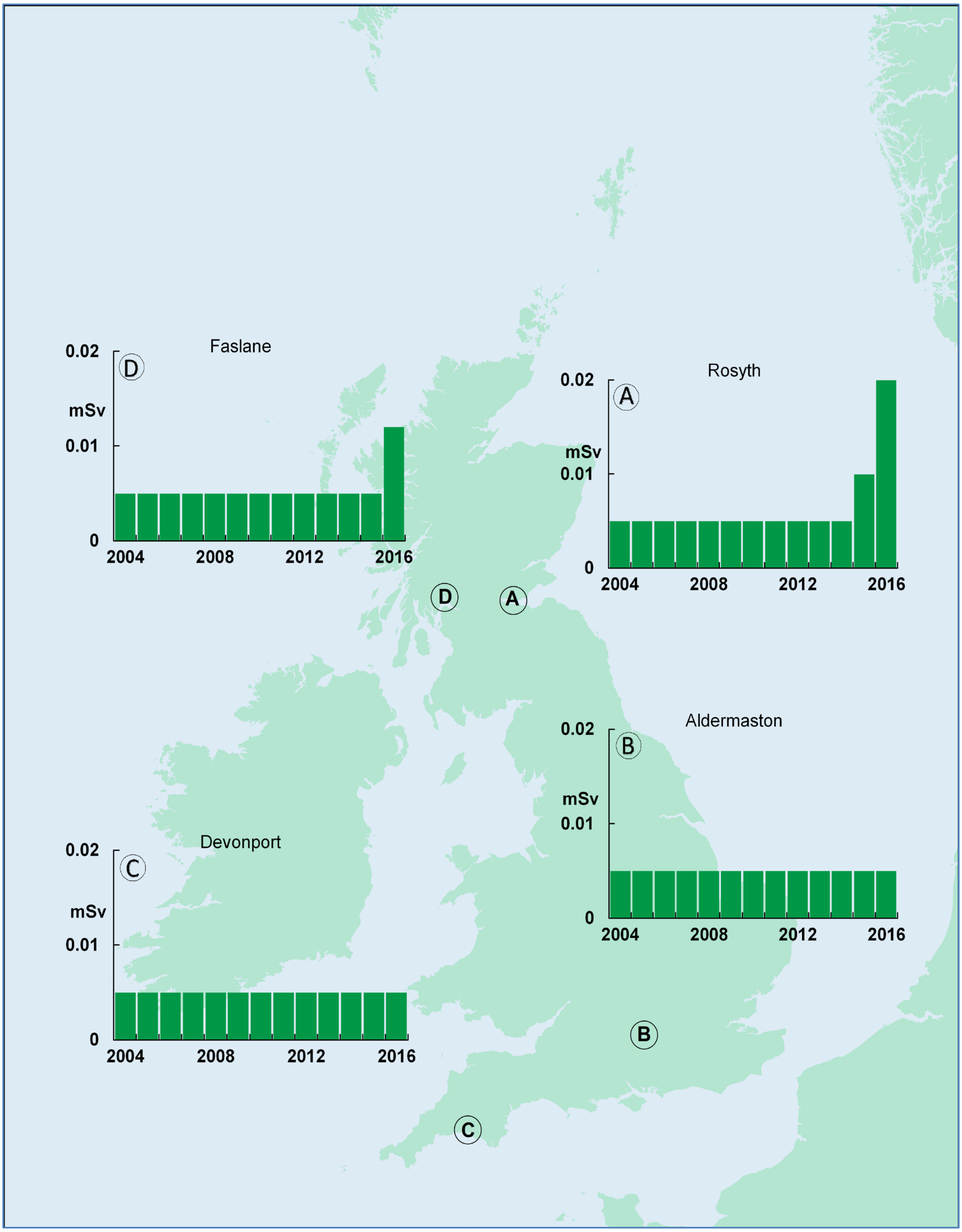

Figure 5.1 Individual radiation exposures to most exposed groups from artificial radionuclides, Aldermaston, Devonport, Faslane and Coulport, and Rosyth (2004-2016) **(Small doses less than 0.005mSv are recorded as being 0.005mSv)**

5.2 Aldermaston, Devonport, Faslane and Coulport, and Rosyth – Discharges of radioactive waste

Gaseous and liquid discharges (mainly tritium, carbon-14 and cobalt-60) are released into the atmosphere and most to the sea. Figure 5.2 shows the trends of discharges over time (2004-2016) for a number of the authorised/permitted radionuclides.

Gaseous tritium discharges from Aldermaston significantly declined between 2004 and 2006 (thereafter, similar over time). Other gaseous radionuclides discharged from the site were very low and reasonably constant with time. Gaseous volatile beta discharges increased in 2015 (81 per cent of the discharge limit) due to a change in operations on the site. There were no detected environmental effects (due to this increase). The Pangbourne pipeline (which previously discharged liquid waste to the River Thames at Pangbourne) closed in 2005. Consequently, liquid discharges of tritium, alpha emitting radionuclides and plutonium-241 decreased after that. At Devonport, liquid discharges generally decreased, whilst gaseous discharges were generally similar, during the period. Gaseous carbon-14 discharges were elevated in 2005-2006, 2009 and 2012 due to the periodic nature of routine submarine refit operations. Gaseous and liquid discharges at Faslane and Coulport, and Rosyth (liquid only) showed some minor changes and decreases over the period, and the discharges were very low.

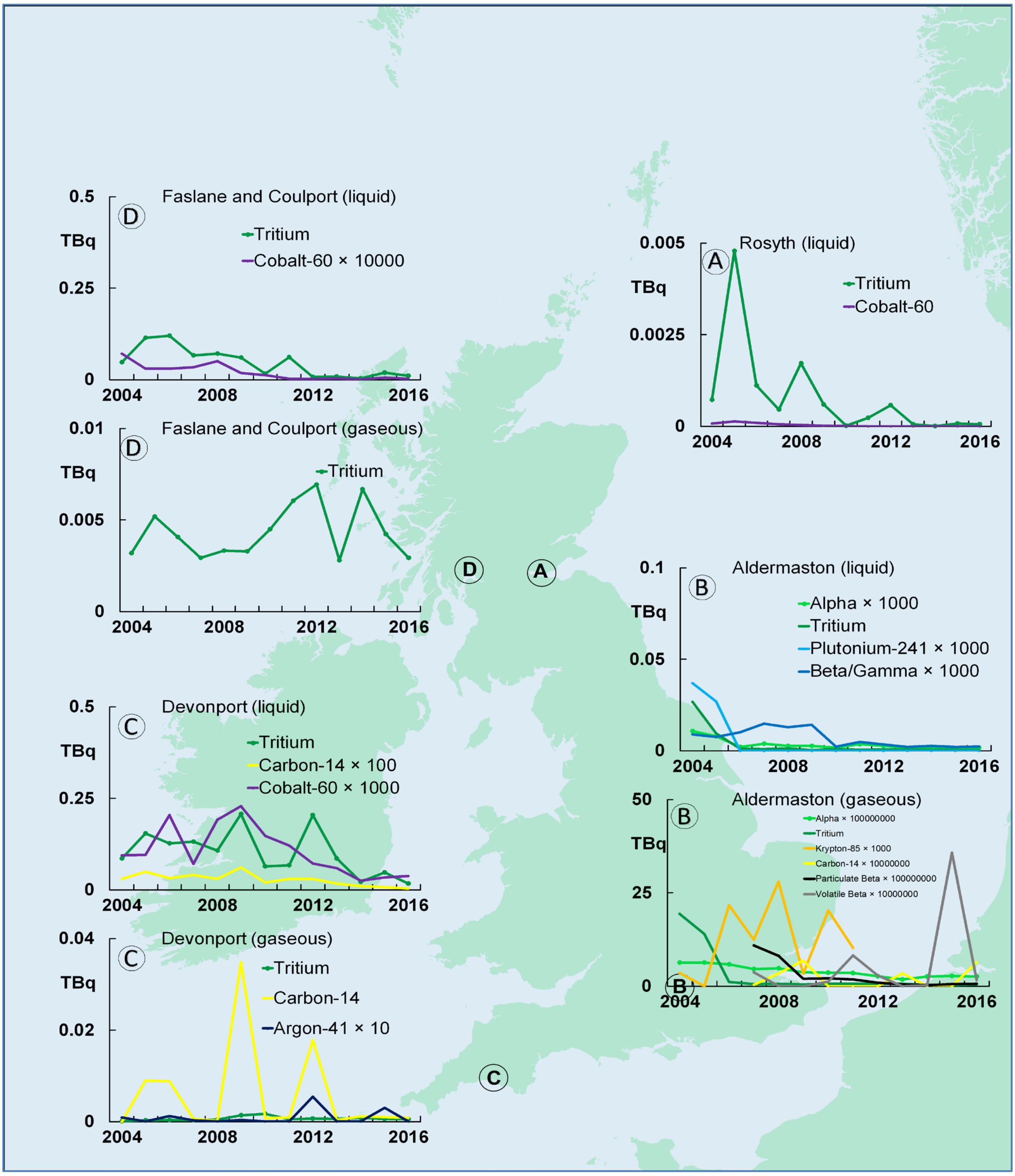

Figure 5.2 Permitted/authorised discharges of gaseous and liquid radioactive wastes, Aldermaston, Devonport, Faslane and Coulport, and Rosyth

5.3 Defence establishments –
Concentrations of radionuclides in food and the environment

The Atomic Weapons Establishment at Aldermaston provides and maintains fundamental components of the UK's nuclear deterrent on behalf of the Ministry of Defence. Gaseous and liquid discharges are released into the atmosphere and to the sewage works at Silchester and to Aldermaston Stream. The concentrations of all artificially detected radionuclides in the Thames catchment area were very low (or below the limit of detection). The gross alpha (and gross beta) activity concentrations were below the World Health Organisation's screening levels for drinking water over the whole period. Figure 5.3 provides some monitoring trends to assess the impact on the surrounding environment. Concentrations of plutonium radionuclides and americium-241 (alpha emitting radionuclides) in freshwater crayfish from Ufton Bridge to Theale also showed low levels. Concentrations of alpha emitting radionuclides in sediments at Aldermaston, Mapledurham and Pangbourne were shown to decrease initially. This corresponded with a reduction in liquid alpha emitting radionuclides from 2004. Any fluctuations in recent years, for both food and sediment, were most likely due to normal variations in the environment.

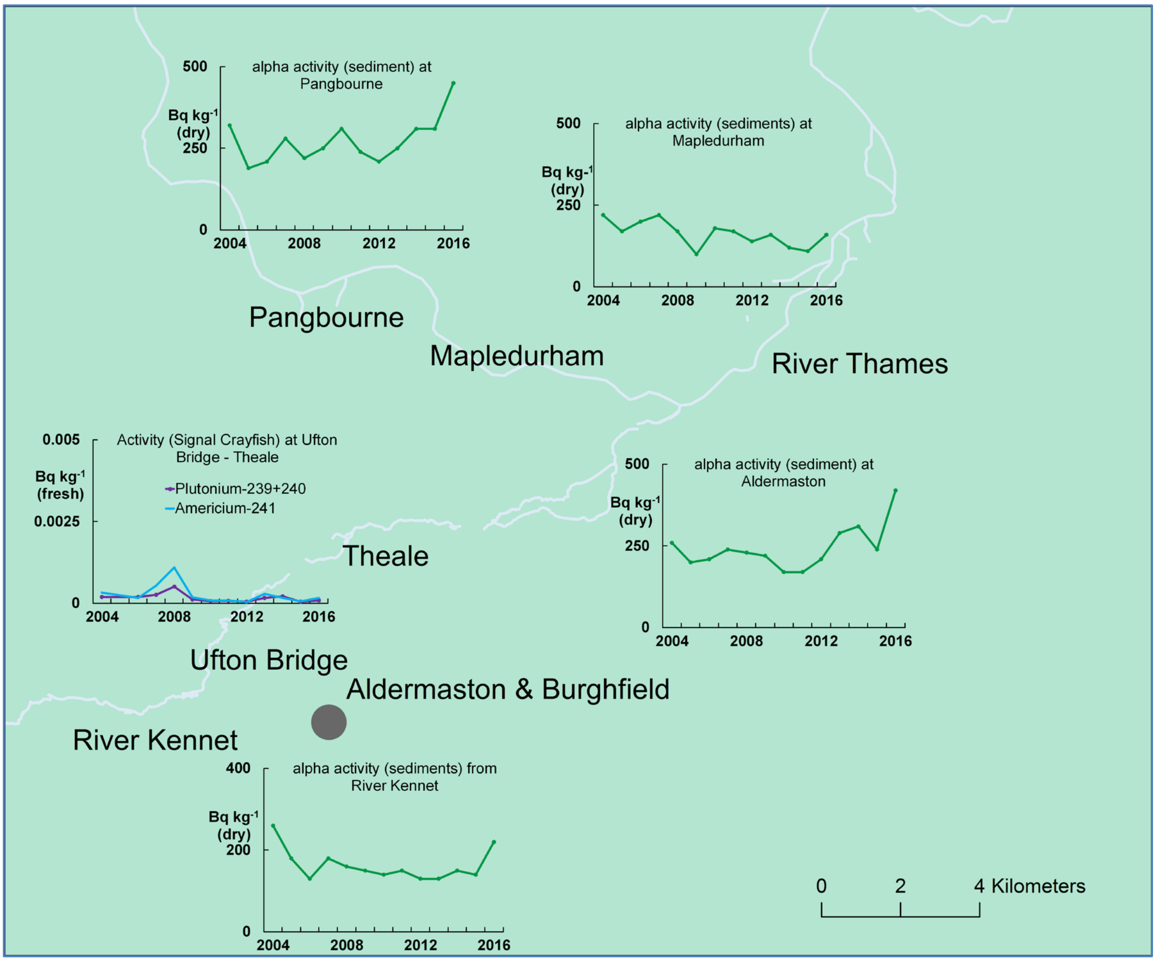

Figure 5.3 Monitoring of the environment from discharges of radioactive wastes, Aldermaston (2004-2016)

For other defence establishments, the majority of measurements of food and environmental samples were at or below the analytical limits of detection, which made it difficult to produce trend data from monitoring results.

5.4 Summary

The information presented in Table 5.1 gives an overview of trends associated with doses, discharges and environmental concentrations described in Section 5.

Table 5.1 Summary of trend data for defence sector (2004-2016)*

Trend data	Downwards	No change	Upwards	Overall
Gaseous discharges	1	2	0	Minority downward trend
Liquid discharges	4	0	0	Downward trend
Overall discharges	5	2	0	Majority downward trend
Food and the environment overall	2	1	2	No overall direction
Overall doses from gaseous and liquid discharges	0	2	2#	No overall direction
All doses were below the dose limit				

* Taken from the number of trend graphs for this sector presented in this report. This is a visual evaluation only.
# Increase mostly due to revised habits data

6. Radiochemical production

Key points

- All doses were less than the dose limit for members of the public of 1 mSv per year.
- Highest annual dose (from artificial radionuclides) was 0.029 mSv at Cardiff.
- Highest group doses continually decreased with time.
- All authorised discharges were well below the authorised limits.
- Concentrations on the land continued to be very low and concentrations in the sea declined following reduction in discharges.

This section looks at the time trends between 2004 and 2016 from the UK's radiochemical production sites. The trends show the public's exposure, discharges of radioactive waste and concentrations of radionuclides in food and the environment. The public's exposure[7] (dose) from radioactive waste discharges is assessed using radionuclide concentrations and gamma dose rates in the environment. GE Healthcare is a health science company operating in world-wide commercial healthcare and life science markets, with radiochemical facilities at Amersham and Cardiff. GE Healthcare Limited (Cardiff) ceased manufacturing a range of radio-labelled products containing tritium in 2009 and products containing carbon-14 in 2010. Furthermore, in 2015, GE Healthcare Limited partially surrendered the environmental permit for the Cardiff site and around 90 per cent of the footprint of the site was de-licensed, following decommissioning and clean-up of the wider Maynard Centre.

6.1 Public's exposure to radiation due to discharges of radioactive waste

Figure 6.1 shows the trends of doses of the public's exposure to radiation (2004-2016) due to the effects of gaseous and liquid waste discharges. For locations near both sites, the doses were all much less than the UK and European limit for members of the public of 1 mSv per year.

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[7] The monitoring results are interpreted in terms of radiation exposures of the public, commonly termed 'doses'. These people are a group, who generally eat large quantities of locally grown food (high-rate consumers) or who spend long periods of time in areas in the locations being assessed. This dose, referred to in Sections 2-6, is an exposure that uses a different assessment method to that of *total dose* in Section 1.

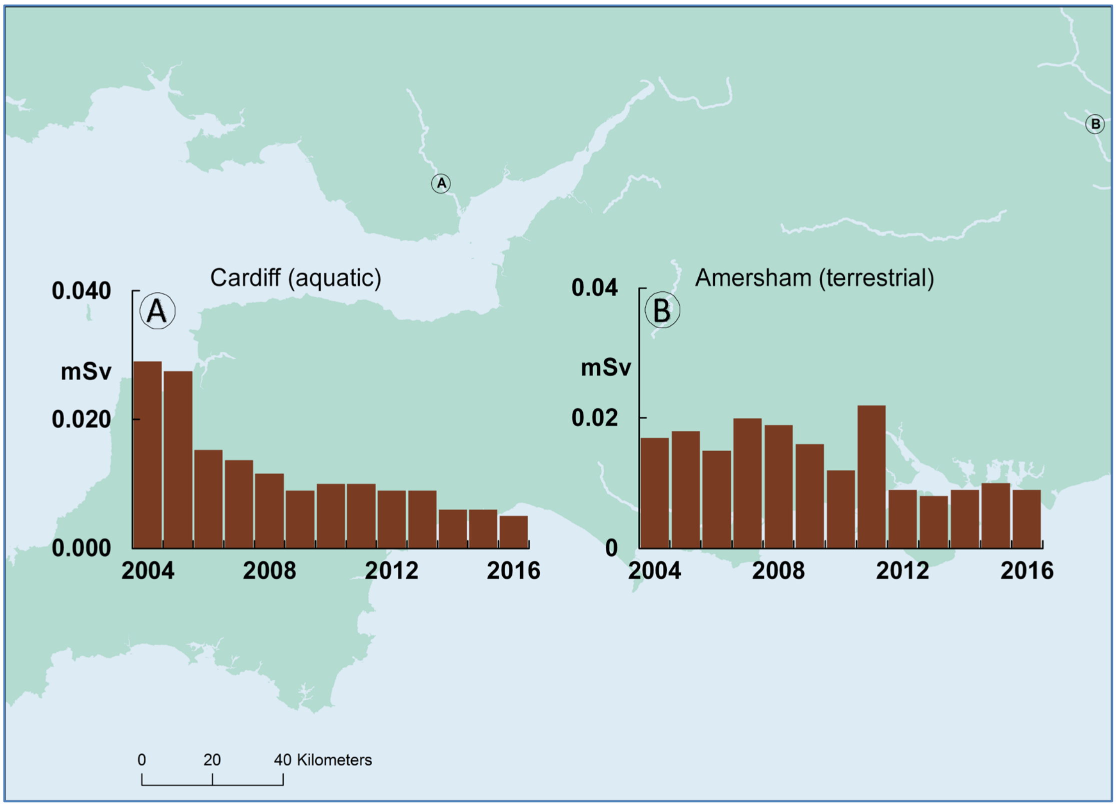

Figure 6.1 Individual radiation exposures to most exposed groups from artificial radionuclides, Amersham and Cardiff (2004-2016)

The annual dose was highest at Cardiff from consuming fish and shellfish (combined with external exposure), and ranged between less than 0.005 and 0.029 mSv over the time period, with a clear and gradual decline with time. The reduction in the doses for the Cardiff site was largely due to the continuing reductions in concentrations of tritium (and carbon-14) in seafood, with the most significant reduction of tritium in seafood occurring in 2006.

At the Amersham site, the annual dose to people who ate locally grown food (combined with a contribution of discharged radionuclides in air) ranged between 0.008 and 0.022 mSv over the time period. The changes in trends at this site were mostly due to variations in the estimated air exposure from inhaling gases and emitted radiation of the gaseous discharges, which much lower atmospheric discharges of radon-222 between 2012 and 2016.

6.2 Amersham –

Discharges of radioactive waste and concentrations of radionuclides in food and the environment

Gaseous and liquid discharges from Amersham are released into the atmosphere and to sewers serving the Maple Lodge sewage works. Releases subsequently enter the Grand Union Canal and the River Colne. Figure 6.2 shows the trends of discharges over time (2004-2016) for a number of the permitted radionuclides.

The gaseous discharges were low over the period. Discharges of iodine-125 declined over the period, whilst radon-222 and alpha also generally declined (but with variations between years). Limits for sulphur-35 and iodine-125 were removed in 2012. There was an overall reduction in liquid discharges of tritium and iodine-125, and caesium-137 and alpha (from the peaks in earlier years).

Figure 6.2 also provides monitoring trends of sulphur-35 and caesium-137 in food and in grass and sediment from three locations, to assess the impact on the surrounding environment. Caesium-137 concentrations in sediment were low over the period and changes between years were attributed to natural variation. Caesium-137 concentrations upstream of the outfall generally declined over the period and the outfall concentrations were lower than further upstream. Caesium-137 activity includes that from fallout from weapons testing and Chernobyl. The trend for sulphur-35 concentrations in grass generally followed the pattern of gaseous discharges (between 2004-2012), although the activity concentrations were very low. In spinach, sulphur-35 concentrations were significantly less than in grass.

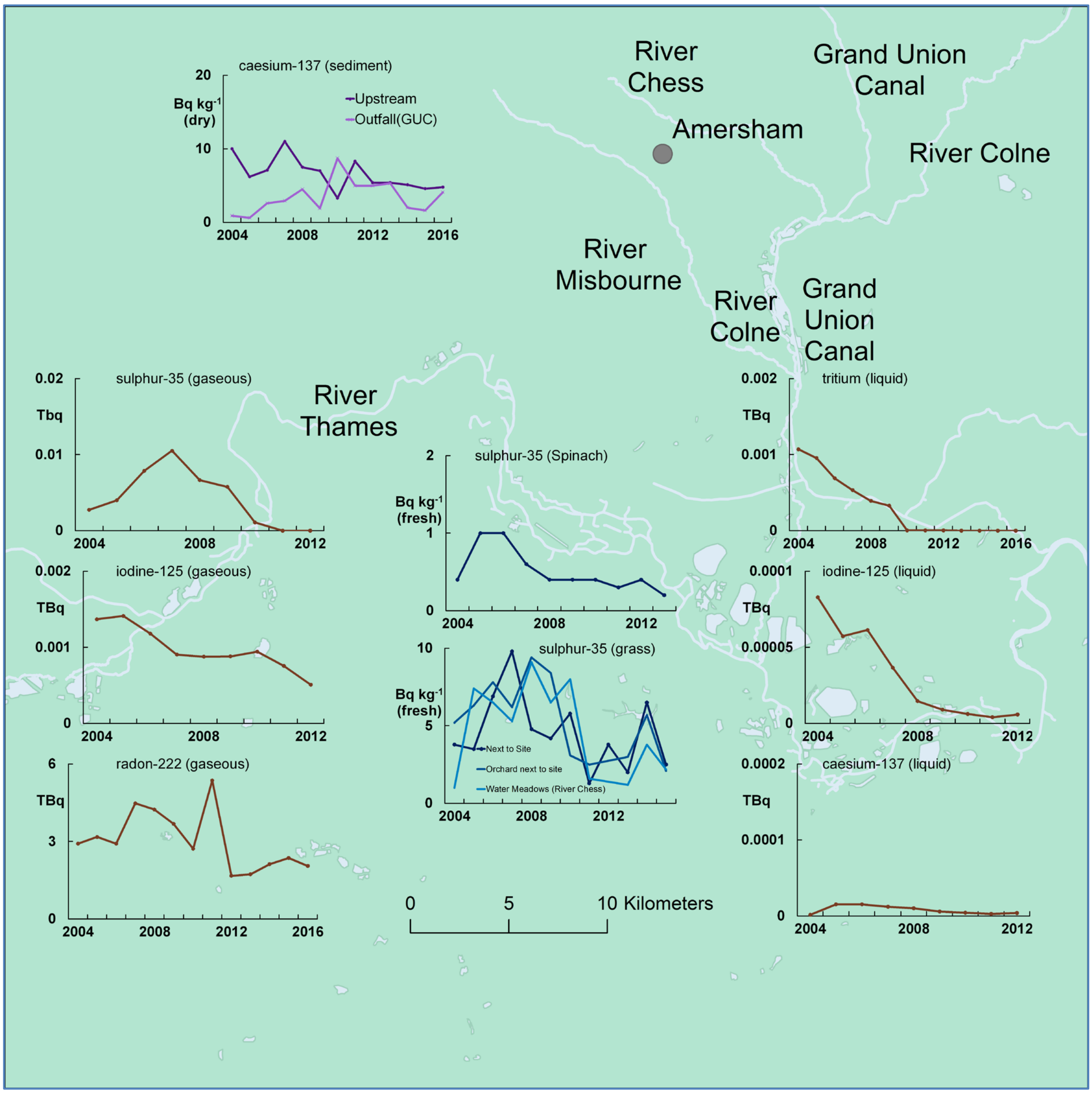

Figure 6.2 Authorised discharges of gaseous and liquid radioactive wastes and monitoring of the environment, Amersham (2004-2016)

6.3 Cardiff –

Discharges of radioactive waste and concentrations of radionuclides in food and the environment

The gaseous discharges into the atmosphere from the Maynard Centre. Liquid waste to the Ystradyfodwg and Pontypridd (YP) public sewer ceased in 2015, because of the partial surrender of the permit. Figure 6.3 shows the trends of discharges over time (2004-2016) for a number of the permitted radionuclides. Gaseous and liquid discharges of all radionuclides declined over the period.

Figure 6.3 also provides monitoring trends of tritium, carbon-14 and caesium-137 in seafood and from three locations, to assess the impact on the surrounding environment. Overall, the trend was for concentrations of tritium in fish, molluscs and sediments to significantly decline over the period, in line with reductions and cessation of liquid discharges. This also included the low tritium concentrations being detected in sediment from the Glamorganshire canal, which is not used as a source of water for public water supply.

Over the period, concentrations of carbon-14 and caesium-137 in seafood and sediments were low and relatively constant. Carbon-14 concentrations detected in sediment from the Glamorganshire canal declined after 2005. Changes between years were most likely due to normal changes in the environment, with caesium-137 coming from other nuclear establishments and fallout from weapons testing and Chernobyl.

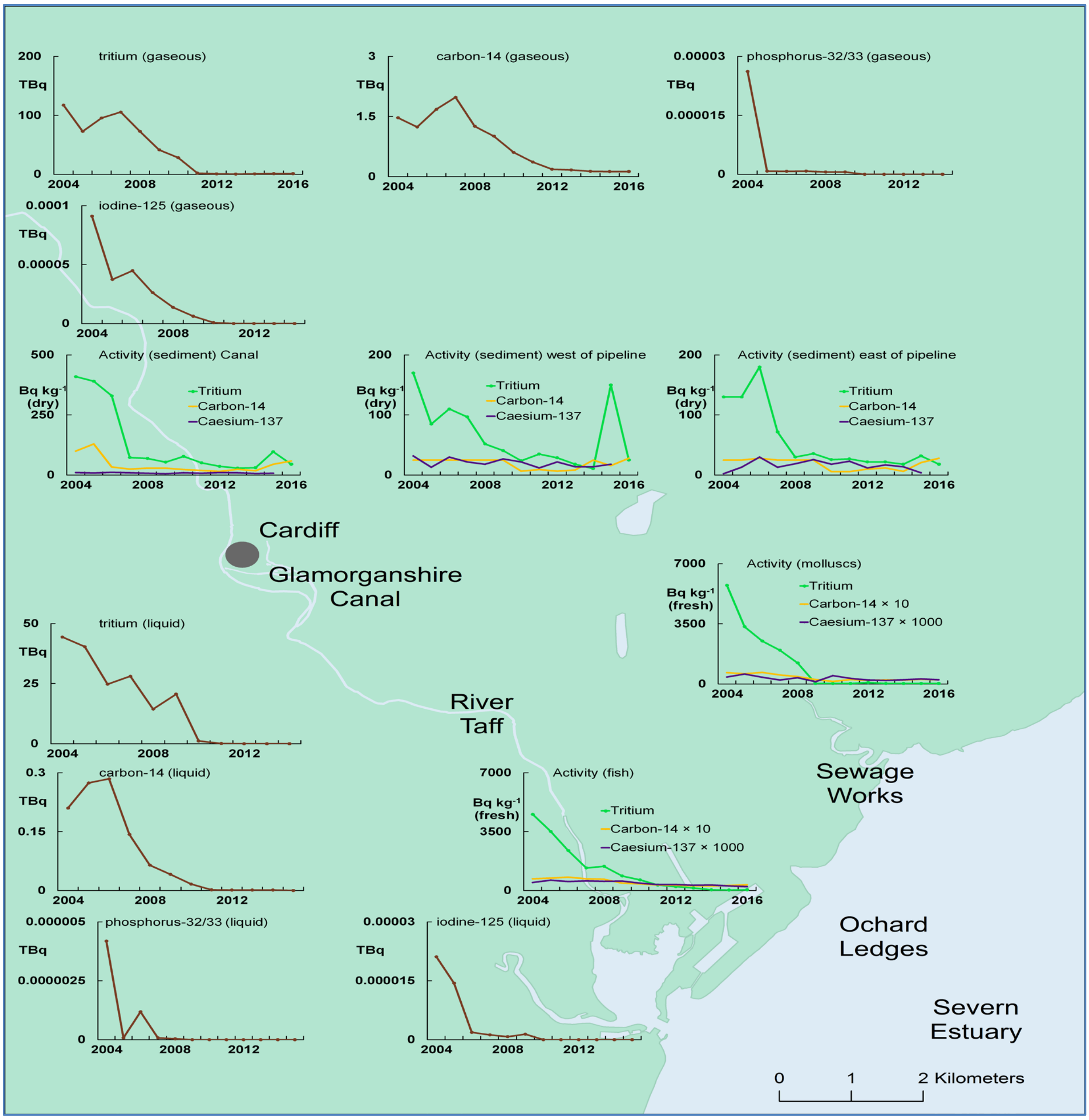

Figure 6.3 Discharges of gaseous and liquid radioactive wastes and monitoring of the environment, Cardiff (2004-2016)

6.4 Summary

The information presented in Table 6.1 gives an overview of trends associated with doses, discharges and environmental concentrations described in Section 6.

Table 6.1 Summary of trend data for radiochemical production (2004-2016)*

Trend data	Downwards	No change	Upwards	Overall
Gaseous discharges	7	0	0	Downward trend
Liquid discharges	7	0	0	Downward trend
Overall discharges	14	0	0	Downward trend
Food and the environment overall	6	2	0	Majority downward trend
Overall doses from gaseous and liquid discharges	2	0	0	Downward trend
All doses were below the dose limit				

***** Taken from the number of trend graphs for this sector presented in this report. This is a visual evaluation only.

7. Summary and Conclusions

Information presented in Table 7.1 gives an overview of trends associated with discharges and environmental concentrations for each of the five nuclear sectors described in Sections 2-6.

Key points

- Discharge trends were downward in all five sectors.
- Trends of radionuclide concentrations in food and the environment were downward in four of the five sectors with no clear trends in the other sectors.
- Dose trends were downward in four of the five sectors.
- Doses at all sites were less than the dose limit, and in most cases, much less.

It was previously noted, over the period 2004–2008, discharges and environmental concentrations of radionuclides both showed a distinct decline in three of the five sectors (Environment Agency, FSA, NIEA and SEPA, 2010). However, during 2004–2008, environmental concentrations responded relatively slowly to these reductions, part due to the legacy of higher environmental concentrations of radionuclides from past higher discharges. Over the period 2004–2016 both discharges and environmental concentrations of radionuclides have fallen further.

Dose estimates are dependent on a number of inputs, including the method of assessment, concentrations of radionuclides in food and the environment, measurements of dose rates and data on human activities. All these are subject to variation and changes from year to year which can affect the dose assessment outcomes and produce step changes or false trends over time. Nevertheless, there is significant evidence to confirm that doses have declined overall, over the period 2004–2016.

Additional information on past discharges, radionuclide concentrations and doses for each year can be found in the RIFE reports.

Table 7.1 Overall summary for nuclear sectors (2004-2016)*

Sector		2004-2016 trend
All sectors	Key Marine Environmental Indicators	Majority downward trend
	Doses to consumers of drinking water	No overall direction
	Doses	Majority downward trend
Nuclear fuel processing	Discharges	Majority downward trend
	Food and environmental concentrations	Majority downward trend
	Doses	Majority downward trend
Research sites	Discharges	Majority downward trend
	Food and environmental concentrations	Minority downward trend
	Doses	Minority downward trend
Power production	Discharges	Majority downward trend
	Food and environmental concentrations	Majority downward trend
	Doses	Majority downward trend
Defence sites	Discharges	Majority downward trend
	Food and environmental concentrations	No overall direction
	Doses	No overall direction[#]
Radiochemical production	Discharges	Downward trend
	Food and environmental concentrations	Majority downward trend
	Doses	Downward trend

* Taken from the trends presented in this report. This is a visual evaluation only.
[#] Changes occurred due to revised habits data

Appendix 1 *Bibliography*

Environment Agency, FSA, NIEA and SEPA, 2010. Summary of Radioactivity in Food and the Environment 2004-2008. Environment Agency, FSA, NIEA and SEPA, Bristol, London, Belfast and Stirling.

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

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

Oatway, W.B., Jones, A.L., Holmes, S., Watson, S.J. and Cabianca, T., 2016. Ionising radiation exposure of the UK population: 2010 Review. PHE-CRCE-026. PHE, Chilton.

Appendix 2 *Acronyms*

AGR	Advanced Gas-cooled Reactor
BAT	Best Available Technology or Techniques
BEIS	Department of Business, Energy and Industrial Strategy
DAERA	Department of Agriculture Environment and Rural Affairs
Defra	Department for Environment, Food and Rural Affairs
EU	European Union
FSA	Food Standards Agency
FSS	Food Standards Scotland
GE	General Electric
KMEI	Key Marine Environmental Indicators
LLWR	Low Level Waste Repository
Magnox	Magnox Reprocessing Plant
NIEA	Northern Ireland Environment Agency
NRW	Natural Resources Wales
OSPAR	Oslo and Paris Convention
PHE	Public Health England
PWR	Pressurised Water Reactor
RIFE	Radioactivity in Food and the Environment
SEPA	Scottish Environment Protection Agency
UUK	Urenco UK
YP	Ystradyfodwg and Pontypridd

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