RIFE - 18

Radioactivity in Food and the Environment, 2012

Environment Agency

Food Standards Agency food.gov.uk

NIEA Northern Ireland Environment Agency www.ni-environment.gov.uk

SEPA Scottish Environment Protection Agency

2013

ENVIRONMENT AGENCY
FOOD STANDARDS AGENCY
NORTHERN IRELAND ENVIRONMENT AGENCY
SCOTTISH ENVIRONMENT PROTECTION AGENCY

Radioactivity in Food and the Environment, 2012

RIFE – 18

October 2013

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

Cefas

Front cover photograph: White Sands at Torness, East Lothian, Scotland. Published by kind permission of SEPA.

Inside cover photograph: Reproduced with kind permission of the Health Protection Agency

© Crown Copyright, 2013

Requests for the reproduction of materials contained in this report and for other information should be addressed to:

- in England and Wales,
  Radiological Monitoring and Assessment Team of the Environment Agency (enquiries@environment-agency.gov.uk) or the Chemical Safety Division of the Food Standards Agency (radiation@foodstandards.gsi.gov.uk)
- in Scotland,
  the Radioactive Substances Unit of SEPA (radiologicalmonitoring@sepa.org.uk) and
- in Northern Ireland,
  the Industrial Pollution and Radiochemical Inspectorate of NIEA (IPRI@doeni.gov.uk)

Contents

Page

LIST OF TABLES *5*

LIST OF FIGURES *7*

PREFACE *9*

TECHNICAL SUMMARY *10*

1. Introduction 17
1.1 Purpose and scope of the monitoring programmes 17
1.2 Summary of doses 18
1.2.1 The assessment process 18
1.2.2 *Total dose* results for 2012 18
1.2.3 *Total dose* trends 19
1.2.4 Source specific dose results for 2012 19
1.2.5 Protecting the environment 19
1.2.6 Food irradiation 22
1.3 Sources of radiation exposure 23
1.3.1 Radioactive waste disposal from nuclear licensed sites 23
1.3.2 International agreements, the UK Discharge Strategy and new nuclear power stations 25
1.3.3 Managing radioactive liabilities in the UK 27
1.3.4 Solid radioactive waste disposal at sea 28
1.3.5 Other sources of radioactivity 28

2. Nuclear fuel production and reprocessing 37
2.1 Capenhurst, Cheshire 38
2.2 Springfields, Lancashire 39
2.3 Sellafield, Cumbria 43
2.3.1 Doses to the public 43
2.3.2 Gaseous discharges 48
2.3.3 Liquid discharges 49
2.3.4 Monitoring of unusual pathways 63
2.4 Windscale, Cumbria 63

3. Research establishments 101
3.1 Culham, Oxfordshire 101
3.2 Dounreay, Highland 102
3.3 Harwell, Oxfordshire 105
3.4 Winfrith, Dorset 106
3.5 Imperial College Reactor Centre, Ascot, Berkshire 108

4. Nuclear power stations 117
4.1 Berkeley, Gloucestershire and Oldbury, South Gloucestershire 119
4.2 Bradwell, Essex 122
4.3 Dungeness, Kent 123
4.4 Hartlepool, County Durham 123
4.5 Heysham, Lancashire 125
4.6 Hinkley Point, Somerset 125
4.7 Sizewell, Suffolk 127
4.8 Chapelcross, Dumfries and Galloway 128
4.9 Hunterston, North Ayrshire 129
4.10 Torness, East Lothian 130
4.11 Trawsfynydd, Gwynedd 131
4.12 Wylfa, Isle of Anglesey 132

5. Defence establishments ... 161
5.1 Aldermaston, Berkshire ... 161
5.2 Barrow, Cumbria ... 163
5.3 Derby, Derbyshire ... 163
5.4 Devonport, Devon ... 163
5.5 Faslane and Coulport, Argyll and Bute ... 165
5.6 Holy Loch, Argyll and Bute ... 165
5.7 Rosyth, Fife ... 165
5.8 Vulcan NRTE, Highland ... 166

6. Radiochemical production ... 175
6.1 Grove Centre, Amersham, Buckinghamshire ... 175
6.2 Maynard Centre, Cardiff ... 176

7. Industrial and landfill sites ... 185
7.1 Low Level Waste Repository near Drigg, Cumbria ... 185
7.2 Other landfill sites ... 186
7.3 Metals Recycling Facility, Lillyhall, Cumbria ... 187
7.4 Phosphate processing, Whitehaven, Cumbria ... 188
7.5 Aberdeen ... 188
7.6 Dalgety Bay, Fife ... 189
7.7 Other non-nuclear sites ... 191

8. Overseas incidents ... 199
8.1 Chernobyl (1986) ... 199
8.2 Fukushima Dai-ichi (2011) ... 200
8.3 General monitoring at importation points of entry to the UK ... 201

9. Regional monitoring ... 203
9.1 Channel Islands ... 203
9.2 Isle of Man ... 203
9.3 Northern Ireland ... 204
9.4 General diet ... 205
9.5 Milk ... 205
9.6 Crops ... 205
9.7 Airborne particulate, rain, freshwater and groundwater ... 205
9.8 Seawater surveys ... 206

10. References ... 227

Appendix 1. Sampling, measurement, presentation and assessment methods and data ... 239

Appendix 2. Disposals of radioactive waste ... 240

Appendix 3. Abbreviations and glossary ... 250

Appendix 4. Research in support of the monitoring programmes ... 253

Appendix 5. Disposal of dredge material from Silloth Docks, Cumbria ... 254

List of Tables

Abbreviated Title	Number	Page
Technical summary		
UK *total dose* from all sources	S	12
Introduction		
Direct radiation from nuclear licensed sites	1.1	30
UK *total dose* from all sources - details	1.2	31
Trends in *total dose*	1.3	33
UK source specific doses	1.4	34
Nuclear fuel production and reprocessing		
Radiation exposure - Capenhurst and Springfields	2.1	64
Capenhurst	2.2	65
Springfields	2.3	67
Terrestrial foodstuffs near Sellafield	2.4	71
Sellafield - fish beta/gamma	2.5	73
Sellafield - shellfish beta/gamma	2.6	77
Sellafield - seafood transuranics	2.7	81
Sellafield - marine sediment	2.8	85
Sellafield - gamma radiation dose rates	2.9	88
Sellafield - beta radiation dose rates on fishing gear	2.10	92
Sellafield - beta radiation dose rates on sediment	2.11	92
Sellafield - aquatic plants	2.12	93
Sellafield - sea to land transfer via seaweed use	2.13	96
Terrestrial foodstuffs near Ravenglass	2.14	97
Sellafield - surface water	2.15	98
Sellafield - road drains	2.16	98
Radiation exposure - Sellafield, Irish Sea groups	2.17	98
Radiation exposure - Sellafield	2.18	99
Research establishments		
Radiation exposure - research	3.1	109
Culham	3.2	109
Dounreay	3.3	110
Harwell	3.4	113
Winfrith	3.5	114
Nuclear power stations		
Radiation exposure - power stations	4.1	134
Berkeley and Oldbury	4.2	136
Bradwell	4.3	137
Dungeness	4.4	139
Hartlepool	4.5	141
Heysham	4.6	143
Hinkley Point	4.7	145
Sizewell	4.8	147
Chapelcross	4.9	148
Hunterston	4.10	151
Torness	4.11	154
Trawsfynydd	4.12	157
Wylfa	4.13	159
Defence establishments		
Radiation exposure - defence	5.1	167
Aldermaston	5.2	168
Other defence sites	5.3	171

Radiochemical production
Radiation exposure - radiochemical 6.1 181
Amersham 6.2 182
Cardiff 6.3 183

Industrial and landfill sites
Radiation exposure - industrial and landfill 7.1 192
Low Level Waste Repository near Drigg 7.2 193
Landfill Scotland 7.3 194
Landfill England and Wales 7.4 194
Whitehaven 7.5 195
Non-nuclear gaseous discharges 7.6 195
Non-nuclear liquid discharges 7.7 196
River Clyde 7.8 197

Overseas incidents
Caesium in freshwater fish 8.1 202

Regional monitoring
Channel Islands 9.1 211
Dairies 9.2 213
Regional crops 9.3 214
Isle of Man 9.4 216
Northern Ireland 9.5 217
Canteen meals 9.6 220
Air and rain 9.7 220
Freshwater Scotland 9.8 221
Freshwater England and Wales 9.9 222
Freshwater Northern Ireland 9.10 223
Radiation exposure - drinking water 9.11 223
Seawater 9.12 224
Sediments 9.13 226

List of Figures

Abbreviated Title	Number	Page
Technical summary		
UK *total dose* from all sources	S	11
Introduction		
UK *total doses*	1.1	20
UK source specific doses	1.2	21
UK sources of waste	1.3	24
Nuclear fuel production and reprocessing		
Capenhurst - technetium-99 in grass	2.1	39
Springfields - monitoring locations	2.2	40
Springfields - *total doses* and external gamma doses	2.3	41
Springfields - discharge and monitoring trends	2.4	42
Sellafield - *total doses* from all sources	2.5	45
Sellafield - *total doses* (gaseous and direct radiation sources)	2.6	46
Sellafield - radioactivity in milk	2.7	49
Sellafield - technetium-99 in seaweed	2.8	50
Sellafield - monitoring locations in Cumbria	2.9	51
Sellafield - monitoring locations	2.10	52
Sellafield - carbon-14 in seafood	2.11	53
Sellafield - cobalt-60 in seafood	2.12	53
Sellafield - technetium-99 in seafood	2.13	53
Sellafield - caesium-137 in seafood	2.14	54
Sellafield - plutonium-239+240 in seafood	2.15	54
Sellafield - americium-241 in seafood	2.16	54
Sellafield - caesium-137 in brown trout	2.17	55
Sellafield - caesium-137 in mud	2.18	56
Sellafield - plutonium in mud	2.19	57
Sellafield - cobalt-60 in mud	2.20	57
Sellafield - americium-241 in mud	2.21	57
Sellafield - Irish Sea sediment concentrations	2.22	58
Sellafield - Irish Sea - dose rates	2.23	60
Research establishments		
Thames sites - monitoring locations	3.1	103
Dounreay - monitoring locations and seaweed	3.2	103
Dounreay - monitoring locations (local)	3.3	104
Harwell - liquid discharges	3.4	107
Winfrith - monitoring locations	3.5	107
Winfrith – liquid discharges	3.6	108
Nuclear power stations		
Power Stations - *total doses* from all sources	4.1	120
Caesium-137 in marine sediments	4.2	121
Trawsfynydd - caesium-137 in sediments	4.3	132
Defence		
Aldermaston - liquid discharges	5.1	162
Devonport - liquid discharges	5.2	164
Radiochemical production		
Cardiff - monitoring locations	6.1	177
Cardiff - *total doses* from all sites in Severn Estuary	6.2	178
Cardiff - tritium in sediments	6.3	179
Cardiff - tritium in seafood	6.4	180
Cardiff - carbon-14 in seafood	6.5	180

Industrial and landfill sites
Landfill monitoring locations 7.1 187
Whitehaven - polonium-210 in winkles 7.2 189
Whitehaven - polonium-210 in crabs 7.3 189
Whitehaven - *total doses* to seafood consumers 7.4 190

Overseas incidents
Chernobyl - doses from sheep meat consumption 8.1 200
Chernobyl - caesium-137 in freshwater fish 8.2 201

Regional monitoring
Northern Ireland - monitoring locations 9.1 204
Drinking water monitoring locations 9.2 206
North Sea - caesium-137 in seawater 9.3 207
Western English Channel - caesium-137 in seawater 9.4 207
North Sea - tritium in seawater 9.5 207
Bristol Channel - tritium in seawater 9.6 207
Western English Channel - tritium in seawater 9.7 208
Caesium-137 in seawater 9.8 209

Preface

As for previous years, this report brings together the nationwide monitoring programmes of the environment agencies and the Food Standards Agency. These monitoring programmes are independent of, and also used as a check on, the site operators' programmes and continue to show that *total doses* to the public, from both authorised/permitted discharges and direct radiation around the nuclear sites, remain low.

In our report for 2011, we described monitoring work to assess the consequences in the UK from the effects of the Fukushima Dai-ichi accident. The effects of this accident in the UK were very small and short lived and so for 2012, the focus of our monitoring programmes has continued to assess the effects of current and legacy sources in the UK. Detailed monitoring data continued to be sent from Japan to the UK authorities during 2012. Food import controls were revised to reflect the evidence on the foods and regions in Japan affected by radioactive contamination. Monitoring at UK ports of entry showed little or no radioactivity in food.

We have continued with our proportionate monitoring following radioactive particle finds at Sellafield, Dounreay and Dalgety Bay, Firth of Forth. In 2012, Dalgety Bay was placed under a FEPA (Food and Environment Protection Act, 1985) control order to prohibit the removal of foods from the beach. The next steps are to develop remediation options which are being taken forward in 2013.

In 2011, the Food Standards Agency reassessed the risks to consumers from eating sheep meat from the remaining UK areas affected by Chernobyl. The assessment showed that the risks are now very low and consequently all controls were lifted in 2012. The Food Standards Agency continued to review other aspects of its monitoring programme and completed a consultation on possible changes to the programme in 2013. A new programme will now be introduced in 2014, which is optimised and proportionate to the risks.

Technical Summary

The technical summary is divided into sections to highlight the main topics within the report. These are:

- Radiation exposures (doses) to people living around UK nuclear licensed sites
- Radioactivity concentrations in samples collected around UK nuclear licensed sites
- External dose rates as a result of exposure to radiation from sediments, etc.
- UK site incidents and non-routine surveys
- Radiation exposures and radioactivity concentrations at other locations remote from UK nuclear licensed sites

Radiation exposure around UK nuclear licensed sites

In this report we make an assessment of doses to the public near nuclear licensed sites using the results of monitoring of radioactivity in food and the environment, supplemented by modelling where appropriate. The assessments use radionuclide concentrations, dose rates and information on the habits of people living near the sites. Changes in the doses received by people can occur from year to year and are mostly caused by variations in radionuclide concentrations and external dose rates. However, in some years doses are affected by changes in people's habits, in particular the food they eat, which is reported in habits surveys. The dose quantity presented in this summary is known as the *'total dose'* and is made up of contributions from all sources (of radioactivity from man-made processes). Source specific dose assessments are also performed in some cases to provide additional information and as a check on the *total dose* assessment method. *Total dose* is confirmed as a robust measure of exposure.

Figure S and Table S show the assessed *total doses* due to the combined effects of authorised/permitted waste discharges and direct radiation for those people most exposed to radiation* near all major nuclear licensed sites in the UK. In 2012, radiation doses from authorised/permitted releases of radioactivity, to adults and children living around nuclear licensed sites, remained well below the UK national and European limit of 1 millisievert (mSv, a measure of dose) per year (see Appendix 3 for explanation of dose units).

For 2012, those sites where the public received the highest doses were Amersham and Sellafield with doses of 0.22 and 0.30 mSv, respectively. The dose at Sellafield included a contribution from the past effects of discharges from the former phosphate processing plant at Whitehaven and the Low-Level Waste Repository (LLWR) near Drigg. The contribution from the LLWR is very small. The dose received near Amersham was dominated by direct radiation from sources on the site. In comparison, the highest doses in 2011 were Amersham, Sellafield and Springfields. The decrease in the ranking of the Springfields site was established following a detailed survey of exposure pathways in 2012.

Permitted discharges were the source of most of the public dose at the Sellafield site. A small number of people in Cumbria who were high-rate consumers of molluscs represented those who received the highest dose of radiation there. Their *total dose* was estimated to be 0.30 mSv in 2012. The contributions to the dose were made up of 0.082 mSv from Sellafield and 0.22 mSv from the phosphate plant at Whitehaven. The *total dose* also included a contribution from external radiation. In 2011, a lower dose of 0.18 mSv was estimated and the people representing those most exposed were high rate consumers of samphire and seaweed. The increase in dose in 2012 was due to increases in concentrations of radionuclides and also in consumption rates of local seafood. The dose from Sellafield was estimated to be 0.082 mSv in 2012, a small increase from the 0.068 mSv reported in 2011. Most of the dose due to Sellafield was from the accumulation of caesium-137, plutonium isotopes and americium-241 in seafood and the environment from historical liquid discharges.

As a result of decreasing discharges of technetium-99 from Sellafield, doses from this radionuclide have been falling for several years. In 2012, technetium-99 in seafood contributed 0.001 mSv (about 1 per cent) to the 0.082 mSv dose. The effects of iodine-129 discharges have also been determined and this radionuclide was estimated to have contributed 0.012 mSv in 2012, or about 15% of the dose due to Sellafield discharges. However, this estimate was based on results at the limit of detection of iodine-129 and is therefore a cautious overestimate of the dose actually received.

Most liquid radioactive discharges from Sellafield have decreased in recent years. Consequently, concentrations of most radionuclides in fish and shellfish were also reduced, or generally unchanged. The trend of generally reducing dose in recent years has also been affected by changes in consumption of local seafood.

As well as the radiation exposure from Sellafield discharges, the people who consumed seafood also received a dose

* *In this report doses to individuals are determined for those people most exposed to radiation. These results are for comparison with legal limits. The method of calculation involves an assessment for the 'average member of the critical group' or the 'representative person'. The terms 'average member of the critical group' and 'representative person' are both in use in radiological protection and are equivalent.'*

Figure S. *Total doses* in the UK due to radioactive waste discharges and direct radiation,2012
(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, 2012[a]

Establishment	Exposure, mSv[b] per year	Contributors[c]
Nuclear fuel production and processing		
Capenhurst	0.085	Direct radiation
Springfields	0.068	Gamma dose rate over sediment
Sellafield[d]	0.30	Crustaceans, fish, molluscs, ^{210}Po
Research establishments		
Dounreay	0.017	Milk, ^{90}Sr, ^{106}Ru, ^{129}I, ^{144}Ce, ^{241}Am
Harwell	0.018	Direct radiation
Winfrith	<0.005	Milk, ^{14}C, ^{137}Cs
Nuclear power stations		
Berkeley and Oldbury	0.014	Gamma dose rate over sediment
Bradwell	<0.005	Green vegetables, potatoes, root vegetables, ^{14}C
Chapelcross	0.011	Milk, ^{3}H, ^{14}C, ^{35}S, ^{90}Sr
Dungeness	0.015	Direct radiation
Hartlepool	0.015	Direct radiation, gamma dose rate over sediment
Heysham	0.025	Fish, gamma dose rate over sediment, molluscs, ^{137}Cs, $^{239/240}$Pu, ^{241}Am
Hinkley Point	0.011	Direct radiation
Hunterston	0.032	Direct radiation
Sizewell	0.021	Direct radiation
Torness	0.020	Direct radiation
Trawsfynydd	0.025	Direct radiation
Wylfa	0.006	Fish, gamma dose rate over sediment
Defence establishment		
Aldermaston and Burghfield	<0.005	Milk, ^{3}H, ^{137}Cs, ^{234}U
Barrow	0.057	Gamma dose rate over sediment
Derby	<0.005	Green vegetables, ^{131}I, ^{241}Am
Devonport	<0.005	Gamma dose rate over sediment
Faslane	<0.005	Cattle meat, ^{137}Cs, ^{241}Am
Rosyth	<0.005	Fish, ^{241}Am
Radiochemical production		
Amersham	0.22	Direct radiation
Cardiff	0.005	Gamma dose rate over sediment
Industrial and landfill		
LLWR near Drigg[d]	0.30	Crustaceans, fish, molluscs, ^{210}Po
Whitehaven[d]	0.30	Crustaceans, fish, molluscs, ^{210}Po

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

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

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

[d] *The doses from man-made and naturally occurring radionuclides were 0.082 and 0.22 mSv respectively. The source of man-made radionuclides was Sellafield; naturally occurring ones were from the phosphate processing works near Sellafield at Whitehaven. Minor discharges of radionuclides were also made from the LLWR near Drigg site into the same area*

of 0.22 mSv in 2012 from the legacy of past discharges of 'Technologically enhanced Naturally-Occurring Radioactive Material' (TNORM) from the phosphate processing works at Whitehaven. This TNORM is also described elsewhere in this Section (see Non-nuclear sites). At Whitehaven, it is now difficult to distinguish between the total naturally-occurring radionuclide concentrations and the range of concentrations normally expected from natural background. However, using an approach based on average concentrations, small increases of some naturally-occurring radionuclides (in particular polonium-210) are observed above expected concentrations from naturally sourced radioactivity. The dose from naturally-occurring radionuclides in 2012 of 0.22 mSv was higher than the dose of 0.11 mSv in 2011. The increase was largely due to (i) an increase in the polonium-210 concentration in crustaceans and (ii) an increase in the consumption rate of crustaceans by the group representing those most exposed.

The highest dose at Sellafield was mostly due to historical liquid discharges. The maximum dose at Sellafield for those people most affected by pathways related to gaseous discharge and direct radiation sources was 0.010 mSv in 2012, and unchanged from 2011. The people most exposed in 2012 were infants who were high-rate consumers of vegetables.

The next highest dose due to waste discharges was received by people living on houseboats in the Ribble Estuary (near Springfields). In 2012, their dose was 0.068 mSv. Most of this exposure was due to external dose from radionuclides from Sellafield deposited in intertidal sediments in the Ribble Estuary. Their dose in 2011 was 0.13 mSv and the decrease was a consequence of a change in the method and data for dose assessment. A similar dose was found for houseboat occupancy near the Barrow site in Cumbria.

In Scotland, the people who received the highest dose from authorised releases of radioactivity were those who consumed fish and shellfish on the Dumfries and Galloway coast. It is estimated that they received 0.046 mSv in 2012. Most of this dose was due to the effects of past discharges from the Sellafield site.

Relatively high concentrations of tritium have previously been found in food and the environment near GE Healthcare Limited's Maynard Centre, at Cardiff, where radiochemicals for life science research were produced until 2010. In 2012, the people most exposed received an estimated dose of 0.005 mSv. Their dose in 2011 was similar. The dose is now mostly due to external radiation that was not derived from operations at the Maynard Centre. Eating fish from the Severn Estuary that contained tritium and carbon-14 also made a small contribution to the dose. In line with decreased discharges, doses at this site have been falling since 2000.

Habits surveys near UK nuclear licensed sites

In 2012, the regular programmes of habits surveys around nuclear licensed sites continued. These give site-specific information on diets and occupancy habits of people near nuclear licensed sites. Surveys were carried out at Barrow, the LLWR near Drigg, Springfields and Sellafield in England, and at Dumfries and Galloway and Hunterston in Scotland. The findings were used to confirm the adequacy of current monitoring programmes or strengthen and update them with a better representation of relevant pathways, and to improve the assessment of doses to members of the public near nuclear licensed sites.

Radioactivity concentrations in samples collected around UK nuclear licensed sites

This section summarises any changes in concentrations of radioactivity in food or the environment, given in becquerels per kilogramme (Bq kg^{-1}) or becquerels per litre (Bq l^{-1}).

A revised UK Radioactive Discharge Strategy was published in 2009, extending and strengthening the scope of the earlier Strategy published in 2002. Both describe how the UK will implement the commitments in the OSPAR Radioactive Substances Strategy on radioactive discharges to the marine environment of the North-East Atlantic. One of the aims of the UK Strategy is to progressively and substantially reduce liquid radioactive discharges. This means that nuclear licensed sites need action plans to achieve reductions in discharges. In 2012, the Environment Agency and SEPA issued new authorisations/permits, or varied existing ones, at nine sites (for fuel cycle sites at Capenhurst and Sellafield, for power stations: Bradwell, Hinkley C, Hunterston B, and Torness, for the defence establishment at Aldermaston, for the research establishment at Dounreay, and for landfill sites: Sita (Lancashire) Limited at Clifton Marsh, resulting in one or more of: strengthened conditions, reduced limits or new routes for disposing of radioactive waste.

There were no major variations in environmental concentrations of radioactivity in 2012 compared to those in 2011. During the past decade, discharges from GE Healthcare Limited at Cardiff have continued to decline. This has led to a downward trend in concentrations of tritium in fish and molluscs near the site. Similarly, lower discharges of technetium-99 from Sellafield have led to a fall in technetium-99 in local food and the environment since the peaks seen in 1997.

During 2012, discharges of technetium-99 from Sellafield continued to be low, following the introduction of abatement technology in previous years. Discharges are expected to remain low in the future. Technetium-99 from Sellafield can be detected in the Irish Sea, in Scottish waters and in the North Sea. Concentrations of technetium-99 have shown a strong trend downward from their most recent peak in 2003, though concentrations in 2012 were similar to those in 2011. Technetium-99 has been found in seaweed, but our monitoring has shown a low transfer from sea to land where seaweed has been used as a soil conditioner.

Marine sediment samples are a useful indicator of trends in the environment. People who spend time on beaches can be exposed to radiation through the radionuclide content of the sediments. Near Sellafield, the environmental concentrations of most radionuclides have declined substantially over the last 20 years. Small increases in plutonium isotopes and americium-241 have been observed in mud samples from the Ravenglass estuary near Sellafield. However, these have had little or no effect on radiation exposures. There were small increases in concentrations of plutonium isotopes and americium-241 in lobster samples from Cumbria in 2012.

On occasion, the effects of non-nuclear sites discharge are detected at low levels by the routine monitoring programme for nuclear licensed sites. In 2012, iodine-131 was detected at several nuclear licensed sites. The source of the iodine-131 is not known with certainty but a likely cause was the therapeutic use of this radionuclide in local hospitals. The concentrations were of low radiological significance.

At Hartlepool, the reported polonium-210 concentration in winkles was enhanced above that value expected due to natural sources. Due to the scarcity of winkles at the normal sampling location (inside the Tees Estuary entrance) in 2012, the sample consisted of a mixture including some winkles collected from an area known previously to be enhanced. The higher levels are not due to discharges from the power station but are believed to be due to the effects of waste slag from local iron and steel industries used in sea defences and the build-up of naturally-occurring radionuclides in sediments at this location following degradation of these materials.

Dose rates from around UK nuclear licensed sites

Sediments in intertidal areas can make a significant contribution to the total radiation exposure of members of the public. For this reason, external doses are recorded by measuring dose rates. These 'external doses' are included in the assessment of doses to the public where they are higher than background levels. Background levels are subtracted in dose assessments.

There were no major changes in external dose rates in intertidal areas in 2012 compared with 2011. At most locations, the external dose rates were close to background levels. Levels were higher in some estuaries near Sellafield (up to twice the background rate) and in the Ribble Estuary.

UK nuclear licensed site incidents and non-routine surveys

During 2012, as a result of an ongoing programme of monitoring by the operator, radioactive items were detected on beaches on the Cumbrian coastline, where particles* (including contaminated pebbles/stones) from Sellafield were removed (249 in financial year 2012/13). Public Health England† (PHE) has provided advice that the overall health risks for beach users from radioactive objects on beaches near Sellafield are very low and significantly lower than other risks that people accept when using the beaches. Monitoring, removal and research into the origins, fate and effects of the particles by Sellafield Limited will continue.

At Chapelcross, a programme of work to reline and grout sections of the discharge pipeline has mitigated the potential release of limescale particles, with no particles being detected on the foreshore during 2012. At Dounreay, the comprehensive beach monitoring programme for fragments of irradiated nuclear fuel (particles) continued and further particles were recovered from local beaches. Offshore particles which could pose significant harm were recovered from the seabed, where fishing restrictions under the Food and Environment Protection Act (FEPA) 1985 are still in force.

'Special' (or *ad hoc*) sampling related to nuclear licensed site operation was undertaken at two sites by SEPA in 2012. At Chapelcross, rainwater was sampled and analysed on a weekly basis, and game birds were sampled and analysed from around Dounreay. Further details of this work can be found in the relevant site text.

Radiation doses and levels at other locations

Additional monitoring was undertaken in the UK and surrounding seas to study the effects of (i) overseas incidents at Chernobyl in 1986 and at Fukushima Dai-ichi in 2011, (ii) non-nuclear sites and (iii) regional variation in levels of radioactivity across the UK.

Overseas incidents

The accident at Fukushima Dai-ichi nuclear power station in Japan in March 2011 resulted in significant quantities of radioactivity being released to air and sea. These began to circulate in the Northern Hemisphere atmosphere, with small quantities reaching Western Europe towards the end of March that year.

---

* *"Particle" is a term used in this report which encompasses discrete radioactive items which can range in radioactivity concentration, size and origin. "Particles" include radioactive scale, fragments of irradiated nuclear fuel, incinerated waste materials, radioactive artefacts (e.g. dials) and stones which have radioactive contamination on their surface. Particles are not physically the same at each of the sites mentioned, but can be compared according to the hazard posed.*

† *Public Health England (PHE) was formed on 1 April 2013. It includes the functions previously undertaken by the Health Protection Agency (HPA). PHE is the national agency for dealing with the health effects of radiation in the UK.*

Actions taken in the UK included:

- Implementing EU controls on importing food from Japan
- Enhanced monitoring across the UK, measuring air, rain, grass and food to check for the effects of atmospheric transport and deposition from Japan

Controls on food imports from Japan took two forms, and these controls continued in 2012. The European Commission (EC) implemented controls on the import of food and feed originating in or consigned from Japan. All food and feed imported from Japan had to be certified by the Japanese authorities. In addition, a percentage of Japanese imports into the EU were monitored at ports of entry. Some imports of seafood from other nations from the region where contamination might be expected in the western Pacific were also monitored. The results of monitoring Japanese imports to the UK have been published by the EC (http://ec.europa.eu/energy/nuclear/radiation_protection/fukushima_en.htm). None of the imports to the UK have contained activity exceeding the maximum permissible levels; most results have been below the limits of detection, with a few being around 10 Bq kg^{-1}. The public doses received due to the imports were of negligible radiological significance.

After the initial detection of iodine-131 by the routine monitoring programmes, the environment agencies and the Food Standards Agency undertook additional monitoring but concentrations of iodine-131 were very low and of minimal risk to public health. The additional monitoring ceased in July 2011 and monitoring returned to normal frequencies.

The environmental effects of the Chernobyl accident continued to be monitored in 2012. There were still restrictions on moving, selling and slaughtering sheep in some upland areas of the UK, but following a detailed appraisal of the possible exposures due to consumption of sheep meat, all restrictions were lifted by the Food Standards Agency in June 2012.

Food imported into the UK may contain radioactive contamination from Chernobyl and other known or unknown sources. A monitoring system is in place to detect radioactivity in consignments. In 2012, the instruments were triggered at Harwich and Hull by the presence of caesium-137 in consignments of food being brought into the UK. The samples of wild blueberries and blueberry juice concentrate from Ukraine were analysed and the activity concentrations were 166 and 580 Bq kg^{-1}, respectively. At these concentrations, the Food Standards Agency considered that there was no food safety requirement to limit their placement on the market for human consumption.

Non-nuclear sites

In the past, liquid slurry containing thorium and uranium was discharged into the Irish Sea from a phosphate plant near Whitehaven in Cumbria. This was a practice that generated what is sometimes known as 'Technologically enhanced Naturally-Occurring Radioactive Material' (TNORM). Where discharges of TNORM occur, this can lead to an increase in the concentrations of naturally-occurring radionuclides in the environment. This site stopped operating at the end of 2001, decommissioned in 2002 and the plant has subsequently been demolished. Concentrations of naturally-occurring radionuclides in fish and shellfish near Whitehaven have been found to be higher than the maximum expected ranges due to natural sources. Concentrations of natural radionuclides have declined in the last 10 years so that by 2012 the concentrations were very close to natural background, making any increase due to the past discharges difficult to distinguish. Estimates of the concentrations of naturally-occurring radionuclides in seafood caused by past discharges from the site have been made by subtracting the expected natural concentration of these radionuclides in UK seafood from the measured levels. Polonium-210, which is naturally-occurring, is present in some seafood samples at slightly above background levels. People in the area who consume large amounts of seafood were estimated to receive a dose of 0.30 mSv, with about 70% from polonium-210. The dose includes a contribution from the effects of discharges from the adjacent sites at Sellafield and the LLWR near Drigg.

Concentrations of tritium were found in leachate from some landfill sites, but only at levels 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, and due to disposals of gaseous tritium light devices (such as fire exit signs).

Radioactive items containing radium-226 and associated daughter products have been detected at Dalgety Bay in Fife since at least 1990. It is thought that contamination has been 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.

A monthly beach monitoring and particle recovery programme was adopted at Dalgety Bay in 2012 and this remains in place. The fence demarcating the area where the highest activity particles were discovered remains in place, as well as the information signs advising the public of the contamination and precautions to be taken. A FEPA Order prohibiting the collection of seafood from the Dalgety Bay area also remains in force.

In 2012, an intrusive site investigation of Dalgety Bay was conducted to determine the extent of the contamination. The investigation involved the digging of trial pits and drilling of boreholes across the site. This work revealed that further

radioactive sources remain in the ground which over time may erode onto the beach area. A report detailing the work undertaken during the investigation is available from SEPA's website (www.sepa.org.uk).

In 2013, a report detailing a risk assessment at Dalgety Bay was published by SEPA, which concluded that there is a significant possibility of harm being caused via skin contact and inadvertent ingestion from particles found on the beach from the currently demarcated area to the slipways. Thereafter the view was endorsed, by Public Health England, reporting that radium-226 contaminated objects recovered include objects that could give rise to radiation doses that exceed the relevant dose criteria for the designation of contaminated land.

Further details of this work can be found in Section 7.6 and on the Dalgety Bay web pages of SEPA's website (www.sepa.org.uk). Work in this area is ongoing and an update will be provided in next year's RIFE report.

Regional monitoring

Monitoring artificial radioactivity on the Isle of Man and in Northern Ireland showed that consumer doses were all less than 2 per cent of the annual limit of 1 mSv for members of the public. A survey on the Channel Islands confirmed that doses due to discharges from the French reprocessing plant at La Hague and other local sources were less than 1 per cent of the limit.

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

The distribution of radionuclides in coastal seas away from nuclear licensed sites continues to be monitored. This supports the UK's marine environmental policies and international treaty commitments. Government research vessels are used in the sampling programme and the results have been used to show trends in the quality of the UK's coastal seas. These surveys, together with the results of monitoring at nuclear licensed sites, contribute to the data collected by the OSPAR Commission. They also help to measure progress towards the UK governments' targets for improving the state of the marine environment.

Disposal of dredge material from harbours and other areas is licensed under the Marine and Coastal Access Act (MCAA), 2009. In 2012, the Marine Management Organisation (MMO) considered a proposal on behalf of the Department for Environment, Food and Rural Affairs (Defra) for the disposal of sediment from a location in north west England. Samples of the dredge material were analysed for radioactivity and an assessment of potential radiation doses was made. Doses to members of the public were all less than the International Atomic Energy Agency (IAEA) *de minimis* criterion of 0.010 mSv per year, and there was no objection to the licence being issued from radiological considerations.

The monitoring programmes and further research

The monitoring programmes in this report involved five specialist laboratories working together, each with rigorous quality assurance audits, and a wide range of sample collectors throughout the United Kingdom. They were organised by the environment agencies and the Food Standards Agency and they are independent of the industries discharging radioactive effluents. The programmes include monitoring on behalf of the Scottish Government, Channel Island States, the Department of Energy and Climate Change (DECC), the Department for Environment, Food and Rural Affairs , the Manx Government and the Welsh Government. Overall, around 12,000 analyses and dose rate measurements were completed in 2012.

The results of the analysis of food samples collected near nuclear licensed sites in England and Wales are published biannually on the Food Standards Agency's website (www.food.gov.uk). More information about all programmes described in this report is available from the sponsoring agencies. Their contact details can be found on the back cover of this report.

The routine monitoring programmes are supported by a number of research studies, investigating specific issues such as determining the depth distributions of technetium-99 concentrations in sea-bed cores of the Irish Sea. Results of the completed studies are used to improve the radiological assessment of monitoring data. The agencies are also funding work to improve the methods for estimating public exposure. Further details of the research studies are contained in this report.

1. Introduction

This section (i) describes the purpose and scope of the UK monitoring programmes for radioactivity in food and the environment, (ii) provides a summary of the key results in terms of radiation exposures at each major industrial site in 2012 and (iii) gives an overview of the main sources of radiation in a regulatory context.

1.1 Purpose and scope of the monitoring programmes

In England and Wales, the Food Standards Agency conducts food monitoring, whilst the Environment Agency carries out environmental and dose rate monitoring*. In Scotland, the Scottish Environment Protection Agency (SEPA) carries out food, environmental and dose rate monitoring, working closely with the Food Standards Agency and the Food Standards Agency in Scotland on its programme, and in Northern Ireland this is carried out by the Northern Ireland Environment Agency (NIEA). In 2012 the Food Standards Agency continued a small programme of monitoring of upland areas in England and Wales for caesium-137, arising from the 1986 Chernobyl accident. All agencies contributed to the Government response to the Fukushima Dai-ichi accident of March 2011. Direct monitoring of the effects of the accident on the UK environment ceased in July 2011 (and was not carried out in the UK in 2012) because of the low levels detected but surveillance of imports from Japan continued. The regular programme of monitoring of drinking water, air and rain continued on behalf of the Department of Energy and Climate Change (DECC), NIEA and the Scottish Government. The Food Standards Agency and SEPA also carry out nationwide monitoring of foodstuffs (including milk, animals, crops and canteen meals) that are remote from nuclear licensed sites. The marine environment of the whole of the British Isles away from nuclear licensed sites is monitored for the Department for Environment, Food and Rural Affairs (Defra).

The Food Standards Agency is responsible for food safety throughout the UK under the Food Standards Act 1999. The Environment Agency, NIEA and SEPA, referred to together as the environment agencies in this report, are responsible for environmental protection in England and Wales, Northern Ireland and Scotland, respectively. The Environment Agency regulates radioactive waste disposal under the Environmental Permitting (England and Wales) Regulations (EPR 10), (United Kingdom - Parliament, 2010a), whilst in Scotland and Northern Ireland, SEPA and NIEA regulate radioactive waste disposal under the Radioactive Substances Act 1993 (RSA 93) (United Kingdom - Parliament, 1993). The Environment Agency and SEPA also have broader responsibilities under the Environment Act 1995 (United Kingdom - Parliament, 1995a) for protecting, and determining general concentrations of pollution in, the environment.

The monitoring programmes have several purposes. Ongoing monitoring helps to establish the long-term trends in concentrations of radioactivity over time within the vicinity of, and at distance from, nuclear licensed sites. The results are also used to confirm the safety of the food chain. Monitoring the environment provides indicators of radionuclide dispersion around each site. Environmental and food results are used to assess dose to the public to confirm that the controls and conditions placed in the authorisations/permits provide the necessary protection and to ensure compliance with statutory dose limits. Most of the monitoring carried out and presented in this report concerns the local effects of discharges from nuclear licensed sites in the UK. Other work includes the Chernobyl monitoring, which provides the authorities with information on caesium-137 concentrations in affected areas and helps them decide if restrictions are still needed. Monitoring of food imports from Japan acts to confirm that controls by the Japanese authorities are working adequately. Monitoring of food and the environment remote from nuclear licensed sites is also carried out, giving information on background concentrations of radionuclides; these data are reported to the European Commission (EC). Guidance on planning and implementing routine environmental programmes has been published (Environment Agency, Food Standards Agency and Scottish Environment Protection Agency, 2010).

Key points

- **The RIFE report represents collaboration by the environment agencies and the Food Standards Agency across the UK, independent of industry**
- **Provides an open check on food safety and the public's exposure to radiation**
- **Monitoring programme results support the UK meeting its international treaty obligations**
- **Dose results are summarised for major industrial sites; all doses were below the legal limit in 2012**

* *On the 1 April 2013, Natural Resources Wales (NRW) formally came into existence. The NRW was created by and reports to the Welsh government. This new body took over the functions previously carried out by the Environment Agency Wales, Countryside Council for Wales and Forestry Commission Wales including independent monitoring of radioactivity in the environment in Wales.*

The Food Standards Agency completed a public consultation exercise to review the way it monitors radioactivity in food in June 2013 (Food Standards Agency, 2012a and 2013). It is intended that the results will be taken forward in revised programmes taking effect in 2014.

An explanatory section giving details of methods of sampling and analysis and explaining how results are interpreted in terms of public radiation exposures is provided in Appendix 1 in a file accompanying the main report. A summary of recent trends in monitoring data and doses for 2004 – 2008 has been published (Environment Agency, Food Standards Agency, Northern Ireland Environment Agency and Scottish Environment Protection Agency, 2010b).

The analytical science for the monitoring programmes was carried out by a number of UK laboratories, including those listed below. These laboratories also carried out most of the sample collection for the programmes.

- Animal Health and Veterinary Laboratories Agency (AHVLA)
- Centre for Environment, Fisheries & Aquaculture Science (Cefas)
- Environmental Scientifics Group (ESG)
- Public Health England (PHE)
- LGC Limited (formerly Laboratory of the Government Chemist)

1.2 Summary of doses

1.2.1 The assessment process

The majority of the monitoring was carried out to check the effects of discharges from nuclear and non-nuclear operators on people's food and their environment. The results are used to assess doses to the public that can then be compared with the relevant dose limits. The dose assessments are retrospective in that they apply to 2012, using monitoring results for that year. The radioactivity concentrations and dose rates reported include the combined radiological impact of all discharges made up to the time of sampling.

In this report, two main types of retrospective dose assessment are made. The first type of assessment is more complete in considering the effects of discharges of radioactive waste discharges together and additionally includes exposure to direct radiation from nuclear licensed sites. This gives an estimate of *total dose* to people around the nuclear licensed sites. Most assessments of dose in this report now use this *total dose* methodology. Direct radiation can be significant close to operating power stations or close to where radioactive materials are stored. The regulation of direct radiation is the responsibility of the Health & Safety Executive (HSE) working through their agency, the Office for Nuclear Regulation (ONR). Operators of nuclear licensed sites provide estimates of direct radiation doses to ONR which are made available for use in these assessments (Table 1.1). The *total dose* assessments use recent habit survey data which has been profiled using an agreed method (Camplin *et al.*, 2005).

The second type of assessment focuses on specific sources and their associated pathways. It serves as a check on the adequacy of the *total dose* method and offers additional information for key pathways.

Both types of assessment consider the people in the population who are most exposed to radiation. These results are for comparison with legal limits. The method of calculation involves an assessment for the 'average member of the critical group' or the 'representative person'. These terms are both in use in radiological protection and are equivalent. The introduction of the term 'representative person' in International Commission on Radiological Protection (ICRP) 101 (International Commission on Radiological Protection, 2006) has made no change to dose assessment methods or data or the continuity of the basis for dose results presented in this report.

The calculated doses can be compared with the dose limit for members of the public of 1 mSv per year. Dose assessments for exposure to skin are also made at some sites and compared with the relevant skin dose limit. The approaches used are for relatively widespread contamination in food and the environment where the probability of encounter/consumption is certain. These methods are not appropriate for exposure to small radioactive particles where the chance of encounter is a relevant factor to be considered (Dale *et al.,* 2008). All dose limits are based on recommendations made by the ICRP (International Commission on Radiological Protection, 1991).

An additional comparison can be made with doses from natural radioactivity. The UK average is 2.2 mSv per year, with a range across counties from 1.5 mSv per year to 7 mSv per year (Watson *et al.*, 2005).

Collective doses are beyond the scope of this report. They are derived using modelling techniques. The EC has published an assessment of individual and collective doses from reported discharges from nuclear power stations and reprocessing sites for the gaseous and liquid waste disposals in the years 2004 to 2008 (Jones *et al.*, 2013).

Radiation exposures to some specific groups of workers are included in the assessment of doses from nuclear licensed sites. These are workers who may be exposed incidentally, but do not work specifically with ionising radiation. These include fishermen, farmers, sewage workers, nature wardens, etc. It is appropriate to compare their doses to the dose limit for members of the public (Allott, 2005). Doses to workers who are involved with ionising radiation and receive a dose from their work should be assessed as part of their employment.

1.2.2 *Total dose* results for 2012

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). The data are presented in three parts. The people receiving the highest dose from the pathways predominantly relating to gaseous discharges and direct radiation are shown in part A and those for liquid discharges in part B. Occasionally the people receiving the highest dose from all pathways are different from those in A and B. Therefore this case is presented in part C. The major contributions to dose are also presented. 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 is provided on the CD accompanying this report.

In all cases, doses estimated for 2012 were less than the limit of 1 mSv for members of the public. The people most affected from gaseous discharges and direct radiation varied from site to site but the dominant pathway was often direct radiation where it was applicable. The people most affected from liquid discharges were generally adult consumers of seafood or occupants over contaminated substrates.

Permitted discharges were the source of most of the dose at the Sellafield site. 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 phosphate plant at Whitehaven and the lesser effects of discharges from the Low Level Waste Repository (LLWR) near Drigg. The people most exposed to radiation in 2012 were seafood consumers in the Cumbrian coastal area and the consumption of seafood contributed to approximately 95 per cent of the *total dose*. The next highest *total dose* was received by people living near the Amersham site; this dose was almost entirely due to direct radiation emanating from the site.

1.2.3 *Total dose* trends

A time-series of *total dose* from 2004 - 2012 is shown in Figure 1.1 (Table 1.3 gives numerical values).

Many sites showed a downward trend in *total dose* over this period. Changes in direct radiation dominated the inter-annual variation at most of the power station sites, and small fluctuations in external dose rates had relatively large effects at some sites where high rates of intertidal occupancy were recorded. The effects of decreases in direct radiation were observed at Dungeness and Sizewell where cessation of power production by Magnox reactors was the cause. The most significant trend in *total dose* due to discharges of waste was for high-rate consumers of seafood on the Cumbrian coast near Sellafield, Whitehaven and Drigg. In this case, the overall downward trend in *total dose* broadly followed the general downward trend in concentrations of naturally-occurring and artificial radionuclides from non-nuclear and nuclear sources, respectively. Year to year changes were also influenced by changes in consumption and occupancy characteristics of local people and the natural variability in radionuclide concentrations in food and the environment.

At Cardiff, there has been a downward trend in total dose which is partly due to reductions in discharges of tritium and carbon-14 to sea. The *total dose* observed at Dounreay in recent years has decreased from the peak value in 2008 due to changes in caesium-137 concentrations in game meat and the type of game meat sampled. The reduction in *total dose* at Heysham, Hinkley Point and Springfields was largely due to findings from new habits surveys in 2011, 2010 and 2012 respectively.

1.2.4 Source specific dose results for 2012

The results of the source specific assessments for the main industrial sites in the UK are summarised in Table 1.4 and Figure 1.2. The focus for these assessments is the effect of gaseous or liquid waste discharges, unlike that for *total dose* which also includes all sources including the effect of direct radiation.

The most significant exposures were found at Whitehaven and Sellafield and at Springfields. At Whitehaven and Sellafield the majority of the dose was from the legacy of historical discharges from Sellafield and from non-nuclear industrial operations resulting in technologically enhanced levels of natural radionuclides. The most important pathways and radionuclides at each site were similar to those found for *total dose* if the effect of direct radiation is taken into account. At Springfields the dose was also largely due to historical discharges from Sellafield.

The results confirm the adequacy of the *total dose* approach of assessment. Radiation doses to adults and children, calculated using the source specific method, were all found to be well below the national and European limit of 1 mSv per year.

1.2.5 Protecting the environment

The main focus of this report is on the protection of people, but the protection of wildlife and the environment is also relevant. ICRP in its 2007 recommendations concluded that there is a need for a systematic approach for the radiological assessment of non-human species to support the management of radiation effects in the environment (International Commission on Radiological Protection, 2007). In pursuit of this aim, ICRP has considered the use of a set of Reference Animals and Plants (RAPs) (International Commission on Radiological Protection, 2008). Further work is planned and whilst this is being undertaken, no dose limits are recommended to apply. The European Commission (EC, formerly Commission of the European Communities) has made a proposal for updating the Directive for basic safety standards for protection against the dangers arising from exposure to ionising radiation (European Commission, 2012a). The purpose of the revised Directive is to simplify the existing arrangements for radiation protection. The proposal also included the requirement for member states to

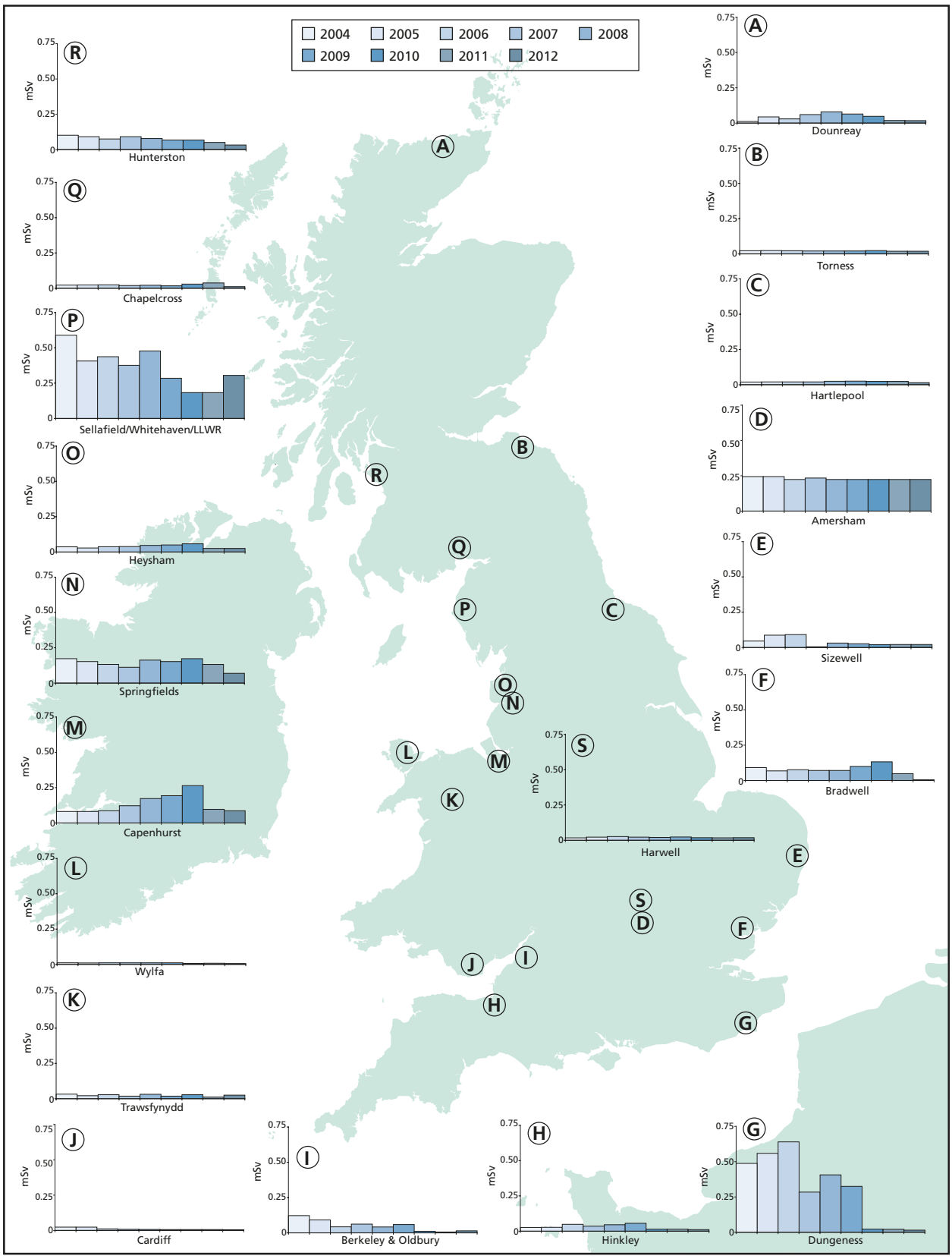


Figure 1.1. *Total doses* around the UK's nuclear sites due to radioactive waste discharges and direct radiation (2004-2012). (Exposures at Sellafield/Whitehaven/LLWR receive a significant contribution to the dose from technologically enhanced naturally occurring radionuclides from previous non-nuclear industrial operations)

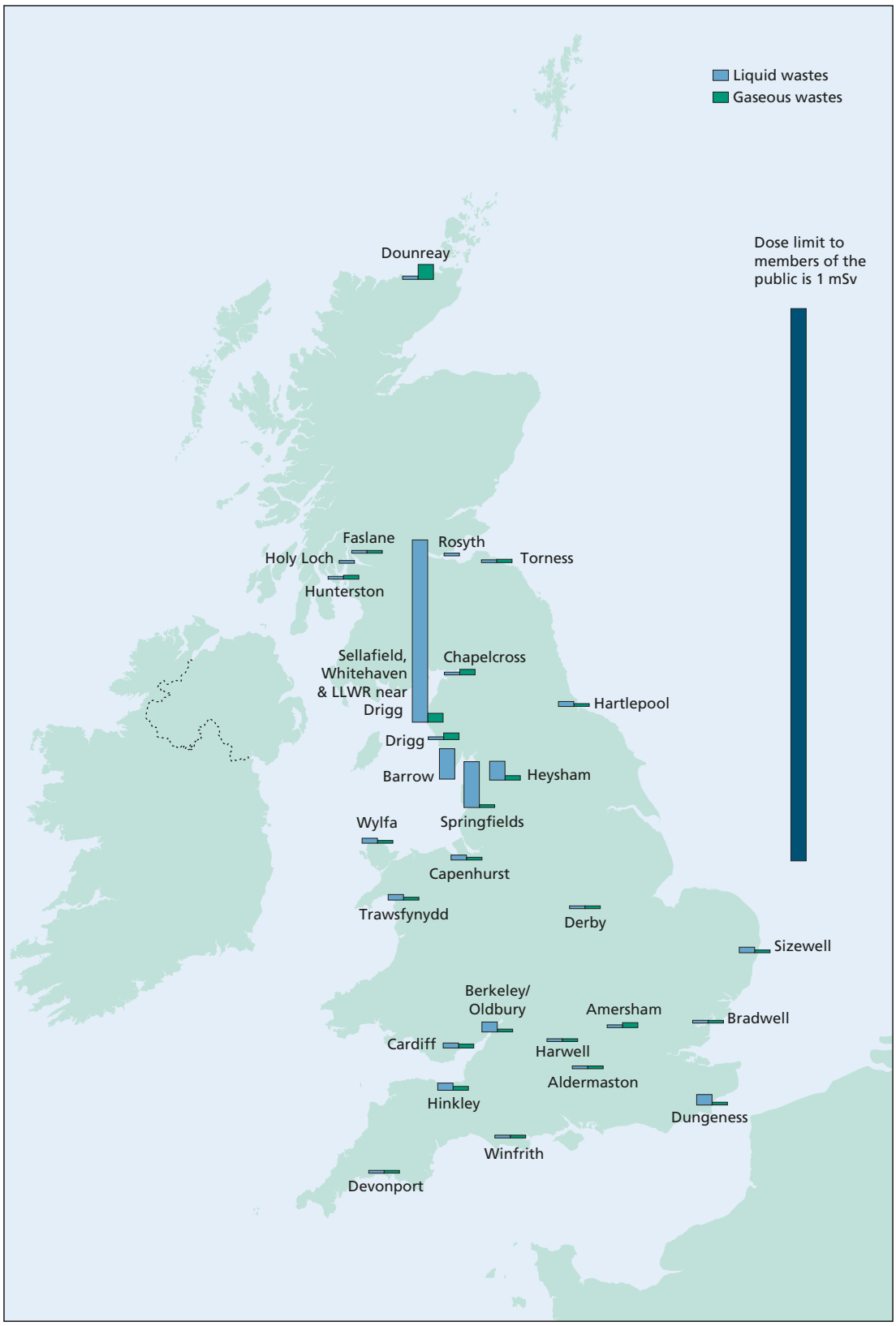


Figure 1.2. Source specific doses in the UK, 2012 (Exposures at Sellafield & Whitehaven receive a significant contribution to the dose from technologically enhanced naturally occurring radionuclides from previous non-nuclear industrial operations)

include provision for protection on non-human species in legal frameworks and for consideration of relevant monitoring. The European Commission's proposal is expected to be adopted by the European Council by the end of 2013, but this will not include the provision for protection on non-human species. The Directive is expected to take effect in 2014 and subsequently be transposed into UK law in due course.

In the UK, the current legislative measures relevant to the protection of wildlife from radiation are the Water Framework Directive (WFD) and the Habitats Directive (Commission of the European Communities, 1992 and 2000b). Defra, the Scottish Government, Welsh Government and the Department of the Environment Northern Ireland have policy responsibility for implementing the WFD in the UK. As competent authorities, the environment agencies are largely responsible for implementing the WFD.

The aim of the WFD is to improve the quality of the aquatic environment of the European Community. It provides a framework for Member States to work within and establishes a planning process with key stages for development towards reaching 'good status' by 2015 for inland and coastal waters. The UK has carried out the first stage, which involved characterising the quality of freshwater, estuarine and coastal environments of the UK, paying particular attention to describing ecosystems and to reviewing the presence of hazardous substances (Department for Environment, Food and Rural Affairs, 2005d). In relation to radioactivity, the environment agencies have characterised the aquatic environment using a screening tool, which forecasts the environmental impact of radioactive waste sources. The outcome of the assessment has been published and provided to the European Commission (Environment Agency, 2005). Subsequent stages within this framework involve designing and implementing monitoring programmes to reflect the results of the initial characterisation, reviewing environmental quality using the results from the monitoring programmes, developing standards and producing management plans to improve the environmental status of the UK aquatic environment.

Under the Habitats Regulations, the Environment Agency and SEPA review new and existing authorisations/permits to ensure that they do not have an adverse effect on the integrity of Natura 2000 habitat sites. The Environment Agency has assessed the dose rates to reference organisms and feature species for authorised discharges under the Radioactive Substances Act 1993 and, since April 2010, the Environmental Permitting (England and Wales) Regulations 2010 (Environment Agency, 2009a). Environmental concentrations were predicted using appropriate dispersion models and the data were used to calculate the dose rates. The assessment concluded that, for all but two of the habitat sites, dose rates to the worst affected organisms were less than an agreed threshold of 40 μGy h^{-1}. Hence, there was no significant impact on the integrity of these habitat sites. The two habitat sites with the potential for dose rates to the worst affected organism to be greater than the agreed threshold were the Drigg coast and the Ribble and Alt Estuaries. A detailed assessment has been carried out for the Drigg coast using monitoring data and this confirmed there was no indication of significant impact from ionising radiation on the sand dune biota (Wood *et al*., 2008). A detailed assessment was also carried out for the Ribble and Alt estuaries using monitoring data and taking into account new discharge limits for the Springfields site which came into force in 2008 (Environment Agency, 2009b). This assessment concluded that the dose rate to the worst affected organism was less than the agreed threshold and hence there was no significant impact on the integrity of this habitat site. The Environment Agency will be carrying out a review of the habitats assessment during 2013/14. When a new authorisation/permit to discharge or dispose of radioactive waste is issued, or one is varied, the applicant is required to make an assessment of the potential impact of the discharges on reference organisms that represent species which may be adversely affected

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. A report of the study is available from SEPA.

1.2.6 Food irradiation

Food irradiation is a processing technique where food is exposed to ionising radiation in a controlled manner. Irradiation may be used to eliminate or reduce food-borne pathogenic organisms, extend shelf life by delaying food from rotting or developing mould, and prevent certain food products from ripening, germinating or sprouting. Irradiation may also be used as a phytosanitary measure to rid imported plants or plant products of harmful organisms which may be harmful to domestic flora. The ionising radiation produces free radicals, which interact within the food to produce the desired effect. It does not make the food radioactive. The ionising radiation is either generated by machine, as is the case for electron beams or x-rays, or produced by the radioactive decay of caesium-137 or cobalt-60 (both unstable isotopes whose decay produces gamma radiation).

Food irradiation has been permitted in the UK since 1990, and UK legislation was amended in 2000 to implement two European Directives on food irradiation (Commission of the European Communities, 1999a, b). These amendments were consolidated into a single Regulation in each country of the UK in 2009 as part of the Food Standards Agency programme of regulatory simplification to reduce administrative burden. In 2010 the Regulations were amended to update the lists of approved food irradiation facilities.

In the UK, one facility in England is licensed to irradiate a range of dried herbs and spices and it is inspected by the Food Standards Agency. Several other irradiation facilities are approved to irradiate food; most are located in Member States

of the EU. Details of food irradiation facilities are available on the Food Standards Agency's website: http://www.food.gov.uk/foodindustry/imports/importers/irradiated

1.3 Sources of radiation exposure

1.3.1 Radioactive waste disposal from nuclear licensed sites

Nuclear licensed sites in the UK discharge radioactive waste as liquid and/or gas as part of their operations. In addition, solid Low Level Waste (LLW) from nuclear licensed sites can be transferred to the Low Level Waste Repository (LLWR) near Drigg for disposal. Solid LLW from Dounreay will be transferred to the new Dounreay Low Level Waste Facility (due to be operational by 2014). These discharges and disposals are regulated by the environment agencies under RSA 93 or EPR 10*.

Figure 1.3 shows the nuclear licensed sites that produce waste containing artificial radionuclides. Nuclear licensed sites are authorised to dispose of radioactive waste (United Kingdom - Parliament, 1993). They are also subject to the Nuclear Installations Act (United Kingdom - Parliament, 1965). The monitoring programmes reported here include studies at each of these sites. Discharges of radioactive waste from other sites such as hospitals, industrial sites and research establishments are also regulated under RSA 93 or EPR 10 but are not subject to the Nuclear Installations Act. Occasionally, these monitoring programmes detect radioactivity in the environment as a result of these discharges. For example, iodine-131 from hospitals is occasionally detected in some river and marine samples. Small amounts of very low level solid radioactive waste are disposed of from some non-nuclear sites. There is also a significant radiological impact due to the legacy of past discharges of radionuclides from non-nuclear industrial activity that also occur naturally in the environment. This includes radionuclides discharged from the former phosphate processing plant at Whitehaven, and so monitoring is carried out near this site. Discharges from other non-nuclear sites are generally considered insignificant in England and Wales and so monitoring to protect public health is not usually carried out by all the environment agencies, although some routine monitoring programmes are undertaken. In Scotland, SEPA undertake routine sampling in the Firth of Clyde and at landfill sites to assess the impact of the non-nuclear industry on the environment. Additionally, SEPA periodically undertake intensive sampling at major sewage treatment plants to monitor the combined discharges from the non-nuclear industry.

Appendix 2 gives a summary of the discharges of liquid and gaseous radioactive waste and disposals of solid radioactive waste from nuclear licensed establishments in the UK during 2012. The tables also list the discharge and disposal limits that are specified or, in the case of the Ministry of Defence (MoD), administratively agreed. In 2012, discharges and disposals were below the limits. The tables show the percentage of the limit actually discharged in 2012. Section 7 gives information on discharges from non-nuclear sites.

The discharge limits are set through an assessment process, which either the operator or the relevant environment agency can initiate. In support of the process, prospective assessments of doses to the public are made assuming discharges at the specified limits. Discharge limits are set so that doses to the public from the site will be below the dose constraint of 0.3 or 0.5 mSv per year if discharges occurred at the limits. The implications of the regulations for the food chain are also considered. During the determination of the limits, the effect of the planned discharges on the environment and wildlife is also considered. In addition, the regulations require Best Available Techniques or Best Available Technology (BAT), under EPR 10, to be used to further minimise discharges. The principles of Best Practicable Means are applied in Scotland.

The discharges and disposals made by sites are generally regular throughout the year. However, from time to time there may be unplanned events that cause unintended leakages, spillages or other emissions that are different to the normal or expected pattern of discharges. These events must be reported to the environment agencies and may lead to follow up action, including reactive monitoring by the site, the environment agencies or the Food Standards Agency. In cases where there has been a breach of limits, or if appropriate actions have not been undertaken to ensure discharges are as low as possible, regulatory action may be taken. Where monitoring took place because of these events, the results are presented and discussed in the relevant site text later in this report. Appendix Table A2.4 summarises the types of events that took place in 2012.

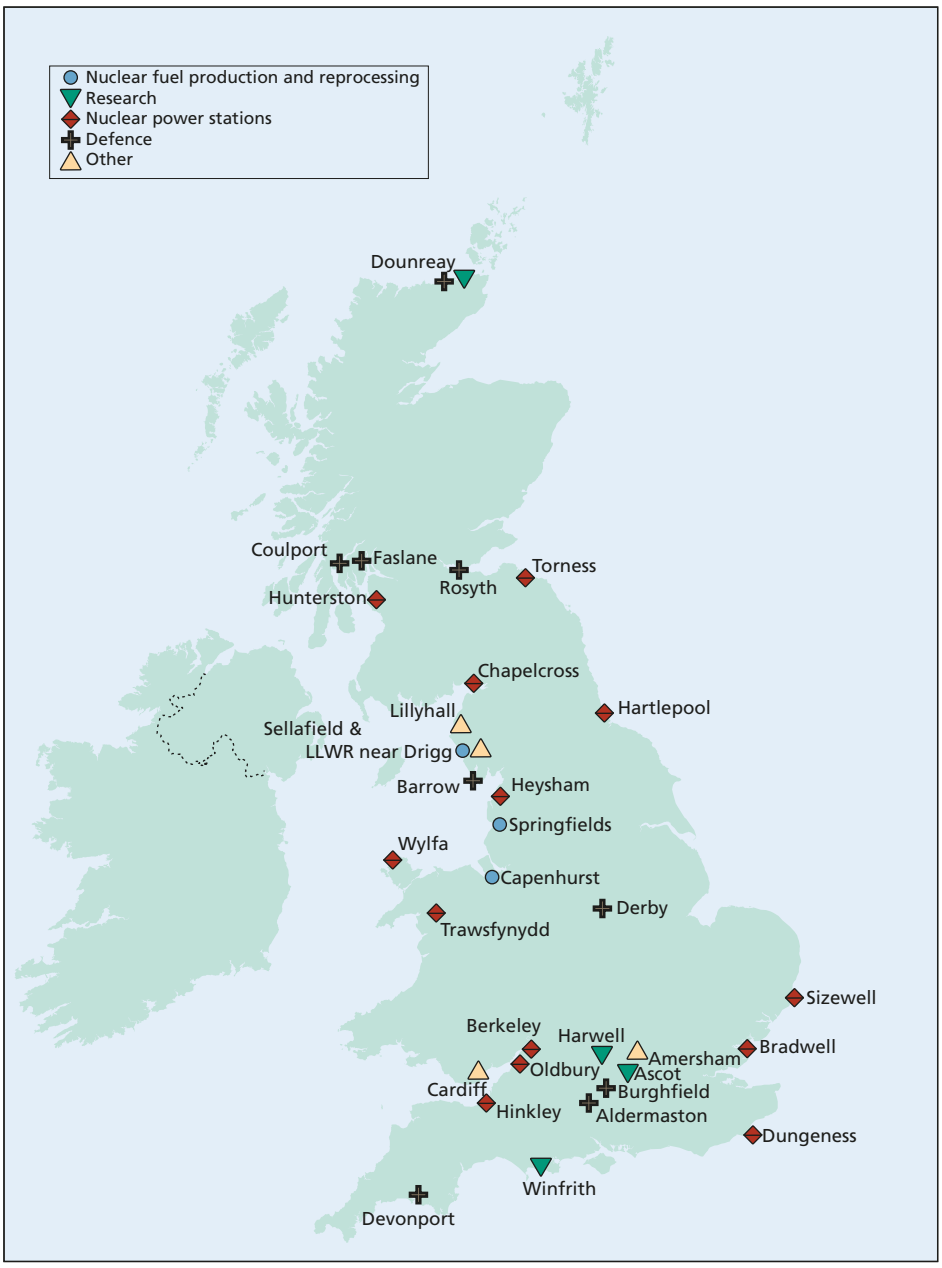
Following a period of consultation (Department for Environment, Food and Rural Affairs, 2008), the Environment Agency and the Scottish Environment Protection Agency published guidance in May 2010 to nuclear operators on how they should assess discharges for reporting to regulators. The benefits of the guidance are:

- Operators can choose the most cost effective method (i.e. monitoring, calculation or estimation) of assessment at the appropriate level of quality
- More reliable reporting by accounting for results below the limit of detection
- Consistent regulatory approach across sites

The guidance is designed to support practicable implementation in the UK of parts of the European Commission's recommendation, 2004/2/Euratom, on standardised reporting of discharges. Defra and the Welsh Government have initiated a public consultation in 2013 to

* *In England and Wales, the term 'authorisation' has been replaced by 'permit' with EPR 10 taking effect from 6th April 2010. 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 6th April 2010. 'Authorisation' remains the relevant term for Scotland and Northern Ireland*

Figure 1.3. Principal sources of radioactive waste disposal in the UK, 2012 (Showing main initial operation. Some operations are undergoing decommissioning)



amend the EPR 10 by introducing a range of new measures (Defra and Welsh Government, 2013).

1.3.2 International agreements, the UK Discharge Strategy and new nuclear power stations

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. The UK has ratified the Convention for the Protection of the Marine Environment of the North-East Atlantic (the 'OSPAR Convention'). This provides a framework for preventing and eliminating pollution in the north-east Atlantic, including the seas around the UK (OSPAR, 2000a). The OSPAR Convention replaced the separate Oslo and Paris Conventions.

In July 1998, the Ministers of the UK Government agreed a long-term Radioactive Discharge Strategy and signed the Sintra Statement which included the following commitment (OSPAR, 1998):

"We shall ensure that discharges, emissions and losses of radioactive substances are reduced by the year 2020 to levels where the additional concentrations in the marine environment above historic levels, resulting from such discharges, emissions, losses, are close to zero."

In July 2002, a UK Strategy for Radioactive Discharges was published (Department for Environment, Food and Rural Affairs, 2002). This described how the UK would implement the agreements reached at the 1998 and subsequent meetings of OSPAR. The aims of the Strategy related to liquid wastes from the major sources, primarily the nuclear industry, and not to gaseous or solid wastes.

Results of a public consultation to update this Strategy were published in 2009 (Department of Energy and Climate Change, 2009). DECC and the Devolved Administrations have now issued a revised Strategy (Department of Energy and Climate Change, Department of the Environment, Northern Ireland, the Scottish Government and Welsh Assembly Government, 2009).

The new Strategy builds on the 2002 publication , and expands its scope to include aerial, as well as liquid discharges, from decommissioning as well as operational activities, and from the non-nuclear as well as the nuclear industry sectors. It also includes considerations of uncertainties associated with discharges from new nuclear power stations, the possible extension of the lives of some of the existing nuclear power reactors, and discharges arising from decommissioning activities. The objectives of this revised Strategy are:

- To implement the UK's obligations, rigorously and transparently, in respect of the OSPAR Radioactive Substances Strategy (RSS) intermediate objective for 2020
- To provide a clear statement of Government policy and a strategic framework for discharge reductions, sector by sector, to inform decision making by industry and regulators

The expected outcomes of the UK Strategy are:

- Progressive and substantial reductions in radioactive discharges, to the extent needed to achieve the sectoral outcomes, while taking into account the uncertainties
- Progressive reductions in concentrations of radionuclides in the marine environment resulting from radioactive discharges, such that by 2020 they add close to zero to historic levels
- Progressive reductions in human exposures to ionising radiation resulting from radioactive discharges, as a result of planned reductions in discharges

To support implementation of Government policy, the Scottish Government has issued Statutory Guidance to SEPA (Scottish Government, 2008). Similarly DECC and the Welsh Government issued guidance to the Environment Agency (Department of Energy and Climate Change and Welsh Assembly Government, 2009). The Environment Agency has developed Radioactive Substances Regulation (RSR) Environmental Principles (RSR Environmental Principles, or REPs) to form a consistent and standardised framework for the technical assessments that will be made when regulating radioactive substances (Environment Agency, 2008a). It has also issued guidance for assessment of Best Available Techniques (Environment Agency, 2008b).

Information on work in progress within the OSPAR Convention can be found on OSPAR's website (www.ospar.org). The basis for OSPAR's approach is the Radioactive Substances Strategy (RSS) whose primary objective is to prevent marine pollution (OSPAR, 2003), as amended in 2010 (OSPAR, 2010a). A recent report from the OSPAR Radioactive Substances Committee records work completed and planned relating to reporting of discharges, environmental measurements, standards and quality assurance (OSPAR, 2013). In particular, it describes the work of its Intersessional Correspondence Group which is evaluating approaches for assessing the objective of additional concentrations in the marine environment above historic levels being close to zero by 2020. It also considers the relationship between OSPAR and its work on radioactivity and the initiative to determine Good Environmental Status (GES) as required by the Marine Strategy Framework Directive. An agreement has been reached on the basis for monitoring of relevance to OSPAR by Contracting Parties (OSPAR, 2006). The programme includes sampling in fifteen divisions of the OSPAR maritime area and is supported by procedures for ensuring quality control. Inputs in the North-East Atlantic have been summarised for both nuclear and non-nuclear sectors (OSPAR, 2011a; b). The UK submission concerning the implementation of the principle of using Best Available Technology (BAT) has also been published (OSPAR, 2009a) and an updated version for 2008-11 has been prepared for publication in 2013. Progress by Contracting Parties towards meeting the objectives in the Radioactive Substances Strategy

has been reviewed (OSPAR, 2009b), as has the quality status of the Convention area (OSPAR, 2010b). The Quality Status Report considers radioactivity in food and the environment and refers to results of the monitoring programmes published in earlier issues of this report. The overall conclusions of the review were that there is evidence of:

- A reduction in total beta discharges from the nuclear sector, including technetium-99 discharges
- Reductions in marine concentrations of radioactive substances in most cases
- Estimated doses to humans were well within international and EU limits and
- An indication that the calculated dose rate to marine biota from selected radionuclides from the nuclear sector are low and are below the lowest levels at which any effects are likely to occur

The European Commission (EC) has considered various options for a new policy instrument concerning the protection and conservation of the marine environment and has now issued a Marine Strategy Directive (Commission of the European Communities, 2008). The Directive has been transposed into UK law (United Kingdom - Parliament, 2010b) and is supported by measures to improve management of the marine environment covering the UK, Scotland and Northern Ireland (United Kingdom - Parliament, 2009; Scotland - Parliament, 2010; Department of the Environment Northern Ireland, 2010). It requires Member States to achieve Good Environmental Status in waters under their jurisdiction by 2020. The UK has submitted an initial assessment to the Commission (European Commission, 2012b).

The importance of an integrated approach to stewardship of the marine environment has been recognised in the UK, and a strategy to achieve this has been published (Department for Environment, Food and Rural Affairs, Scottish Executive and Welsh Assembly Government, 2002). The report *"Safeguarding Our Seas"* considers conservation and sustainable development of the marine environment and sets out how the UK is addressing those issues in relation to radioactive and other substances and effects. The UK completed a fully integrated assessment of the marine environment in 2005 (Department for Environment, Food and Rural Affairs, 2005a, b; Department for Environment, Food and Rural Affairs, Department of the Environment, Northern Ireland, Scottish Executive, Welsh Assembly Government, 2005) and has completed a new assessment *"Charting Progress 2"* in 2010 (Department for Environment, Food and Rural Affairs, 2010). The Department of the Environment, Northern Ireland and the Scottish Government have also published individual assessments of the state of the seas around their coasts (Baxter *et al.,* 2011; Department of the Environment, Northern Ireland 2011).

The UK Government is of the view that companies should have the option of building new nuclear power stations (Department for Business, Enterprise and Regulatory Reform, 2008) and the national policy statement for nuclear power generation has been issued (Department of Energy and Climate Change, 2011b). The statement includes information on:

- The needs for new nuclear power stations
- Policy and regulatory framework
- Assessment of arrangements for the management and disposal of waste from new nuclear power stations
- The impacts of new nuclear power stations and potential ways to mitigate them
- Suitable sites

In October 2010, DECC published for consultation revised draft National Policy Statement (NPS), for Nuclear Power Generation and other energy sources. The nuclear NPS listed eight sites assessed as potentially suitable for the development of new nuclear power stations and stated that any new nuclear power station would play a vitally important role in providing reliable electricity supplies and a secure and diverse energy mix as the UK makes the transition to a low carbon economy. The consultation of NPS's closed in January 2011. These were approved by Parliament on 18 July 2011 and designated under the Planning Act 2008 on 19 July 2011. The Scottish Government is opposed to the development of new nuclear power stations in Scotland. It is committed to enhancing Scotland's generation advantage based on renewables and fossil fuel with carbon capture and storage, as well as energy efficiency as the best long term solution to Scotland's energy security.

During 2011, the ONR and the Environment Agency continued to assess the design of potential new nuclear power stations. The assessment process, called "Generic Design Assessment" (GDA), allows the safety, security and environmental implications of new power station designs to be assessed, and is commenced before an application is made to build that design at a particular site in England and Wales. The designs being assessed are AP1000 (Westinghouse) and UK-EPR (EDF and AREVA) nuclear plants. The Environment Agency's assessment of the two new nuclear power station designs is to make sure that, if they were built, their environmental impact, including the radioactive wastes they create and the discharges they make, would be acceptable.

In December 2011, ONR and the Environment Agency concluded their initial assessments, including taking into consideration the effects and review of the accident at the Fukushima Dai-ichi power station in Japan. The Environment Agency is content with the environmental aspects of both designs and has issued interim Statements of Design Acceptability (Environment Agency, 2011a). Similarly, ONR issued an interim Design Acceptance Confirmation to the designers of each of the reactors (Office for Nuclear Regulation, 2011). The GDA process has continued with a focus on the UK-EPR design, because Westinghouse is not presently addressing the GDA issues for the AP1000 design. In December 2012, ONR finalised their GDA assessment following EDF and AREVA submissions of revised safety case documents and associated changes to generic design. A Design Acceptance Confirmation for the UK EPR reactor has been issued and ONR have concluded that the reactor is

suitable for construction on licensed sites in the UK, subject to site specific assessment and licensing (Office for Nuclear Regulation, 2012).

In November 2012, ONR granted a nuclear site licence to NNB Generation Company Limited (NNB GenCo) for its proposed site at Hinkley Point C in Somerset. Now that it is licensed, the Company will be subject to statutory obligations and regulation by ONR. More details can be found at: http://www.hse.gov.uk/newreactors/index.htm.

The Environment Agency has issued a Permit for the proposed Hinkley Point C development by EDF Energy and Centrica's joint venture company, NNB Generation Company Limited (NNB GenCo) to discharge (non-radioactive) waste water discharges for offsite construction (Environment Agency, 2012a). In addition, in 2013, the Environment Agency issued three further environmental permits for the site covering (i) disposal and discharge of radioactive wastes, (ii) operation of standby power supply systems using diesel generators and (iii) discharge cooling water and liquid effluents into the Bristol Channel. More information can be found at: http://www.environment-agency.gov.uk/hinkleypoint.

1.3.3 Managing radioactive liabilities in the UK

The UK Government and Devolved Administrations have ratified the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management (International Atomic Energy Agency, 1997). This agreement aims to ensure that individuals, society and the environment are protected from the harmful effects of ionising radiation as a result of the management of spent nuclear fuel and radioactive waste. The UK has regularly issued reports, demonstrating compliance with the Convention and these are provided to the International Atomic Energy Agency (IAEA) as part of an international review process (for example, Department for Environment, Food and Rural Affairs, 2004a; 2005c and Department of Energy and Climate Change, 2008; 2010)

The current arrangements for managing civil sector nuclear clean up are founded in the Energy Act 2004, which led to the establishment of the Nuclear Decommissioning Authority (NDA) in April 2005. The NDA is responsible for nuclear sites formerly owned by British Nuclear Fuels Limited (BNFL), including ownership of its assets and liabilities, and United Kingdom Atomic Energy Authority (UKAEA). It is responsible for developing and implementing an overall strategy for cleaning up the civil public sector nuclear legacy safely, securely, and in ways that protect the environment. The current strategy was published in 2012 (Nuclear Decommissioning Authority, 2012) and the plan for 2013/16 is available (Nuclear Decommissioning Authority, 2013). The NDA published an up-to-date inventory and forecast of radioactive wastes in the UK jointly with DECC in 2011 (Department of Energy and Climate Change, 2011a). A recent report has considered the financial implications of nuclear decommissioning and waste management (MacKerron, 2012).

In 2007, the UK Government and Devolved Administrations issued a new UK-wide policy for managing low level waste (Department for Environment, Food and Rural Affairs, 2007a), which includes:

- Maintaining a focus on safety whilst allowing greater flexibility in managing LLW
- An emphasis on community involvement
- The NDA creating a UK-wide strategy for managing LLW from the nuclear industry, including considering whether a replacement(s) of the national disposal facility near Drigg in Cumbria might be needed
- Initiating a UK-wide strategy for managing LLW from non-nuclear industries
- Minimising waste

Complementing the low-level waste policy, the UK Government published its policy for managing higher activity radioactive waste in the White Paper *'Managing Radioactive Waste Safely (MRWS): A Framework for Implementing Geological Disposal'* in June 2008 (Department for Environment, Food and Rural Affairs, Department for Business, Enterprise and Regulatory Reform, Welsh Assembly Government and Northern Ireland Assembly, 2008). This followed from the independent Committee on Radioactive Waste Management's (CoRWM) recommendations that geological disposal, preceded by safe and secure interim storage, was the best available approach for the long-term management of higher activity radioactive waste (Department for Environment, Food and Rural Affairs, 2007b). The UK Government takes a volunteer and partnership approach to siting a facility, and communities were invited to discuss with Government the possibility of hosting a geological disposal facility at some point in the future. The UK Government and the Devolved Administrations of Northern Ireland, Scotland and Wales have published their response to CoRWM's report on national research and development for the long term management of higher activity radioactive waste (Department of Energy and Climate Change, Department of Environment (Northern Ireland), the Scottish Government and the Welsh Assembly Government, 2010). Independent scrutiny of the Government's long-term management, storage and disposal of radioactive waste will continue by CoRWM who have published their proposed work programme for 2012-2015 (Committee on Radioactive Waste Management, 2012).

An annual report has been issued by DECC summarising progress in implementing plans for geological disposal, including the setting up of a Geological Disposal Implementation Board (Department of Energy and Climate Change, 2011a). The Board enables key stakeholders including nuclear operators, local government representatives, regulators and non-government organisations to observe and provide input to the MRWS programme. DECC has issued two reports on the assessment and identification of candidate sites for disposal (Department of Energy and Climate Change, 2012a and b).

In 2013, the existing site selection process ended when the west Cumbrian option was rejected by Cumbria County Council, although it was favoured by both Allerdale and Copeland Borough Councils. The UK Government remains firmly committed to geological disposal as the right policy for the long-term safe and secure management of higher activity radioactive waste and has issued a call for evidence on the site selection aspects of the ongoing MRWS programme (Department of Energy and Climate Change, 2013).

The Scottish Government has decided not to progress geological disposal as it does not consider that this is the right way forward for Scotland. For higher activity waste, the Scottish Government's policy is that the long-term management of such waste should be in near-surface facilities. Facilities should be located as near to the site as possible. Developers will need to demonstrate how the facilities will be monitored and how packages of waste could be retrieved (Scottish Government, 2011).

The Welsh Government continues to play a full part in the Managing Radioactive Waste Safely programme in order to secure the long term safety of radioactive wastes, to ensure the implementation of a framework appropriate to the needs of Wales and to ensure that the interests of Wales are taken into account in the development of policies in this area. The Welsh Government has reserved its position about the policy for geological disposal of radioactive waste.

Some low level radioactive waste, mostly from non-nuclear sites, and some very low level radioactive waste is currently disposed of in landfill by controlled burial (Section 7). There is still a large amount of solid low level radioactive wastes that will require disposal. Some will be sent to the LLWR near Drigg, the low level radioactive waste from Dounreay will be disposed of at a new facility close to the site, and further alternative disposal options are also being considered. Guidance on requirements for authorisation for geological and near-surface disposal facilities has now been issued (Environment Agency and Northern Ireland Environment Agency (2009), Environment Agency, Northern Ireland Environment Agency and Scottish Environment Protection Agency (2009) and Environment Agency (2013a)). In addition, SEPA has issued a policy statement which specifies how it will regulate the disposal of Low Level Waste from nuclear licensed sites. The position identified has several practical implications including simplification of the process such that individual disposal sites need no longer be named in authorisations (SEPA, 2012).

1.3.4 Solid radioactive waste disposal at sea

In the past, packaged solid waste of low specific activity was disposed of deep in the North Atlantic Ocean. The last disposal of this type was in 1982. The UK Government announced at the OSPAR Ministerial meeting in 1998 that it was stopping disposal of this material at sea. At that meeting, Contracting Parties agreed that there would no longer be any exception to prohibiting the dumping of radioactive substances, including waste (OSPAR, 1998). The environmental impact of the deep ocean disposals was predicted by detailed mathematical modelling and has been shown to be negligible (Organisation for Economic Co-operation and Development, Nuclear Energy Agency, 1985). Disposals of small amounts of waste also took place from 1950 to 1963 in a part of the English Channel known as the Hurd Deep. The results of environmental monitoring of this area in 2012 are presented in Section 9 and confirm that the radiological impact of these disposals was insignificant.

In England, the Marine Management Organisation (MMO) administers a range of statutory controls that apply to marine works on behalf of the Secretary of State for Environment, Food and Rural Affairs; this includes issuing licences under the Marine and Coastal Access Act (MCAA), 2009 (United Kingdom - Parliament, 2009) for the disposal of dredged material at sea. Licences for disposals made in Scottish waters and around the coast of Northern Ireland are the responsibility of the Scottish Government (Marine Scotland) and the Department of Environment (NIEA), respectively. As of 1 April 2010, licences for Welsh waters are the responsibility of the Welsh Government.

The protection of the marine environment is considered before a licence is issued. Since dredge materials will contain varying concentrations of radioactivity from natural and artificial sources, assessments are carried out, when appropriate, to provide reassurance that there is no significant risk to the food chain or other risk from the disposal. Guidance on exemption criteria for radioactivity in relation to sea disposal is available from the IAEA (International Atomic Energy Agency, 1999). IAEA has published a system of assessment that can be applied to dredge spoil disposal (International Atomic Energy Agency, 2003) and which has been adapted to reflect operational practices in England and Wales (McCubbin and Vivian, 2006). An assessment of a licence application is provided in Appendix 5.

1.3.5 Other sources of radioactivity

There are several other man-made sources of radioactivity that may affect the food chain and the environment. These could include disposals of material from offshore installations, transport incidents, satellite re-entry, releases from overseas nuclear installations and the operation of nuclear powered submarines. PHE has assessed incidents involving the transport of radioactive materials in the UK (Harvey and Jones, 2012) and have also considered the effects of discharges from the oil and gas industry into the marine environment (Harvey *et al.,* 2010). Using modelling, the highest individual (per head of population) annual doses for discharges from 2005-2008 were estimated to be less than 0.001 mSv. Submarine berths in the UK are monitored by the MoD (DSTL Radiological Protection Services, 2013). General monitoring of the British Isles is carried out as part of the programmes described in this report, to detect any gross effects from the sources above. No such effects were found in 2012. Low concentrations

of radionuclides were detected in the marine environment around the Channel Islands (Section 9) and these may be partly due to discharges from the nuclear fuel reprocessing plant at La Hague in France.

The Environmental Protection Act 1990 provides the basis, through the Environment Act 1995, for a regulatory regime for identifying and remediating contaminated land. The regime provides a system for identifying and remediating land, where contamination is causing people to be exposed to lasting exposure to radiation resulting from the after-effects of a radiological emergency, past practice or post work activity; and where intervention is liable to be justified. A profile of industries which may have caused land contamination has been published (Department for Environment, Food and Rural Affairs, 2006). Dose criteria for the designation of contaminated land have been determined for England and Wales (Smith *et al*., 2006). A report giving an overview of the progress made by local authorities and the Environment Agency in identifying and remediating contaminated land was published in 2009 (Environment Agency, 2009c). Defra has consulted on proposals for revising Statutory Guidance on contaminated land, including the separation of guidance for radioactive and non-radioactive contamination into separate documents. The consultation closed in March 2011 and new Statutory Guidance has now been published (Department of Energy and Climate Change, 2012c). The Environment Agency has issued a series of Briefing Notes that provide information on land contaminated with radioactivity in England and Wales (Environment Agency, 2012b). To date, no site has been determined as 'contaminated land' due to radioactivity in England and Wales.

Equivalent legislation for identifying and remediating contaminated land comprising The Radioactive Contaminated Land Regulations (Northern Ireland) 2006 and subsequent amending legislation, issued in 2007 and 2010, exists as Statutory Instruments in Northern Ireland (Statutory Instruments, 2007; 2010).

In October 2007, the Radioactive Contaminated Land (Scotland) Regulations came into force by amending Part ll A of the Environmental Protection Act 1990. SEPA has powers to inspect land that may be contaminated with radioactivity, to decide if land should be identified as radioactive contaminated land and require remediation if considered necessary. Revised Statutory Guidance was issued to SEPA in 2009. This guidance is broadly similar to that issued to the Environment Agency, apart from the fact that for the designation of radioactive contaminated land, clear dose criteria are set for homogeneous and heterogeneous contamination, and whether or not the probability of receiving the dose should be taken into account.

The contribution of aerial radioactive discharges from UK installations to concentrations of radionuclides in the marine environment has been studied (Department for Environment, Food and Rural Affairs, 2004b). Tritium and carbon-14 were predicted to be at concentrations that were particularly high in relation to actual measured values in the Irish Sea. However, the study suggested that this was due to unrealistic assumptions being made in the assessment. The main conclusion was that aerial discharges do not make a significant contribution to levels in the marine environment. On occasion, the effects of aerial discharges are detected in the aquatic environment, and conversely the effects of aquatic discharges are detected on land. Where this is found, appropriate comments are made in this report.

All sources of ionising radiation exposure to the UK population are reviewed, the most recent report being published in 2005 (Watson *et al*., 2005). Sources of naturally-occurring radiation and man-made radiation produced for medical use predominate. The average annual dose from naturally-occurring radiation was found to be 2.2 mSv and about half of this was from radon exposure indoors. The average annual dose from artificial radiation was 0.42 mSv, mainly derived from medical procedures, such as x-rays. The overall average annual dose was 2.7 mSv. Exposures from non-medical man-made sources were very low and discharges of radioactive wastes contributed less than 0.1 per cent of the total. These figures represent the exposure of the average person.

To ensure protection of the public and environment, this RIFE report is directed at establishing the exposure of people who might receive the highest possible doses due to radioactive waste discharges as a result of their age, diet, location or habits. It is the exposure of these people which forms the basis for comparisons with dose limits in EU and UK law.

Table 1.1. Individual doses – direct radiation pathway, 2012

Site	Exposure, mSv
Nuclear fuel production and reprocessing	
Capenhurst	0.085
Sellafield	0.002
Springfields	<0.029
Research establishments	
Dounreay	0.004
Harwell	0.018
Winfrith	Bgd[a]
Nuclear power stations	
Berkeley	Bgd[a]
Bradwell	Bgd[a]
Chapelcross	Bgd[a]
Dungeness	0.013[b]
Hartlepool	<0.010
Heysham	<0.010
Hinkley Point	<0.010[c]
Hunterston	0.031[d]
Oldbury	Bgd[a]
Sizewell	<0.020[e]
Torness	<0.020
Trawsfynydd	0.023
Wylfa	Bgd[a]
Defence establishments	
Aldermaston	Bgd[a]
Barrow	Bgd[a]
Burghfield	Bgd[a]
Derby	Bgd[a]
Devonport	Bgd[a]
Faslane	Bgd[a]
Rosyth	Bgd[a]
Radiochemical production	
Amersham	0.22
Cardiff	Bgd[a]
Industrial and landfill sites	
LLWR near Drigg	0.035

[a] *Doses not significantly different from natural background*
[b] *Datum for Dungeness A. Dungeness B (<0.010) not used*
[c] *Datum for Hinkley B. Hinkley A (Bgd[a]) not used*
[d] *Datum for Hunterston A. Hunterston B (<0.020) not used*
[e] *Datum for Sizewell B. Sizewell A (Bgd[a]) not used*

Table 1.2. *Total doses* integrated across pathways, 2012

Site	Most exposed people[a]	Exposure, mSv	
		Total	Dominant contributions[b]
A Gaseous releases and direct radiation from the site			
Aldermaston and Burghfield	Infant milk consumers	<0.005	Milk, ^{3}H, ^{137}Cs, ^{234}U
Amersham	Local adult inhabitants (0-0.25km)	0.22	Direct radiation
Barrow[c]	–	–	–
Berkeley and Oldbury	Infant milk consumers	<0.005	Milk, ^{14}C, ^{35}S
Bradwell	Prenatal children of green vegetable consumers	<0.005	Green vegetables, potatoes, root vegetables, ^{14}C
Capenhurst	Local inhabitants aged 10yr (0-0.25km)	0.085	Direct radiation
Cardiff	Infant milk consumers	<0.005	Milk, ^{14}C, ^{32}P, ^{35}S, ^{137}Cs
Chapelcross	Infant milk consumers	0.011	Milk, ^{3}H, ^{14}C, ^{35}S, ^{90}Sr
Derby	Infant cattle meat consumers	<0.005	Green vegetables, ^{131}I, ^{241}Am
Devonport	Prenatal children of domestic fruit consumers	<0.005	Domestic fruit, green vegetables, ^{3}H
Dounreay	Infant milk consumers	0.017	Milk, ^{90}Sr, ^{106}Ru, ^{129}I, ^{144}Ce, ^{241}Am
Dungeness	Local adult inhabitants (0-0.25km)	0.014	Direct radiation
Faslane	Adult consumers of cattle meat	<0.005	Cattle meat, ^{137}Cs, ^{241}Am
Hartlepool	Local adult inhabitants (0.5-1km)	0.010	Direct radiation
Harwell	Prenatal children of local inhabitants (0-0.25km)	0.018	Direct radiation
Heysham	Local adult inhabitants (0-0.25km)	0.011	Direct radiation, ^{14}C
Hinkley Point	Occupants for direct radiation aged 10y	0.011	Direct radiation
Hunterston	Prenatal children of local inhabitants (0.25-0.5km)	0.032	Direct radiation
LLWR near Drigg	Local infant inhabitants (0.5-1km)	0.040	Direct radiation
Rosyth[c]	–	–	
Sellafield	Infant root vegetable consumers	0.010	Domestic fruit, other vegetables, potatoes, root vegetables, ^{90}Sr, ^{106}Ru
Sizewell	Local adult inhabitants (0-0.25km)	0.021	Direct radiation
Springfields	Local adult inhabitants (0-0.25km)	0.029	Direct radiation
Torness	Local adult inhabitants (0.5-1km)	0.020	Direct radiation
Trawsfynydd	Infant local inhabitants (0.25-0.5km)	0.025	Direct radiation
Winfrith	Infant milk consumers	<0.005	Milk, ^{14}C, ^{137}Cs
Wylfa	Local inhabitants aged 1y (0.25-0.5km)	<0.005	Milk, ^{14}C, ^{35}S, ^{137}Cs
B Liquid releases from the site			
Aldermaston and Burghfield	Adult occupants over riverbank	<0.005	Exposure over riverbank
Amersham	Adult occupants over riverbank	<0.005	Gamma dose rate over riverbank
Barrow	Adult occupants on houseboat	0.057	Gamma dose rate over sediment
Berkeley and Oldbury	Adult occupants over sediment	0.014	Gamma dose rate over sediment
Bradwell	Adult occupants over sediment	<0.005	Exposure over sediments
Capenhurst	Occupants over riverbank aged 10y	0.007	Gamma dose rate over sediment
Cardiff	Prenatal children of occupants over sediment	0.005	Gamma dose rate over sediment
Chapelcross	Adult occupants over sediment	0.010	Gamma dose rate over sediment
Derby	Adult consumers of locally sourced water	<0.005	Water, ^{60}Co
Devonport	Adult occupants on houseboats	<0.005	Exposure over sediments
Dounreay	Adult occupants over sediment	0.005	Gamma dose rate over sediment
Dungeness	Adult occupants over sediment	0.010	Direct radiation, gamma dose rate over sediment
Faslane	Adult occupants over sediment	<0.005	Gamma dose rate over sediment
Hartlepool	Adult occupants over sea coal/sand	0.009	Gamma dose rate over sea coal/sand
Harwell	Prenatal children of occupants over sediment	0.005	Gamma dose rate over riverbank
Heysham	Adult mollusc consumers	0.025	Fish, gamma dose rate over sediment, molluscs, ^{137}Cs, $^{239/240}Pu$, ^{241}Am
Hinkley Point	Adult occupants over sediment	0.010	Direct radiation, gamma dose rate over sediment
Hunterston	Adult fish consumers	<0.005	Crustaceans, fish, ^{137}Cs, ^{241}Am
Rosyth	Adult fish consumers	<0.005	Fish, ^{241}Am
Sellafield, Whitehaven and LLWR[d]	Adult mollusc consumers	0.30[e]	Crustaceans, fish, molluscs, ^{210}Po
Sizewell	Adult occupants over sediment	0.010	Gamma dose rate over sediment
Springfields	Adult occupants on houseboats	0.068	Gamma dose rate over sediment
Torness	Adult fish consumers	0.005	Direct radiation, fish, ^{241}Am
Trawsfynydd	Adult fish consumers	0.010	Exposure over sediment, fish, ^{137}Cs, ^{241}Am
Winfrith	Adult occupants over sediment	<0.005	Gamma dose rate over sediment
Wylfa	Adult occupants over sediment	0.006	Gamma dose rate over sediment

Table 1.2. continued

Site	Most exposed people[a]	Exposure, mSv	
		Total	Dominant contributions[b]
C All sources			
Aldermaston and Burghfield	Infant milk consumers	<0.005	Milk, ^{3}H, ^{137}Cs, ^{234}U
Amersham	Local adult inhabitants (0-0.25km)	0.22	Direct radiation
Barrow	Adult occupants on houseboat	0.057	Gamma dose rate over sediment
Berkeley and Oldbury	Adult occupants over sediment	0.014	Gamma dose rate over sediment
Bradwell	Prenatal children of green vegetable consumers	<0.005	Green vegetables, potatoes, root vegetables, ^{14}C
Capenhurst	Local inhabitants aged 10y (0-0.25km)	0.085	Direct radiation
Cardiff	Prenatal children of occupants over sediment	0.005	Gamma dose rate over sediment
Chapelcross	Infant milk consumers	0.011	Milk, ^{3}H, ^{14}C, ^{35}S, ^{90}Sr
Derby	Infant cattle meat consumers	<0.005	Green vegetables, ^{131}I, ^{241}Am
Devonport	Adult occupants on houseboats	<0.005	Exposure over sediments
Dounreay	Infant milk consumers	0.017	Milk, ^{90}Sr, ^{106}Ru, ^{129}I, ^{144}Ce, ^{241}Am
Dungeness	Local adult inhabitants (0.5-1km)	0.015	Direct radiation
Faslane	Adult consumers of cattle meat	<0.005	Cattle meat, ^{137}Cs, ^{241}Am
Hartlepool	Local adult inhabitants (0-0.25km)	0.015	Direct radiation, gamma dose rate over sediment
Harwell	Prenatal children of local inhabitants (0-0.25km)	0.018	Direct radiation
Heysham	Adult mollusc consumers	0.025	Fish, gamma dose rate over sediment, molluscs, ^{137}Cs, $^{239/240}Pu$, ^{241}Am
Hinkley Point	Prenatal children of occupants for direct radiation	0.011	Direct radiation
Hunterston	Prenatal children of local inhabitants (0.25-0.5km)	0.032	Direct radiation
Rosyth	Adult fish consumers	<0.005	Fish, ^{241}Am
Sellafield, Whitehaven and LLWR[d]	Adult mollusc consumers	0.30[e]	Crustaceans, fish, molluscs, ^{210}Po
Sizewell	Local adult inhabitants (0-0.25km)	0.021	Direct radiation
Springfields	Adult occupants on houseboats	0.068	Gamma dose rate over sediment
Torness	Local adult inhabitants (0.5-1km)	0.020	Direct radiation
Trawsfynydd	Infant local inhabitants (0.25-0.5km)	0.025	Direct radiation
Winfrith	Infant milk consumers	<0.005	Milk, ^{14}C, ^{137}Cs
Wylfa	Adult consumers of marine plants and algae	0.006	Fish, gamma dose rate over sediment

[a] *Selected on the basis of providing the highest dose from the pathways associated with the sources as defined in A, B or C*

[b] *Pathways and radionuclides that contribute more than 10% of the total dose. Some radionuclides are reported as being at the limits of detection and based on these measurements, an upper estimate of dose is calculated*

[c] *The effects of gaseous discharges and direct radiation are not assessed for this site*

[d] *Sellafield, Whitehaven and LLWR near Drigg sites are considered together as their effects are dominated by radioactivity in a common area of the Cumbrian coast*

[e] *The doses from man-made and naturally occurring radionuclides were 0.082 and 0.22 mSv respectively. The source of naturally occurring radionuclides was a phosphate processing works near Sellafield at Whitehaven. Minor discharges of radionuclides were also made from the LLWR near Drigg site into the same area*

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

Site	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Aldermaston and Burghfield	<0.005	<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										0.057
Berkeley and 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
Cardiff	0.038	0.023	0.023	0.011	0.008	0.007	0.006	0.006	0.006	0.005
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	0.012	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	0.021	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	0.011
Hunterston		0.10	0.090	0.074	0.090	0.077	0.067	0.067	0.050	0.032
Rosyth		*<0.005*	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Sellafield, Whitehaven and LLWR[b]	0.66	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
Winfrith	<0.005	<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

[a] *Where no data is given, no assessment was undertaken due to a lack of suitable habits data at the time. Data in italics signify assessments performed to show trends in total dose over the five-year period from 2004-2008, using subsequently obtained habits data*

[b] *Sellafield, Whitehaven and LLWR near Drigg sites are considered together as their effects are dominated by radioactivity in a common area of the Cumbrian coast*

Table 1.4. Source specific doses due to discharges of radioactive waste in the United Kingdom, 2012

Establishment	Radiation exposure pathways	Gaseous or liquid source[d]	Exposure, mSv[b] per year	Contributors[c]
Nuclear fuel production and processing				
Capenhurst	Inadvertent ingestion of water and sediment and external[g]	L	0.009	Ext
	Terrestrial foods, external and inhalation near site[i]	G	<0.005[h]	^{234}U
Springfields	External (skin) to fishermen	L	0.054[f]	Beta
	Fish and shellfish consumption	L	0.022	Ext ^{241}Am
	Terrestrial foods, external and inhalation near site	G	<0.005[h]	$^{230/232}Th$
	External in intertidal areas (children playing)[a,g]	L	<0.005	Ext ^{241}Am
	Occupancy of houseboats	L	0.083	Ext
	External in intertidal areas (farmers)	L	0.034	Ext
	Wildfowl consumers	L	0.006	Ext ^{137}Cs
Sellafield[e]	Fish and shellfish consumption and external in intertidal areas (2008-2012 surveys) (excluding naturally occurring radionuclides)[k]	L	0.14	Ext ^{241}Am
	Fish and shellfish consumption and external in intertidal areas (2008-2012 surveys) (including naturally occurring radionuclides)[l]	L	0.33	^{210}Po ^{241}Am
	Fish and shellfish consumption and external in intertidal areas (2012 surveys) (excluding naturally occurring radionuclides)[k]	L	0.094	Ext ^{241}Am
	Terrestrial foods, external and inhalation near Sellafield[i]	G	0.016	^{90}Sr
	Terrestrial foods at Ravenglass[i]	G/L	0.018	^{90}Sr ^{14}C
	External in intertidal areas (Ravenglass)[a]	L	0.017	Ext ^{241}Am
	Occupancy of houseboats (Ribble estuary)	L	0.083	Ext
	External (skin) to bait diggers	L	0.040[f]	Beta
	Handling of fishing gear	L	0.060[f]	Beta
	Porphyra/laverbread consumption in South Wales	L	<0.005	^{241}Am
	Seaweed/crops at Sellafield	L	0.008	
Research establishments				
Culham	Water consumption[n]	L	<0.005	
Dounreay	Fish and shellfish consumption and external in intertidal areas	L	0.006	Ext ^{241}Am
	Terrestrial foods, external and inhalation near site[i]	G	0.027	^{241}Am
Harwell	Fish consumption and external to anglers	L	0.005	Ext
	Terrestrial foods, external and inhalation near site[i]	G	<0.005	^{3}H ^{222}Rn
Winfrith	Fish and shellfish consumption and external in intertidal areas	L	<0.005	Ext ^{241}Am
	Terrestrial foods, external and inhalation near site[i]	G	<0.005	^{14}C ^{137}Cs
Nuclear power production				
Berkeley and Oldbury	Fish and shellfish consumption and external in intertidal areas	L	0.018	Ext ^{241}Am
	Terrestrial foods, external and inhalation near site[i]	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[o]	G	<0.005	^{3}H ^{14}C
Chapelcross	Wildfowl and fish consumption and external in intertidal areas	L	<0.005	Ext
	Crustacean consumption	L	<0.005	^{137}Cs ^{241}Am
	Terrestrial foods, external and inhalation near site[i]	G	0.010	^{14}C ^{90}Sr
Dungeness	Fish and shellfish consumption and external in intertidal areas	L	0.012	Ext ^{241}Am
	Occupancy of houseboats	L	0.019	Ext
	Terrestrial foods, external and inhalation near site[i]	G	0.005	^{14}C
Hartlepool	Fish and shellfish consumption and external in intertidal areas	L	0.008	Ext ^{241}Am
	Exposure over sand and sea coal	L	0.009	Ext
	Terrestrial foods, external and inhalation near site[i]	G	0.005	^{14}C
Heysham	Fish and shellfish consumption and external in intertidal areas	L	0.034	Ext ^{241}Am
	External in intertidal areas (turf cutters)	L	0.018	Ext
	Terrestrial foods, external and inhalation near site[i]	G	0.008	^{14}C
Hinkley Point	Fish and shellfish consumption and external in intertidal areas	L	0.013	Ext ^{241}Am
	Terrestrial foods, external and inhalation near site[i]	G	0.007	^{14}C
Hunterston	Fish and shellfish consumption and external in intertidal areas	L	<0.005	^{137}Cs ^{241}Am
	Terrestrial foods, external and inhalation near site[i]	G	0.007	^{14}C ^{90}Sr
Sizewell	Fish and shellfish consumption and external in intertidal areas	L	<0.005	Ext ^{241}Am
	Occupancy of houseboats	L	0.010	Ext
	Terrestrial foods, external and inhalation near site[i]	G	<0.005	^{14}C ^{35}S

Table 1.4. continued

Establishment	Radiation exposure pathways	Gaseous or liquid source[d]	Exposure, mSv[b] per year	Contributors[c]
Torness	Fish and shellfish consumption and external in intertidal areas	L	<0.005	^{110}Ag ^{241}Am
	Terrestrial foods, external and inhalation near site[i]	G	0.006	^{90}Sr
Trawsfynydd	Fish consumption and external to anglers	L	0.010	Ext ^{241}Am
	Terrestrial foods, external and inhalation near site[i]	G	<0.005	^{14}C ^{90}Sr
Wylfa	Fish and shellfish consumption and external in intertidal areas	L	0.009	Ext ^{241}Am
	Terrestrial foods, external and inhalation near site[i]	G	<0.005	^{14}C ^{35}S
Defence establishments				
Aldermaston	Fish consumption and external to anglers	L	<0.005[h]	Ext ^{234}U
	Terrestrial foods, external and inhalation near site[i]	G	<0.005[h]	^{3}H
Barrow	Occupancy of houseboats	L	0.055	Ext
	Fish and shellfish consumption and external in intertidal areas	L	0.033	Ext ^{241}Am
Derby	Water consumption, fish consumption and external to anglers[n]	L	<0.005	Ext
	Terrestrial foods, external and inhalation near site[i]	G	<0.005	
Devonport	Fish and shellfish consumption and external in intertidal areas	L	<0.005	Ext ^{14}C
	Occupancy of houseboats	L	<0.005	Ext
	Terrestrial foods, external and inhalation near site[o]	G	<0.005	^{14}C
Faslane	Fish and shellfish consumption and external in intertidal areas	L	<0.005	Ext ^{241}Am
	Terrestrial food consumption	G	<0.005	^{137}Cs
Holy Loch	External in intertidal areas	L	<0.005	Ext
Rosyth	Fish and shellfish consumption and external in intertidal areas	L	<0.005	Ext ^{241}Am
Radiochemical production				
Amersham	Fish consumption and external to anglers	L	<0.005	Ext ^{137}Cs
	Terrestrial foods, external and inhalation near site[i]	G	0.009	^{222}Rn
Cardiff	Fish and shellfish consumption and external in intertidal areas[o]	L	0.009	Ext ^{3}H
	Terrestrial foods, external and inhalation near site[i]	G	0.007	^{14}C
	Inadvertent ingestion and riverbank occupancy (River Taff)	L	<0.005	
Industrial and landfill				
LLWR near Drigg	Terrestrial foods[i]	G	0.012	
	Water consumption[n]	L	<0.005	
Whitehaven	Fish and shellfish consumption[j]	L	0.19	^{210}Po ^{210}Pb
	Fish and shellfish consumption[m]	L	0.33	^{210}Po ^{241}Am

[a] *Includes a component due to inadvertent ingestion of water or sediment or inhalation of resuspended sediment where appropriate*
[b] *Unless otherwise stated represents committed effective dose calculated using methodology of ICRP-60 to be compared with the dose limit of 1 mSv (see Appendix 1). Exposures due to marine pathways include the far-field effects of discharges of liquid waste from Sellafield. Unless stated otherwise, the critical group is represented by adults*
[c] *The top two contributors 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. Some assessments for contributions are based on data being wholly at limits of detection. Where this is the case the contributor is not listed in the table. 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] *Dominant source of exposure. G for gaseous wastes. L for liquid wastes or surface water near solid waste sites. See also footnote 'c'*
[e] *The estimates for marine pathways include the effects of liquid discharges from LLWR. The contribution due to LLWR is negligible*
[f] *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)*
[g] *10 y old*
[h] *Includes a component due to natural sources of radionuclides*
[i] *1 y old*
[j] *Excluding the effects of artificial radionuclides from Sellafield*
[k] *Excluding the effects of enhanced concentrations due to the legacy of discharges of naturally occurring radionuclides from a phosphate processing works, Whitehaven*
[l] *Including the effects of enhanced concentrations due to the legacy of discharges of naturally occurring radionuclides from a phosphate processing works, Whitehaven*
[m] *Including the effects of artificial radionuclides from Sellafield*
[n] *Water is from rivers and streams and not tap water*
[o] *Prenatal children*

2. Nuclear fuel production and reprocessing

Key points

- Doses, discharges, environmental concentrations and dose rates in 2012 were broadly similar to those in 2011

Capenhurst, Cheshire

- The NDA completed the Capenhurst Site Integration in 2012
- Public radiation doses from all sources decreased in 2012
- Concentrations of technetium-99 in grass were the lowest reported in 2012

Springfields, Lancashire

- Public radiation doses from all sources were lower in 2012 and less than 7 per cent of the dose limit. People living on houseboats received the highest exposure
- Gaseous discharges of krypton-85 decreased and liquid discharges of uranium and technetium-99 increased
- Gamma dose rates were generally similar in the vicinity of the houseboats in 2012

Sellafield, Cumbria

- Public radiation doses from all sources (*total dose*) were less than 30 per cent of the public dose limit
- The highest doses were from seafood affected by past phosphate processing at Whitehaven and by historical discharges from Sellafield
- The consumption of seafood contributed to approximately 95 per cent of the *total dose*
- There was a change in the people representative of those most exposed in 2012
- Radiation dose to seafood consumers from natural radionuclides was higher than in 2011, due to an increase in polonium-210 in crustaceans from past phosphate processing at Whitehaven. The *total dose* from Sellafield discharges increased due to the revision in mollusc consumption rate
- A revised permit was issued, including a rationalisation of some gaseous and liquid discharge limits
- Gaseous discharges were generally similar to 2011, except antimony-125, krypton-85 and iodine-129 which decreased in 2012
- Liquid discharges of tritium, carbon-14, iodine-129, caesium-137, cerium-144 and americium-241 were lower in 2012
- Concentrations and dose rates were generally similar to those in 2011. Plutonium radionuclides and americium-241 were generally similar in shellfish

This section considers the results of monitoring by the Environment Agency, Food Standards Agency, Northern Ireland Environment Agency and the Scottish Environment Protection Agency of four sites in the UK associated with civil nuclear fuel production and reprocessing. These sites are at:

Capenhurst, where there are two nuclear licensed sites (one carrying out uranium enrichment and owned by Urenco UK Limited (UUK), the other undergoing decommissioning and owned by the NDA); Springfields, a site where fuel for nuclear power stations is fabricated; Sellafield, a site where irradiated fuel from nuclear power stations is reprocessed.

Both the Springfields and Sellafield sites are owned by the NDA. In 2008, the NDA confirmed that the programme to secure a new Parent Body Organisation (PBO) for the Sellafield Site Licence Company (SLC), Sellafield Limited, had been completed, with the site management contract being transferred to a consortium, Nuclear Management Partners Limited (NMP). The NDA's Capenhurst site was also included in the contract, but a further contract was signed for the site to be leased long-term to Urenco and so it became part of the UUK licensed site. On 30 November 2012, the NDA completed the transfer of its Capenhurst site, with the transition of Sellafield Limited activities to Capenhurst Nuclear Services (CNS), an Urenco Group company, creating one nuclear licensed site (Capenhurst Site Integration). The Springfields site is leased long-term to Springfields Fuels Limited and have a contract with NDA to decommission legacy facilities on the site. The Windscale nuclear licensed site, also owned by the NDA, is located on the Sellafield site and holds its own nuclear licence, which was transferred to Sellafield Limited in 2008. An integrated environment permit was also issued for the Windscale and Sellafield sites in 2008. Windscale is discussed in Section 2.4. The LLWR near Drigg is discussed in Section 7.1.

Gaseous and liquid discharges from each of these sites are regulated by the Environment Agency. In 2012, gaseous and liquid discharges were below permit limits for each of the sites (see Appendix 2). The medium-term trends in doses, discharges and environmental concentrations at these sites were considered in a summary report (Environment Agency, Food Standards Agency, Northern Ireland Environment Agency and Scottish Environment Protection Agency, 2010b).

2.1 Capenhurst, Cheshire

There are two adjacent nuclear licensed sites at Capenhurst, near Ellesmere Port, one owned by the NDA and one by Urenco UK Limited (UUK). The NDA site comprises uranic material storage facilities and activities associated with decommissioning redundant plant. The UUK site operates three plants producing enriched uranium for nuclear power stations.

With effect from 1 September 2012, the environmental permits for Urenco UK Limited and Sellafield Limited (Capenhurst) were varied to reflect the granting of an environmental permit to Sita (Lancashire) Limited, in respect of the Clifton Marsh landfill site. The consignors were previously permitted to dispose of solid LLW at Clifton Marsh in their own right. Following the variations, the permits allowed transfer instead, but only to receiving sites who themselves hold permits to receive the waste.

In 2010, the NDA and UUK signed a set of non-binding commercial principles to support a potential transfer of the NDA-owned Capenhurst site to UUK. A further agreement was signed in December 2011 confirming the future transfer of the NDA-owned site, enabling existing decommissioning and storage operations to transfer to UUK and the Capenhurst site to transition to a single licensee status. The NDA completed the transfer of its Capenhurst site, with the transition of Sellafield Limited activities to Capenhurst Nuclear Services (CNS) on 30 November 2012. Totalled between the operators, the overall gaseous and liquid discharge limits were unchanged.

The most recent habits survey was conducted in 2008 (Tipple *et al*., 2009).

Doses to the public

In 2012, the *total dose* from all pathways and sources is assessed to have been 0.085 mSv (Table 2.1), or less than 9 per cent of the dose limit, and down from 0.095 mSv (in 2011). The dose was mostly due to direct radiation from the Capenhurst site. The dose assessment identifies local children living near to the site as the most exposed group. The decrease from 0.095 mSv in 2011 was due to a lower estimate of direct radiation from the site. The trend in *total dose* over the period 2004 – 2012 is given in Figure 1.1. Any changes in total doses with time are attributable to changes in the estimates of direct radiation from the site.

Source specific assessments indicated exposures for high-rate consumers of locally grown foods, and for children playing in and around Rivacre Brook, were less than 0.085 mSv in 2012 (Table 2.1). As in previous years, the highest dose was 0.009 mSv in 2012 for 10 year old children (who play near the brook and may inadvertently ingest water and sediment) and similar to that in 2011 (0.010 mSv). The dose is estimated using cautious assumptions for occupancy of the bank of the brook, inadvertent ingestion rates of water and sediment and gamma dose rates.

Gaseous discharges and terrestrial monitoring

Uranium is the main radioactive constituent of gaseous discharges from Capenhurst, with small amounts of other radionuclides present in discharges by CNS Limited (previously Sellafield Limited). The main focus for terrestrial sampling was on the content of technetium-99 and uranium in milk, fruit, vegetables, silage, grass and soil. Results for 2012 are given in Table 2.2(a). Concentrations of radionuclides in milk and food samples around the site were very low and similar to previous years, as were concentrations of technetium-99 and uranium in soils. Figure 2.1 shows the trend of technetium-99 concentrations in grass from 2003. The trend reflects the reductions in discharges of technetium-99 from recycled uranium and the reported technetium-99 concentration is the lowest value in 2012. In future UUK is expecting to increase the enrichment of reprocessed uranium, which may lead to increases in discharges of technetium-99 and neptunium-237. However, no increase in the discharge limits is expected.

Liquid waste discharges and aquatic monitoring

The permit held by UUK (previously held by Sellafield Limited) 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). In 2012, discharges from Capenhurst were similar to those in 2011.

Monitoring included the collection of samples of fish and shellfish from the local 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. Results for 2012 are given in Tables 2.2(a) and (b). Concentrations of radionuclides in foods from the local marine environment and dose rates were very low and generally similar to those in previous years; although downstream of the Rivacre Brook (at the location where children play) dose rates have been decreasing in recent years. The low concentrations in fish and shellfish reflect the distant effects of discharges from Sellafield. Sediment samples from the Rivacre Brook contained very low but measurable concentrations of uranium (enhanced above

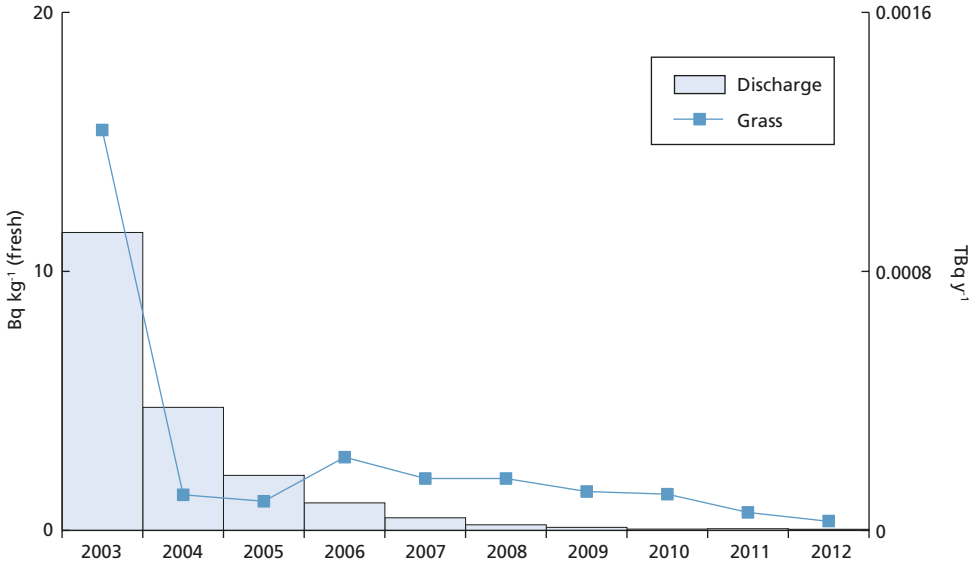


Figure 2.1. Technetium-99 annual discharges from and concentrations in grass at Capenhurst, 2003-2012

natural levels) and technetium-99. Some enhancement of these radionuclides was measured close to the discharge point. Variations in concentrations in sediment from the brook are to be expected due to differences in the size distribution of the sedimentary particles. Concentrations of radionuclides in freshwaters were also very low. As in recent years, measured dose rates were higher, relative to natural background, near to the discharge point.

2.2 Springfields, Lancashire

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

Monitoring around the site is carried out to check not only for uranium concentrations, but also for other radionuclides discharged in the past (such as actinide daughter products from past discharges when uranium ore concentrate was the main feed material) and for radionuclides discharged from Sellafield.

A study commissioned by the Environment Agency considered the exposures of houseboat owners and wildfowlers in the Ribble Estuary area in relation to variables such as tidal inundation of channels and shielding from boat hulls and other materials (Punt *et al*., 2011). Additional summary information is given in RIFE 16 (Appendix 4). The monitoring locations (excluding farms) used to determine the effects of gaseous and liquid discharges are shown in Figure 2.2.

With effect from 1 September 2012, the environmental permit for SFL was varied to reflect the granting of an environmental permit to Sita (Lancashire) Limited, in respect of the Clifton Marsh landfill site. SFL was previously permitted to dispose of solid LLW at Clifton Marsh in its own right. Following the variation, the permit allowed transfer instead, but only to receiving sites who themselves hold permits to receive the waste.

During September 2012, a habits survey was conducted to determine the consumption and occupancy rates by members of the public (Ly *et al*., 2013). A decrease in the fish and crustacean consumption rates has been observed, together with an increase in the mollusc consumption rate, in comparison with those of the previous survey in 2006. Occupancy and handling rates for fishermen, farmers and wildfowlers were also changed in 2012. The habits information, based on a five-year rolling average (2008 – 2012) was revised, resulting in a lower occupancy rate for high-rate houseboat dwellers. Revised figures for consumption rates, together with occupancy and handling rates, are provided in Appendix 1 (Table X2.2).

Doses to the public

In 2012, the *total dose* from all pathways and sources is assessed to have been 0.068 mSv (Table 2.1), or less than 7 per cent of the dose limit. The people most affected were

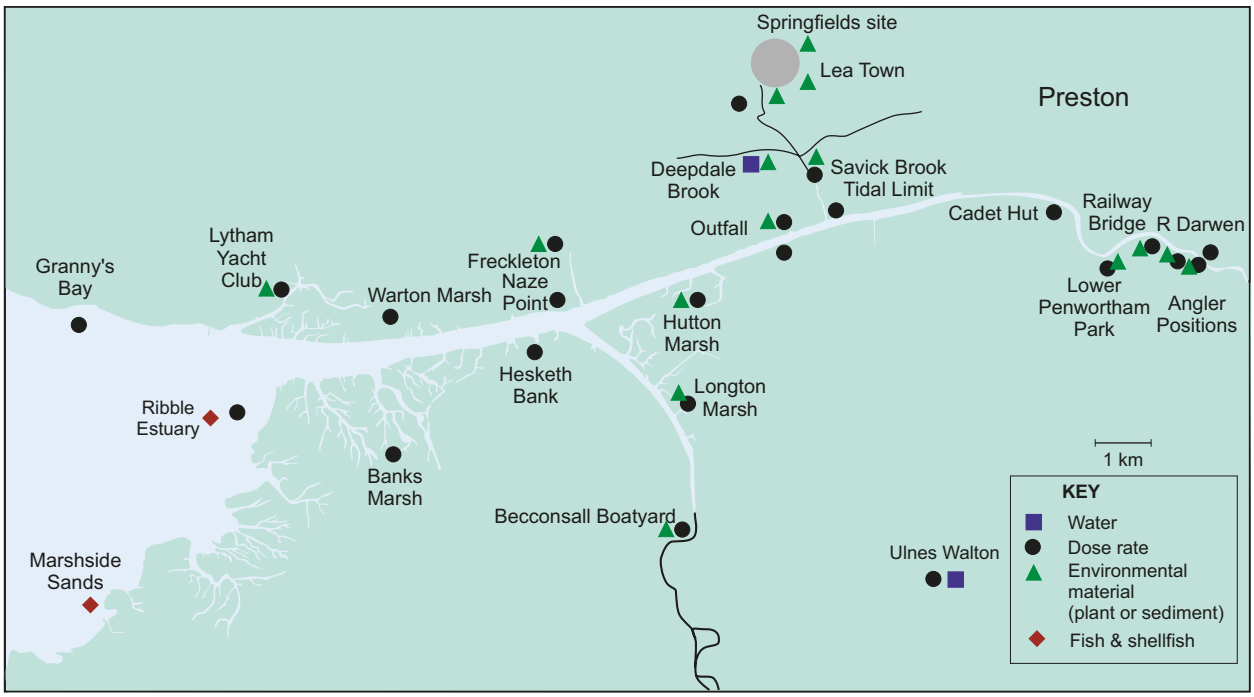


Figure 2.2. Monitoring locations at Springfields, 2012 (not including farms)

adult houseboat dwellers in the Becconsall and Freckleton boatyards, who were exposed to external radiation from activity in muddy sediments. The dose to the houseboat dwellers in 2012 was lower than in 2011 (0.13 mSv). The reduction in *total dose* was not directly due to either a reduction in dose rates measured over sediments in the estuary or to a change in occupancy. It was a consequence of a change in the method for dose assessment due to measurements on the houseboat being available from the habits survey in 2012. *Total doses* over the period 2004 – 2012 are given in Figure 2.3. The data indicate that *total dose* initially decreased over time, although there was an increase in 2008 compared with 2007 due to increased dose rates over sediments near the houseboat. The trend at this site was primarily due to variations in gamma dose rates over sediment.

Source specific assessments indicated that exposures were all less than or similar to the *total dose* (Table 2.1) for;

- Consumers of locally grown food and of seafood
- High-occupancy houseboat dwellers in the Ribble Estuary
- Children playing on the banks of the estuary
- Fishermen handling their gear
- Farmers spending time on the banks of the estuary
- Wildfowlers consuming game obtained from the estuary area

In 2012, the dose to people who were high-rate consumers of seafood (including a contribution from external exposure) was 0.022 mSv, or approximately 2 per cent of the dose limit for members of the public of 1 mSv. Of this dose, 0.020 mSv was from external exposure and the remainder was from the consumption of fish and shellfish. The increase in dose, from 0.017 mSv in 2011, was mostly due to a higher occupancy rate over the outer estuary (Warton and Banks Marshes) in 2012. Nevertheless, the dose from fish and shellfish consumption decreased, compared to that in 2011, mostly due to the lower consumption rates in 2012. The most important radionuclides were caesium-137 and americium-241 from past discharges from the Sellafield site. The dose to fishermen from handling their gear was 0.054 mSv in 2012, which was less than 0.5 per cent of the appropriate annual dose limit of 50 mSv specifically for skin. The decrease in dose in 2012 from 0.069 mSv (in 2011) was mostly due to lower handling rates, despite generally higher beta dose rates on fishing gear.

In 2012 (as identified in the recent habits survey), revised assessments were undertaken to determine the dose to wildfowlers from external exposure over salt marsh and the consumption of game, and to determine the dose to farmers from external exposure, at Springfields. The estimated doses were 0.006 mSv and 0.034 mSv, respectively, for these pathways (Table 2.1).

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

Gaseous discharges and terrestrial monitoring

Uranium is the main radioactive constituent of gaseous discharges, with small amounts of other radionuclides present in discharges from the National Nuclear Laboratory's research and development facilities. In 2011, Springfields Fuels Limited was granted a temporary variation to its permit, allowing

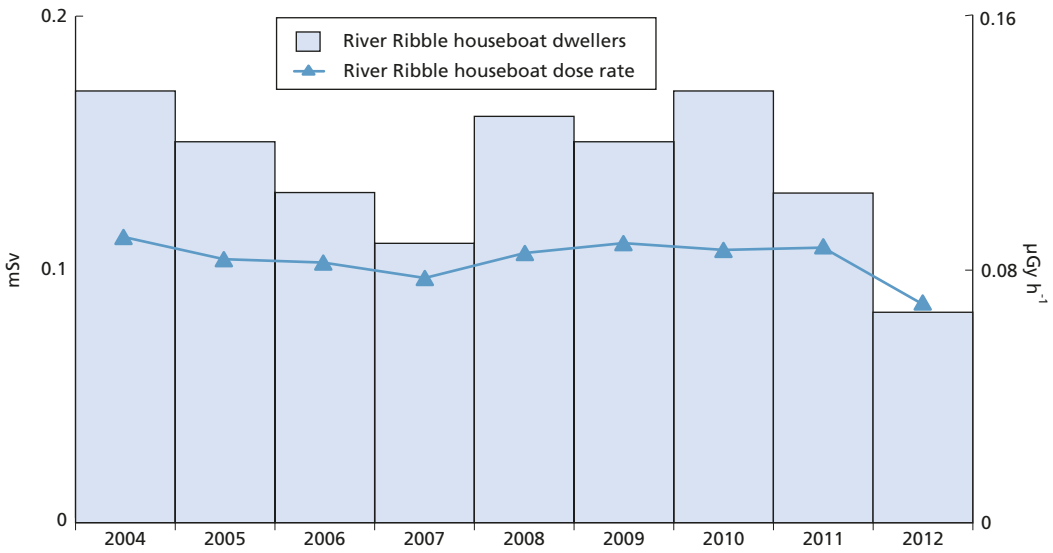


Figure 2.3. *Total dose* from all sources and dose rates at Springfields, 2004-2012

the operator to discharge some gas containing krypton-85 to atmosphere. As krypton is an inert gas, the radiological consequences of the additional discharge will have been negligible. Discharges of krypton-85 from the site decreased in 2012, in comparison to 2011, although discharges of other beta radionuclides increased from the research and development facilities.

The main focus of the terrestrial sampling was for the content of tritium, carbon-14, strontium-90, iodine-129, and isotopes of uranium, thorium, plutonium and americium in milk, fruit and vegetables. Grass and soil samples were collected and analysed for isotopes of uranium. The concentrations of radionuclides found in 2012 are shown in Table 2.3(a). As in previous years, elevated concentrations of uranium isotopes, compared with those at a greater distance, were found in soils around the site, but the isotopic ratio showed they are most likely to be from natural abundance. Low concentrations of thorium were found in fruit and vegetables. Carbon-14 concentrations were generally increased in foodstuffs (in comparison to those in 2011) and enhanced relative to the default values used to represent background levels (apples, beetroot, rabbit and blackberries). Most other concentrations of radionuclides were at limits of detection. Results were broadly similar to those of previous years.

Figure 2.4 shows the trends over time (2004 – 2012) of uranium discharges and total uranium radionuclide concentrations in food (cabbage). Over the period, concentrations of uranium were also found in soil around the site, but the isotopic ratio showed that they were naturally-occurring. Total uranium was detected in cabbage samples during the period (no data in 2006), but the concentrations were very low. The apparent peak of uranium in cabbage in 2007 was also low and significantly less than that found in soil samples.

Liquid waste discharges and aquatic monitoring

Permitted discharges of liquid waste (including gross alpha and beta, technetium-99, thorium-230, thorium-232, neptunium-237, uranium and other transuranic radionuclides) are made from the Springfields site to the Ribble Estuary by two pipelines. Discharges in 2012 were generally similar to those in recent years, including the short half-life beta-emitting radionuclides (mostly thorium-234) that have decreased following the end of the Uranium Ore Concentrate (UOC) purification process in 2006. Discharges of uranium and technetium-99 increased in 2012 due to further increased processing of legacy uranic residues. The Ribble Estuary monitoring programme consisted of dose rate measurements, and the analysis of sediments for uranium and thorium isotopes, and gamma emitting radionuclides. Locally obtained fish, shellfish and samphire were analysed by gamma-ray spectrometry and for uranium, thorium and plutonium isotopes.

Results for 2012 are shown in Tables 2.3(a) and (b). As in previous years, radionuclides due to discharges from both Springfields and Sellafield were found in the Ribble Estuary sediment and biota. 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 radionuclides thorium-234 and protactinium-234, from Springfields, were also found. Concentrations of the latter were closely linked to recent discharges from the Springfields site. In 2012, thorium-234 concentrations in sediments (over the range of sampling sites) were generally similar compared to those in 2011. Over a much longer timescale (2004 – 2012), 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 2.4). The most significant change in the discharge trends was the step reduction of short half-life beta emitting radionuclides in liquid discharges, mostly

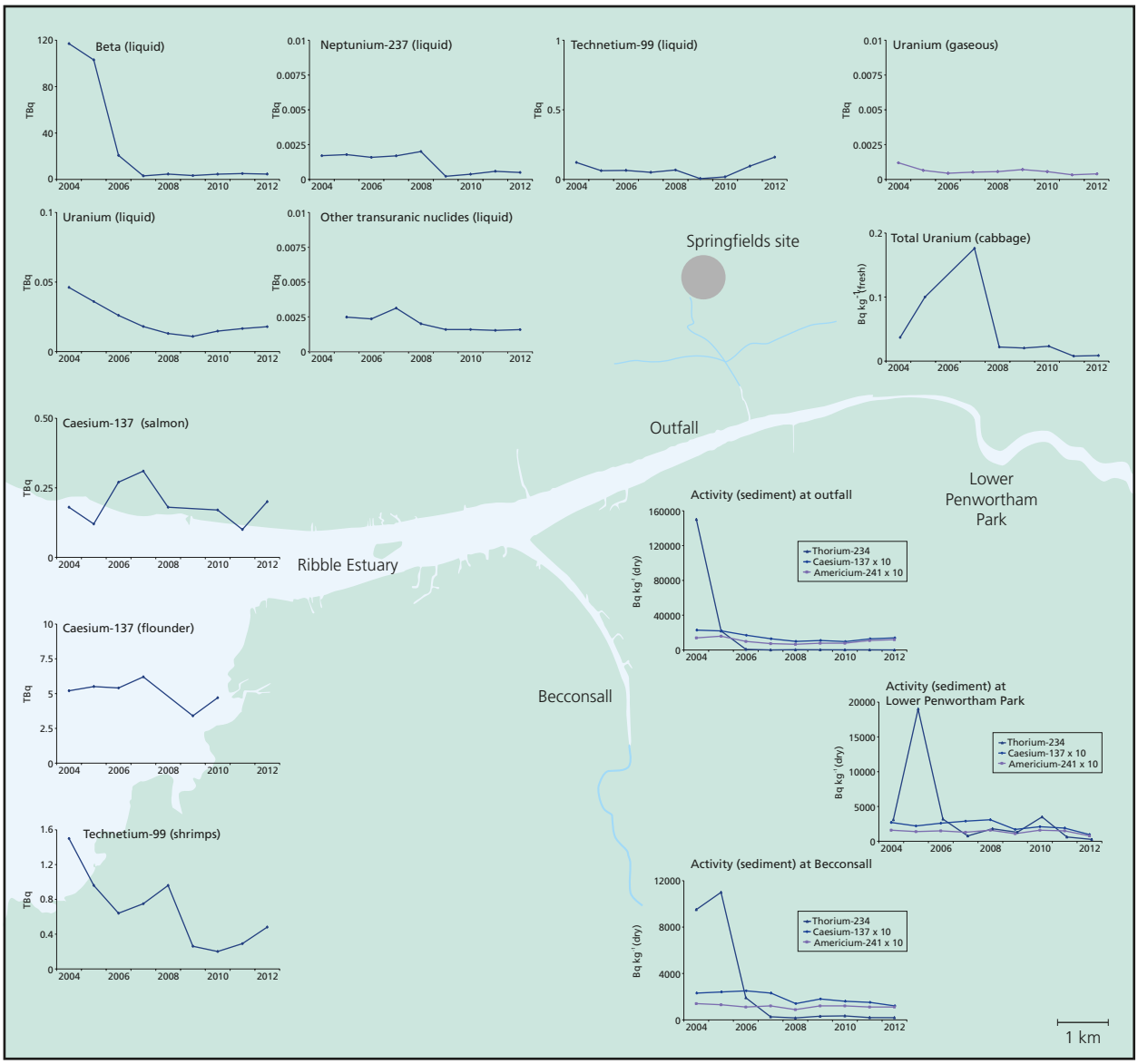


Figure 2.4. Discharges of gaseous and liquid radioactive wastes and monitoring of the environment, Springfields (2004-2012)

thorium-234. The reduction was because the Uranium Ore Concentrate purification process ended in 2006.

Caesium-137, americium-241 and plutonium radionuclides were found in biota and sediments from the Ribble Estuary in 2012. 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 similar to those in recent years.

Figure 2.4 also provides trend information over time (2004 – 2012) 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 increased (to a small extent) in recent years. Caesium-137 concentrations in flounder and salmon showed variations between years and this was mostly due to natural changes in the environment. Concentrations of technetium-99 in shrimps declined over the whole period, consistent with the reduction in technetium-99 discharges from Sellafield (Figure 2.13).

Gamma dose rates in the estuary were generally higher than expected natural background levels (see Appendix 1, Section 3.7), and this is due to Sellafield-derived gamma-emitting radionuclides (caesium-137 and americium-241). In 2012, gamma dose rates in the estuary, excluding rates taken for houseboat assessments, were generally similar to those in 2011, but with some small variations at some sites. Gamma dose rates measured in the vicinity of houseboat dwellers in 2012 (at Becconsall) were generally similar to those in 2011. Beta dose rates on fishing nets in 2012 also appeared enhanced above those expected due to natural background and were generally higher than those in 2011. Where comparisons can be made from similar ground types and locations, beta dose rates from sediments in 2012 were generally similar to those in recent years.

Solid waste disposals and related monitoring

The Springfields and Capenhurst permits allow disposal of solid LLW by controlled burial at Clifton Marsh landfill site, near Preston in Lancashire. In 2011, the Environment Agency conducted a public consultation, on an application made by Sita (Lancashire) Limited, to allow Clifton Marsh landfill to accept waste containing low levels of radioactivity from a range of sources. In August 2012, the Environment Agency issued a new permit (Environment Agency, 2012c). Until 1983, BNFL had also disposed of LLW to the Ulnes Walton landfill site. Permits were also effective to allow additional flexibility in solid waste disposal routes, to other sites such as the LLWR, near Drigg. The results of Environment Agency monitoring of waters, with respect to these landfill sites are given in Section 7, Table 7.4 (Landfill Sites).

2.3 Sellafield, Cumbria

This site is operated by Sellafield Limited (formerly called British Nuclear Group Sellafield Limited (BNGSL)), but is owned by the NDA. The main operations on the Sellafield site are: fuel reprocessing at the Magnox Reprocessing Plant and the Thermal Oxide Reprocessing Plant (THORP); decommissioning and clean-up of redundant nuclear facilities; and waste treatment and storage. The site also contains the Calder Hall Magnox nuclear power station, which ceased generating in 2003 and is undergoing decommissioning. The Windscale site is located at Sellafield, and is discussed in Section 2.4.

In 2011, Sellafield Limited and the NDA published their plans for decommissioning of the Sellafield site (http://www.sellafieldsites.com/wp-content/uploads/2012/08/Sellafield_Plan.pdf). Sellafield Limited continues to prepare for retrievals of intermediate level waste from legacy facilities and to reduce environmental risk. Some of these projects have the potential to impact on discharges to the environment and examples of projects are described elsewhere (Environment Agency, Food Standards Agency, Northern Ireland Environment Agency and Scottish Environment Protection Agency, 2011). In 2012, a number of decommissioning projects continued including that of the Calder Hall reactors.

During the financial year 2012/13, 228.5 tonnes of spent oxide fuel was reprocessed in THORP, compared with an original performance target of 408 tonnes. The reprocessing of spent Magnox fuel for 2012/13 was a total of 383 tonnes of fuel, which is consistent with an end to reprocessing in 2020.

Every five years, a full habits survey is conducted in the vicinity of the Sellafield site which investigates the exposure pathways relating to liquid and gaseous discharges, and direct radiation. Annual review habits surveys are undertaken between these full habits surveys. These annual surveys investigate the pathways relating to liquid discharges, review high-rate fish and shellfish consumption by local people (known as the Sellafield Fishing Community) and review their intertidal occupancy rates. The most recent five-year habits survey was conducted in 2008 (Clyne *et al.*, 2009). In the 2012 annual survey, changes were found in the amounts and mixes of species consumed (Papworth *et al.*, 2013). The consumption rates decreased for molluscs and fish, whilst crustacean consumption and occupancy rates over sediments increased in 2012, all by small amounts. During July and August 2012, a habits survey was conducted to determine the consumption and occupancy rates by members of the public on the Dumfries and Galloway coast (Garrod *et al.*, *in press*). 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. A decrease in the fish consumption and occupancy rates has been observed in comparison with those of the previous survey in 2007. Mollusc and crustacean consumption rates were increased and unchanged, respectively, with changes in the mixes of species consumed. Revised figures for consumption rates, together with occupancy rates, are provided in Appendix 1 (Table X2.2).

Habits surveys to obtain data on activities undertaken on beaches relating to potential public exposure to radioactive particles in the vicinity of the Sellafield nuclear licensed site were undertaken in 2007 and 2009 (Clyne *et al.*, 2008a; Clyne *et al.*, 2010a).

Monitoring of the environment and food around Sellafield reflects the historical and present day site activities. In view of the importance of this monitoring and the assessment of public radiation exposures, the components of the programme are considered here in depth. The discussion is provided in four sub-sections, relating to the assessment of dose, the effects of gaseous discharges, the effects of liquid discharges and unusual pathways of exposure identified around the site.

2.3.1 Doses to the public

Total dose from all pathways and sources

The *total dose* from all pathways and sources is assessed using consumption and occupancy data from the full habits survey of 2008 and the yearly review in 2012. Calculations are performed for four age groups (adult, 10y, 1y and prenatal). The effects on Sellafield's high-rate consumers of fish and shellfish from historical discharges of naturally-occurring radionuclides from non-nuclear industrial activity from the former phosphate works at Whitehaven are included to determine their contribution to the *total dose*. These

works were demolished in 2004 and the authorisation to discharge radioactive wastes was revoked. The increase in concentrations of naturally-occurring radionuclides due to the historical discharges is difficult to determine above a variable background (see Appendix 1).

In 2012, the highest *total dose* was assessed to have been 0.30 mSv, or 30 per cent of the dose limit to members of the public (Table 2.18). The most exposed age group was adults, who were high-rate consumers of molluscan shellfish. This represents a change in the people representative of those most exposed, from high-rate consumers of locally harvested marine plants in 2011, and a significant increase from the *total dose* of 0.18 mSv in 2011. This was mostly attributable to an increase in concentrations of polonium-210 in locally caught crustaceans and from the higher rates consumed (from the revision of habits information) by the people representative of those most exposed in 2012, compared to those in 2011.

In percentage terms, the most significant contributors to the *total dose* in 2012 were from the consumption of crustaceans, fish, molluscs and from external exposure over sediments (63, 19, 13 and 5 per cent, respectively), the most important radionuclides were polonium-210, americium-241, lead-210 and plutonium-239+240 (65, 9, 6 and 4 per cent, respectively).

Artificial radionuclides discharged by Sellafield (including external radiation) and historical discharges of naturally-occurring radionuclides from Whitehaven contributed 0.082 mSv and 0.22 mSv, respectively (values are rounded to two significant figures). In 2011, the contributions were 0.068 mSv and 0.11 mSv, respectively. In 2012, the contribution from the external radiation was approximately 0.016 mSv (0.022 mSv in 2011). Data for naturally-occurring radionuclides in fish and shellfish, and their variation in recent years, are discussed in Section 7.

The contribution to the *total dose* of 0.082 mSv in 2012 from artificial radionuclides (including external radiation) was higher than in 2011 (0.068 mSv). In 2012, the contributing radionuclides were mostly americium-241 (33 per cent) and to a lesser extent plutonium-239+240 (15 per cent) and iodine-129 (14 per cent). The contribution to *total dose* from external exposure was 19 per cent (32 per cent in 2011). The increase in the contribution to the *total dose* from 2011 was mostly due to the revision in the amount of mollusc consumption (from the revision of habits information) of the most exposed people.

The contribution to the *total dose* of 0.22 mSv in 2012 from naturally-occurring radionuclides was higher than in 2011 (0.11 mSv). In 2012, the contributing radionuclides were mostly polonium-210 (90 per cent), and to a lesser extent, lead-210 (8 per cent). An increase in the polonium-210 concentrations in locally caught crustaceans and their higher rates consumed, both contributed to a higher *total dose* in 2012. As in 2011, polonium-210 concentrations (above expected background) in mollusc samples did not contribute to the *total dose* in 2012 (~ 0.007 mSv in 2010).

Contributions to the highest *total dose* each year from all sources, by specific radionuclides, are given in Figure 2.5 over the period 2003 – 2012. The trend of generally reducing dose broadly reflected a general reduction in concentrations in seafood of both naturally-occurring and artificial radionuclides from the non-nuclear and nuclear industries respectively. Inter-annual variations were more complex and governed by both natural variability in seafood concentrations and real changes in the consumption and occupancy characteristics of the local population.

The larger step changes (from 2004 to 2005 and from 2008 to 2009) were due to variations in naturally-occurring radionuclides (mainly polonium-210 and lead-210). The changes in *total dose* in the intervening years (from 2005 to 2007) were mainly a result of changes in seafood consumption rates. The decrease in 2010 was due to both reductions in naturally-occurring radionuclides concentrations (polonium-210) and consumption rates, whilst the variation in the radionuclide contributors in 2011 (from previous years) resulted from a change in the people representative of those most exposed (from consumers of molluscan shellfish to locally harvested marine plants). The largest proportion of the *total dose,* up till 2008 and again in 2011 and 2012, was mostly due to enhanced naturally-occurring radionuclides from the historical discharges at Whitehaven and a smaller contribution from the historical discharges from Sellafield. From 2008 to 2010, the net result of progressive reductions of the naturally-occurring radionuclides contribution to the *total dose* has been a relative increase in the proportion from artificial radionuclides. In 2012, the artificial radionuclides giving the largest contribution to the *total dose* were americium-241, plutonium-239+240 and iodine-129. Recent and current discharges of technetium-99 contributed approximately 1 per cent of the dose (from artificial radionuclides and external exposure), whilst iodine-129 contributed approximately 14 per cent, to the Sellafield seafood consumers in 2012.

Other age groups received less exposure than the adult *total dose* of 0.30 mSv in 2012 (10y: 0.14; 1y: 0.084; prenatal: 0.060, rounded to two significant figures). *Total doses* estimated for each age group may be compared with an average dose of approximately 2.2 mSv to members of the UK public from all natural sources of radiation (Watson *et al.*, 2005) and to the annual dose limit to members of the public of 1 mSv.

Doses from gaseous discharges and direct radiation

In 2012, the dose to people receiving the highest *total dose* from the pathways predominantly relating to gaseous discharges and direct radiation was 0.010 mSv (Table 2.18) and unchanged from 2011 (values rounded to two significant figures). The most exposed age group were infants (1y) who were high-rate consumers of root vegetables. This represents a change in the people representative of those most exposed, from high-rate consumers of milk in 2011. The most significant contributors in 2012 to the *total dose*

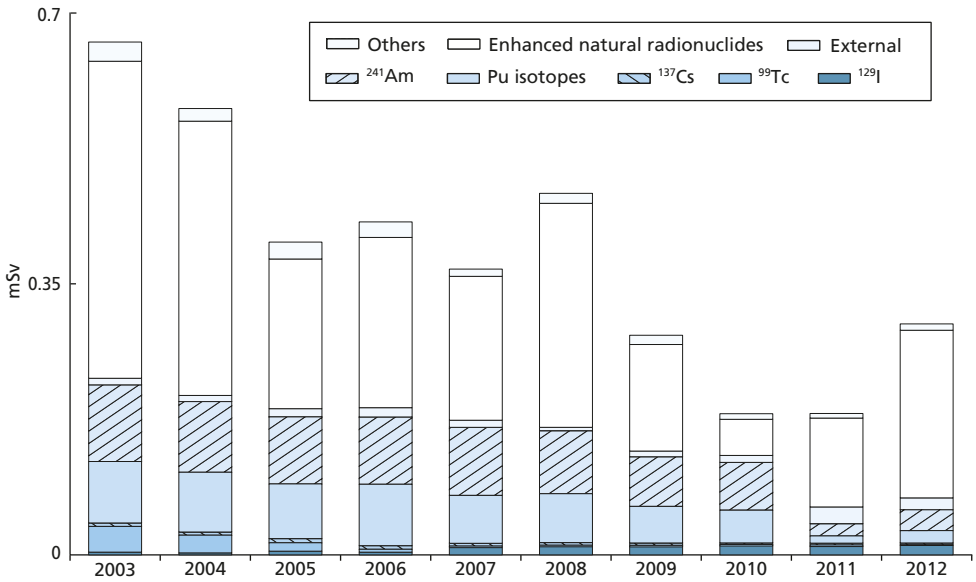


Figure 2.5. Contributions to *total dose* from all sources at Sellafield, 2003-2012

for children were from the consumption of domestic fruit, root vegetables, potatoes and other domestic vegetables (30, 28, 27 and 11 per cent, respectively), the most important radionuclides were ruthenium-106 and strontium-90 (64 and 19 per cent, respectively). Other age groups received less exposure than the 1 year-old children *total dose* of 0.010 mSv in 2012 (adult: 0.007; 10y: 0.008; prenatal: <0.005).

Contributions to the highest *total dose* each year, by specific radionuclides, are given in Figure 2.6 over the period 2003 – 2012. Up until 2007, the *total dose* was reducing each year 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 included cobalt-60 results (below Limit of Detection (LoD)) because detectable activity was observed in other samples from the terrestrial environment. This increased the *total dose* over previous years. The relative increase and the change in the radionuclide contributors in 2009 (and not observed thereafter) resulted from the increase of total caesium in game and the change of the age group representative of the most exposed. In 2012, the variation in contributions to the highest *total dose* was due to a change in the people representative of those most exposed.

Doses from liquid discharges

The people receiving the highest *total dose* from the pathways predominantly relating to liquid discharges are given in Table 2.18. They are the same as those giving the maximum *total dose* for all sources and pathways.

Source specific doses

Important source specific assessments of exposures, as a result of radioactive waste discharges from Sellafield, continued to be due to high-rate consumption of fish and shellfish and to external exposure from gamma rays over long periods. Other pathways were kept under review, particularly high-rate consumption of locally grown food (from atmospheric discharges), to account for the potential for sea to land transfer at the Ravenglass Estuary to the south of the site and exposure from contact with beta emitters during handling of sediments and/or handling of fishing gear.

Doses from terrestrial food consumption

In 2012, 1 year-old children, who were high-rate consumers of milk and were exposed to external and inhalation pathways from gaseous discharges, received the highest dose for all age groups, at 0.016 mSv (adult: 0.010; 10y: 0.011; prenatal: 0.007) or less than 2 per cent of the dose limit to members of the public (Table 2.18). The reason for the lower dose in 2012 (from 0.020 mSv in 2011) is mostly due to a combination of a decreased maximum strontium-90 concentration in milk, a deceased strontium-90 concentration in domestic fruit, and cobalt-60 not being detected in any terrestrial samples and therefore not included in the assessment.

Doses from seafood consumption

Two sets of habits data are used in these dose assessments. One is based on the habits seen in the area each year (2012 habits survey). The second is based on a five-year rolling average using habits data gathered from 2008 to 2012. Small changes were found in the amounts and mixes of species consumed. For molluscs and fish, the consumption rate decreased in both the 2012 and the 2008 – 2012 data sets. Crustacean consumption rates increased for both data sets. The occupancy rate over sediments increased in 2012, but was unchanged from 2008 to 2012. The revised habits data are given in Appendix 1 (Table X2.2). Aquatic pathway habits are normally the most important in terms of dose near Sellafield and are surveyed every year. This allows

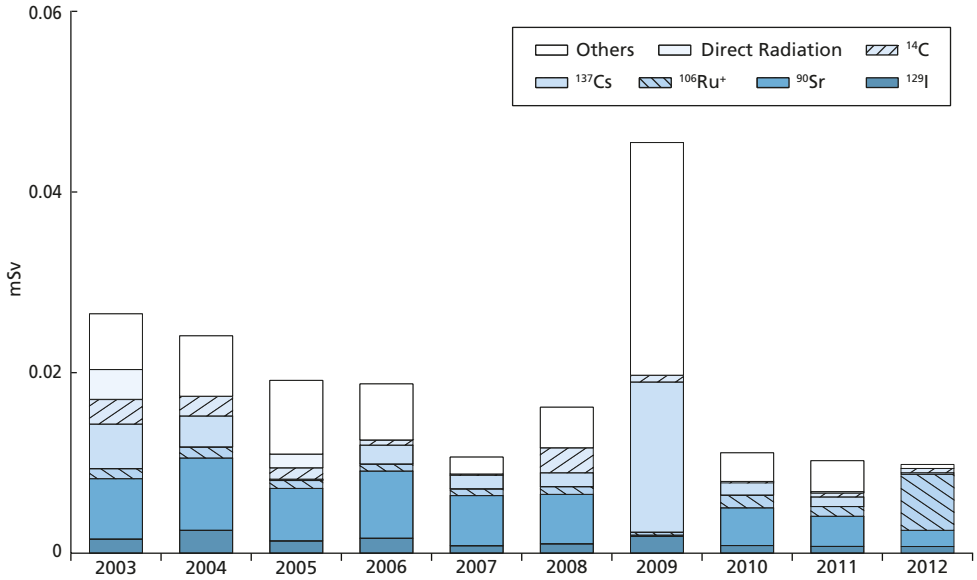


Figure 2.6. Contributions to *total dose* from gaseous discharge and direct radiation sources at Sellafield, 2003-2012 (+ based on limits of detection for concentrations in foods)

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 (Food Standards Agency, 2001a).

Table 2.18 summarises source specific doses to seafood consumers in 2012. The doses from artificial radionuclides to people, who consume a large amount of seafood, were 0.094 mSv and 0.14 mSv, using the annual and five-year rolling average habits data, respectively. These doses each include a contribution due to external radiation exposure over sediments. Both the annual and the rolling average derived doses were lower than the corresponding dose in 2011 (0.11 mSv and 0.15 mSv, respectively). The reason for the decrease in doses in 2012 is the same as that contributing to maximum *total dose* from liquid discharges.

The dose to local people (for high-rate consumers of seafood) due to the enhancement of concentrations of naturally-occurring radionuclides from former non-nuclear industrial activity in the Sellafield area (using maximising assumptions for the dose coefficients and the five-year rolling average habits data) is estimated to have been 0.19 mSv in 2012. Most of this was due to polonium-210 (92 per cent), and lead-210 to a lesser extent (6 per cent). The reason for the increase in dose in 2012 (from 0.11 mSv in 2011) is the same as that contributing to maximum *total dose* from liquid discharges. For comparison with the assessment using the five-year rolling average habits data, the dose from the single-year assessment for the Sellafield seafood consumers (based on consumption rates and habits survey data in 2012) was 0.23 mSv (Table 2.18).

Taking artificial and enhanced radionuclides together, the source specific doses were 0.32 mSv and 0.33 mSv for annual and five-year rolling average habits data, respectively. These estimates are larger than the estimate of *total dose* from all sources of 0.30 mSv. The main reason for this is a difference in the approach to selecting consumption rates for seafood to represent the most exposed people. The source specific method pessimistically assumes that consumption of high rates of fish, crustaceans and molluscs is additive whereas the *total dose* method takes more realistic consumption rate information from the local habits survey. The differences in dose are not unexpected, are well within the uncertainties in the assessments and confirm *total dose* as a robust measure of exposure.

Exposures representative of the wider communities associated with fisheries in Whitehaven, Dumfries and Galloway, the Morecambe Bay area, Fleetwood, Northern Ireland, North Wales and the Isle of Man are kept under review (Table 2.18). Where appropriate, the dose from consumption of seafood is summed with a contribution from external exposure over intertidal areas. The doses received by people in the wider communities were significantly less than for the local Sellafield people 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 when compared with those in 2011 (Table 2.17). In 2012 (as identified in the recent habits survey), a revised assessment was undertaken to determine the dose to seafood and wildfowl consumers, combined with external exposure over salt marsh, along the Dumfries and Galloway coast. The estimated dose was 0.046 mSv (Table 2.18) and the dominant contribution to dose from this pathway was from consumption of fish, shellfish and wildfowl (0.038 mSv). All doses were well within the dose limit for members of the public of 1 mSv.

The doses to people, who typically consume 15 kg of fish per year from landings at Whitehaven and Fleetwood, are also given in Table 2.18. This consumption rate used represents an average for a typical consumer of seafood from the north-east Irish Sea. The doses were very low, less than 0.008 mSv in 2012.

Doses from sediments

The main radiation exposure pathway associated with sediments is due to external dose from gamma-emitting radionuclides adsorbed on intertidal sediments in areas frequented by the public. This dose can make a significant contribution to the total exposure of members of the public in coastal communities of the north-east Irish Sea but particularly in Cumbria and Lancashire. Gamma dose rates currently observed in intertidal areas are mainly due to radiocaesium and naturally-occurring radionuclides. For some people, the following pathways may also contribute to doses from sediments: exposure due to beta-emitters during handling of sediments or fishing gear; inhalation of re-suspended beach sediments; and inadvertent ingestion of beach sediments. These pathways are considered later: in the main, they give rise to only minor doses compared with those due to external gamma emitters.

Gamma radiation dose rates over areas of the Cumbrian coast and further afield in 2012 are given in Table 2.9. The results of the assessment of external exposure pathways are included in Table 2.18. The highest whole body exposures due to external radiation resulting from Sellafield discharges, past and present, were received by people who live in houseboats in the Ribble Estuary in Lancashire. In 2012, their dose was 0.083 mSv or less than 9 per cent of the dose limit for members of the public (see Section 2.2). Other people received lower external doses in 2012. The estimated dose to people who spend time over the marsh in the Ravenglass Estuary was 0.017 mSv. In 2011, this dose was 0.038 mSv. Overall, gamma dose rates measurements in 2012 were generally similar to those in 2011 in the Ravenglass Estuary. The decrease in dose in 2012 was attributed to the lower occupancy rates (from the revision of habits information in 2012) of the most exposed people, with only a small reduction in dose from inhalation and ingestion of sediment.

The doses to people in 2012 from a number of other activities were also estimated. Assessments were undertaken for typical residents using local intertidal areas for recreational purposes at 300 hours per year, and for the typical tourist visiting the coast of Cumbria with a beach occupancy of 30 hours per year. The use by residents for two different environments, at a number of locations (at a distance from the Sellafield influence), were assessed: residents that visit and use beaches and residents that visit local muddy areas or salt marsh. Typical occupancy rates (Clyne *et al.*, 2008a; 2010a) are assumed and appropriate gamma dose rates have been used from Table 2.9. The activities for the typical tourist include consumption of local seafood and occupancy on beaches. Concentrations of radioactivity in fish and shellfish have been used from Tables 2.5 – 2.7, and appropriate gamma dose rates used from Table 2.9. The consumption and occupancy rates for activities of typical residents and tourists are provided in Appendix 1 (Table X2.2).

In 2012, the dose to people from recreational use of beaches varied from 0.006 to 0.010 mSv with the higher doses being closer to the Sellafield source. The doses for recreational use of salt marsh and muddy areas had a greater variation from <0.005 to 0.014 mSv but were of a similar order of magnitude. The values for these activities were similar to those in 2011. The dose to the typical tourist visiting the coast of Cumbria, including a contribution from external exposure, was estimated to be less than 0.005 mSv.

Doses from handling fishing gear and sediment

Exposures can also arise from contact with beta-emitters during handling of sediments, or fishing gear on which fine particulates have become entrained. 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. Revised handling figures are provided in Appendix 1 (Table X2.2). For those most exposed, an increase in the rate for handling nets and pots was observed, together with a decrease in the rate for handling sediments (in comparison with those previously reported in 2008). In 2012, the skin doses to fishermen from handling their gear (including a component due to naturally-occurring radiation), and bait diggers and shellfish collectors from handling sediment, were 0.060 mSv and 0.040 mSv, respectively and both were less than 0.5 per cent of the appropriate annual dose limit of 50 mSv specifically for skin. Therefore, both handling of fishing gear and sediments continued to be minor pathways of radiation exposure.

Doses from atmospheric sea to land transfer

At Ravenglass, the infant age group received the highest dose from consuming terrestrial foods that were potentially affected by radionuclides transported to land by sea spray. In 2012, their dose (including contributions from Chernobyl and weapon test fallout) was estimated to be 0.018 mSv, which was less than 2 per cent of the dose limit for members of the public. The largest contributions of the dose were from strontium-90 in green vegetables and carbon-14 in milk. This represents an increase in the dose, in comparison to that in 2011 (0.011 mSv). The increase in dose was mostly attributed to a higher strontium-90 concentration in a cabbage sample. Nevertheless, as in previous years, sea-to-land transfer was not of radiological importance in the Ravenglass area.

Doses from seaweed and seawashed pasture

In South Wales the food item laverbread, made from the brown seaweed *Porphyra,* is eaten. In 2012, high-rate consumers received less than 0.005 mSv. Only small quantities of samphire, *Porphyra* and *Rhodymenia* (a red seaweed) are generally consumed, confirming this exposure pathway was of low radiological significance.

Seaweeds are sometimes used as fertilisers and soil conditioners. Assuming that high-rate vegetable consumers obtain all of their supplies from the monitored plots near Sellafield, the dose in 2012 was estimated to be 0.008 mSv This dose was similar to that in 2011 (0.009 mSv). Overall doses from this pathway remain similar, and minor variations from year to year are due to different foods being grown and sampled from the monitored plots. The adult age group received the highest dose; the change in the most exposed age group (from infant in 2011) was mostly due to an increase in the LoD for americium-241 in potatoes in 2012. 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 graze on seaweeds on beaches in coastal areas. However, there was no evidence of this taking place significantly near Sellafield. The Food Standards Agency undertook an assessment of the potential dose to a high-rate consumer of meat and liver from sheep grazing the seaweed using data relevant to the Shetlands and Orkneys. This showed that doses would have been well within the dose limit of 1 mSv per year for members of the public in 1998 when concentrations of technetium-99 would have been at substantially higher levels than in 2012 (Ministry of Agriculture, Fisheries and Food and Scottish Environment Protection Agency, 1999). A further research study (relevant to the Scottish islands and coastal communities), conducted by PHE on behalf of the Food Standards Agency and SEPA, investigated the potential transfer of radionuclides from seaweed to meat products and also to crops grown on land where seaweed had been applied as a soil conditioner (Brown *et al*., 2009). The study concluded that the highest levels of dose to people using seaweed, as a soil conditioner or an animal feed, were in the range of a few microsieverts and the majority of the doses are at least a factor of 100 lower. The report is available on SEPA's website: http://www.sepa.org.uk/radioactive_substances/publications/other_reports.aspx.

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 2012 are summarised in Appendix 2 (Table A2.1). A revised permit, effective from 1 June 2012, made variations including the removal of some plant gaseous discharge limits, removal of all weekly limits and weekly advisory levels. The revised permit limits gaseous discharges for gross alpha and beta activities, and 13 specified radionuclides. In addition to overall site limits, individual limits have been set on discharges from the main contributing plants on site.

Discharges of gaseous wastes from Sellafield in 2012 were much less than the permit limits, and were generally similar to those in 2011. Discharges of antimony-125, krypton-85 and iodine-129 decreased in 2012, together with small increases in plutonium radionuclides, in comparison to those in 2011.

Monitoring around the site related to gaseous discharges

There is substantial monitoring of terrestrial foods in the vicinity of Sellafield conducted by the Food Standards Agency. This monitoring is the most extensive of that for the nuclear licensed sites in the UK, reflecting the scale of the discharges from the site. A wide range of foodstuffs was sampled in 2012 including milk, fruit, vegetables, meat and offal, game, cereals and environmental materials such as 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 2012 are given in Table 2.4. The concentrations of all radionuclides around the site were low. Concentrations in terrestrial foodstuffs were generally similar to those in 2011. Concentrations of radionuclides in meat and offal from cattle and sheep were low (many at, or below, the LoD), with only limited evidence of the effects of Sellafield's atmospheric discharges detected in data for carbon-14 and strontium-90 (values for OBT and iodine radionuclides were below the limit of detection). Tritium (total) concentrations were low but higher in comparison to those reported in recent years. Plutonium concentrations and americium-241 in game (wood pigeon), when detectable, were low and much lower than those found in seafood.

A wide range of fruit and vegetables was sampled in 2012 and the activity concentrations were generally similar to those found in previous years. In common with meat and offal samples, only limited evidence of the atmospheric discharges from Sellafield was found in some of these foods. Iodine-129 was positively detected in milk in 2012, just above the LoD. Small enhancements (above expected background) in concentrations of carbon-14 were found in some food samples (including meat and offal) in 2012 (as in recent years). Concentrations of transuranic radionuclides, when detectable in these foods, were very low. As in 2011, antimony-125 concentrations in 2012 were below limits of detection in foods and soil, and just above the detection limit in grass, despite relatively enhanced discharges in recent years.

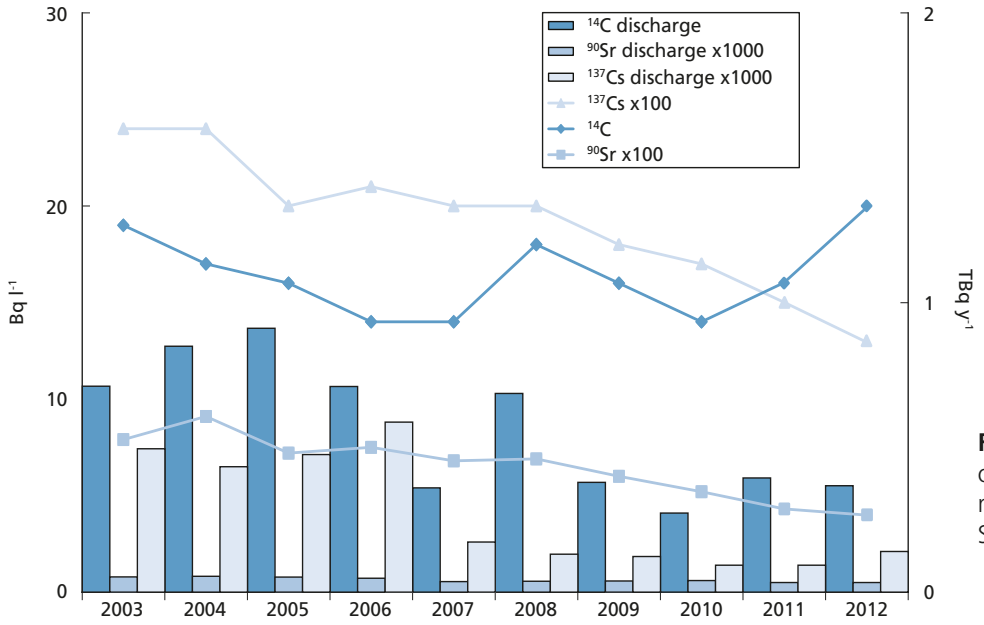


Figure 2.7. Discharges of gaseous wastes and monitoring of milk near Sellafield, 2003-2012

Trends in maximum concentrations of radionuclides in milk, and corresponding discharge levels, near Sellafield over the last decade are shown in Figure 2.7. Over the whole period, concentrations of carbon-14 were relatively constant, and caesium-137 concentrations (and strontium-90 to a lesser extent) were declining overall.

2.3.3 Liquid discharges

Regulated liquid discharges derive from a variety of sources at the site including the fuel storage ponds, the reprocessing plants, from the retrieval and treatment of legacy wastes, the laundry and from general site drainage. Wastes from these sources are treated and then discharged to the Irish Sea via the sea pipelines that terminate 2.1 km beyond low water mark. Liquid wastes are also discharged from the factory sewer to the River Ehen Estuary. Discharges from the Sellafield pipelines during 2012 are summarised in Appendix 2 (Table A2.2). The current permit sets limits on gross alpha and beta, and 16 individual nuclides. In addition to overall site limits, individual limits have been set on discharges from the main contributing plants on site (Segregated Effluent Treatment Plant, SIXEP, Enhanced Actinide Removal Plant (EARP) and THORP). All of the discharges in 2012 were well below the limits in the permit. Most liquid discharges were generally similar, in comparison to those in 2011, although tritium, carbon-14, iodine-129, caesium-137, cerium-144 and americium-241 releases decreased in 2012. Overall, the discharges continue to reflect the varying amounts of fuel reprocessed in the THORP and Magnox reprocessing plant, and periods of planned and unplanned reprocessing plant shutdown that occur from year to year.

Discharges of technetium-99 were low and reduced in 2012 compared to 2011. The long-term downward trend, from their peak of 192 TBq in 1995, has continued (Figure 2.8). Technetium-99 discharges from Sellafield are now substantially reduced and met the target set for 2006 in the UK National Discharges Strategy (Department for Environment, Food and Rural Affairs, 2002). The reduction of technetium-99 discharges was due to the diversion, since 2003, of the Medium Active Concentrate (MAC) waste stream from Magnox reprocessing to vitrification and, between 2003 and 2007, use of a chemical precipitant (Tetraphenylphosphonium Bromide) in the EARP to remove technetium-99 from the historic stock of MAC.

Monitoring of the marine environment

Regular monitoring of the marine environment near to Sellafield and further afield was conducted during 2012, by the Environment Agency and Food Standards Agency (for England and Wales), NIEA (for Northern Ireland) and SEPA (for Scotland). The monitoring locations for seafood, water, environmental materials and dose rates near the Sellafield site are shown in Figures 2.9 and 2.10. The medium-term trends in discharges, environmental concentrations and dose were considered in a recent RIFE summary report, and overall showed a decrease in concentrations over time reflecting reduced discharges at Sellafield (Environment Agency, Food Standards Agency, Northern Ireland Environment Agency and Scottish Environment Protection Agency, 2010b).

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. Concentrations of specific naturally-occurring radionuclides in fish and shellfish in the Sellafield area are given in Section 7. The 'Sellafield Coastal Area' extends 15 km to the north and to the south of Sellafield, from St Bees Head to Selker, and 11 km offshore; most of the fish and shellfish eaten by local people, and who are high-rate consumers, are

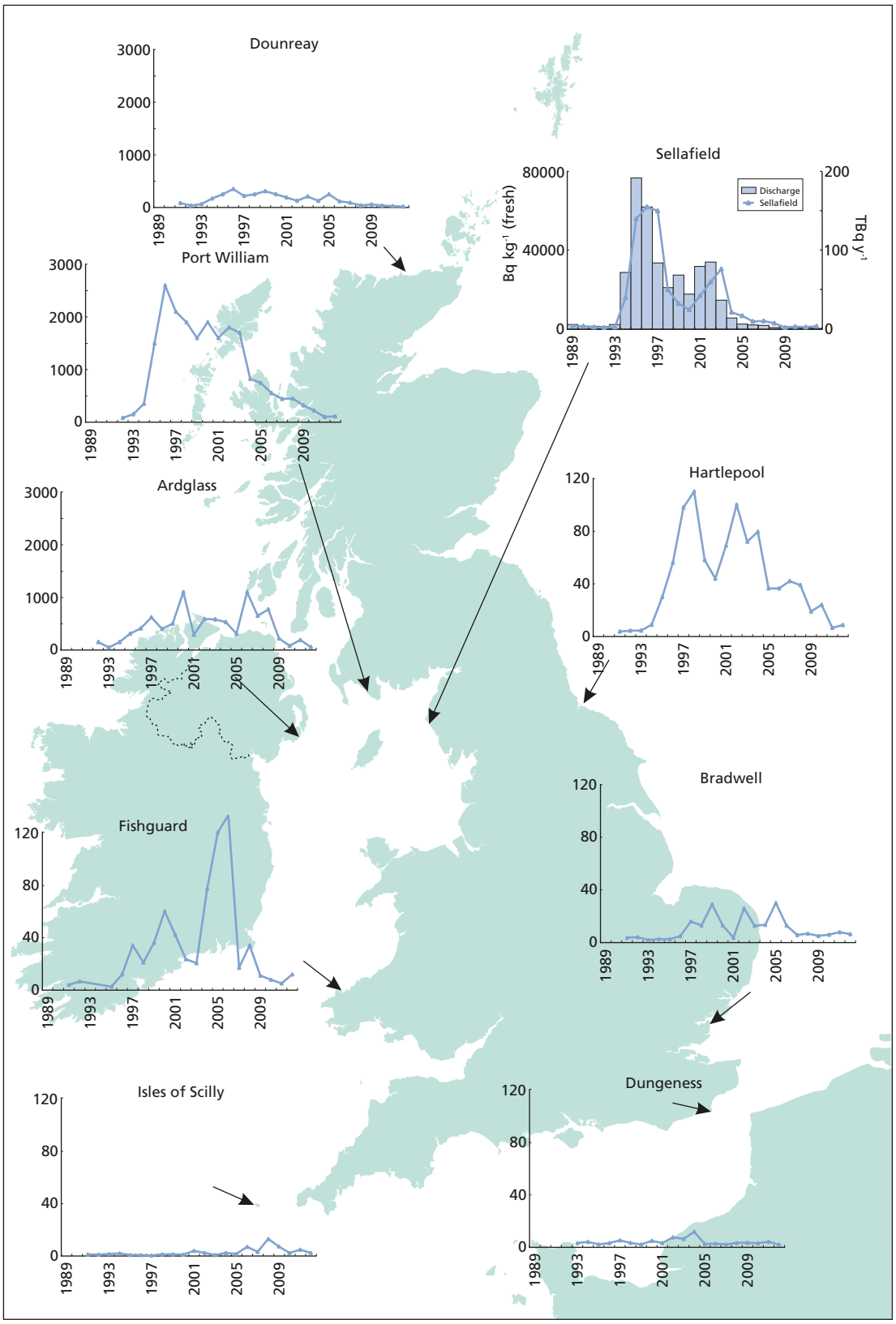


Figure 2.8. Technetium-99 in UK seaweed (*Fucus vesiculosus*) from Sellafield liquid discharges between 1989-2012

taken from this area. Specific surveys are conducted in the smaller 'Sellafield Offshore Area' where experience has shown that good catch rates may be obtained. This area consists of a rectangle, one nautical mile (1.8 km) wide by two nautical miles (3.6 km) long, situated south of the pipelines with the long side parallel to the shoreline; it averages about 5 km from the pipeline outlet.

The concentrations of most radionuclides have decreased over the previous decades in response to decreases in discharges.

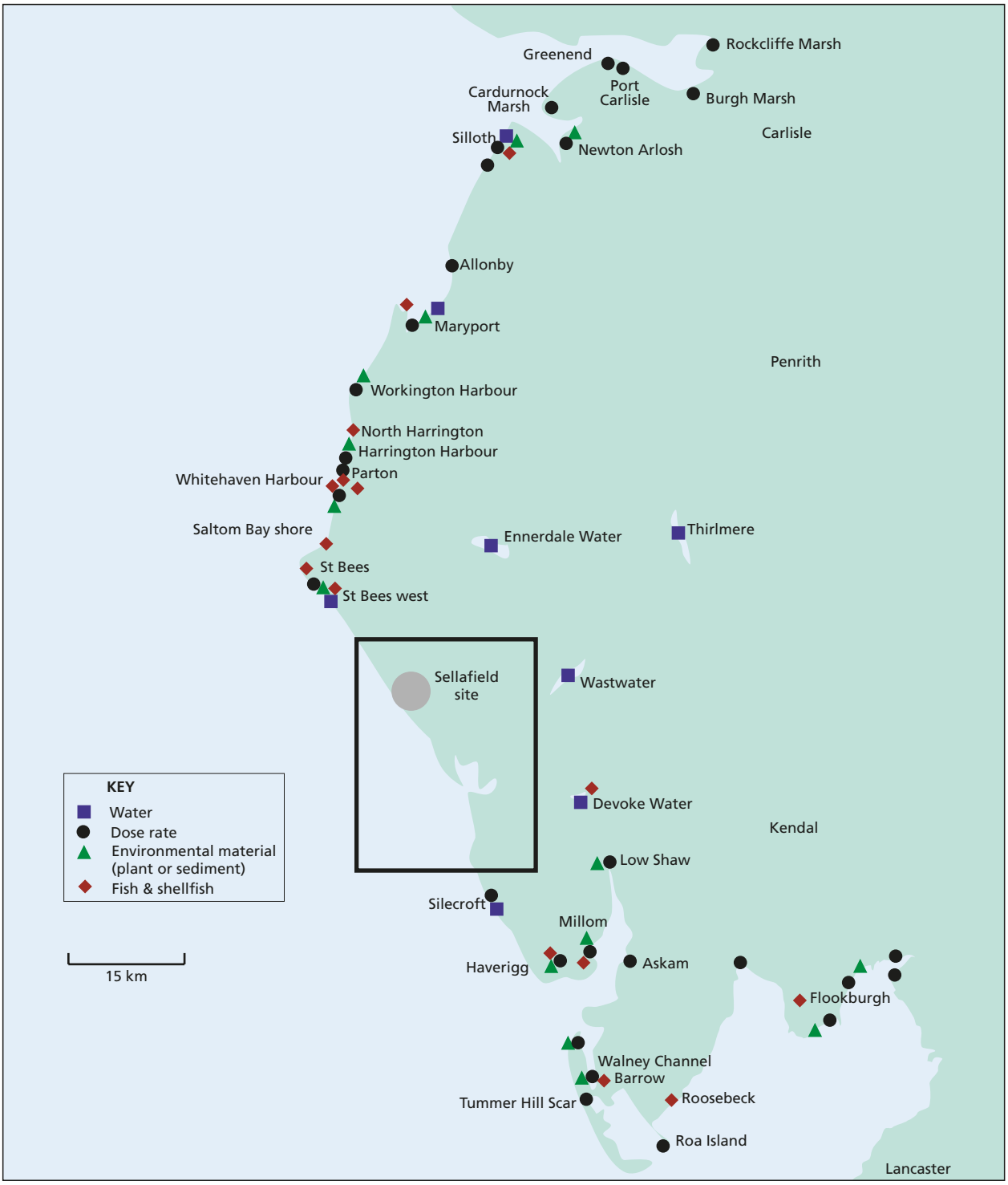


Figure 2.9. Monitoring locations in Cumbria, 2012 (not including farms)

Concentrations generally continue to reflect changes in discharges over time periods, characteristic of radionuclide mobility and organism uptake. Trends in concentrations of radionuclides, and corresponding discharge levels, in seafood near Sellafield (over the last decade) are shown in Figures 2.11 – 2.16. There was variability from year to year, particularly for the more mobile radionuclides. Liquid discharges of technetium-99 in 2012 were lower compared to those in 2011. Overall, concentrations of technetium-99 in fish and shellfish have shown a continued reduction from the elevated levels in 2003, but were generally similar (with minor variations) over most recent years (Figure 2.13). For the transuranic elements (Figures 2.15 – 2.16), the long-term trends in reductions of concentrations from earlier decades appear to be slowing. Over the last decade, despite generally decreasing discharges, concentrations of americium-241 and plutonium-239+240 in fish and shellfish have shown some variations from year to year. Overall, concentrations of plutonium radionuclides and americium-241 in lobsters were higher in 2012 compared to those in 2011.

Figure 2.10. Monitoring locations at Sellafield, 2012 (not including farms)

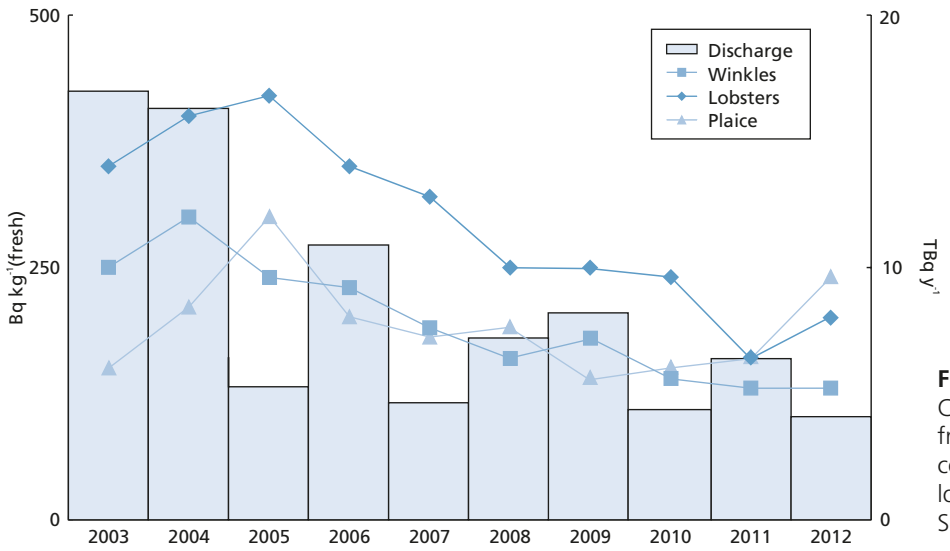


Figure 2.11.
Carbon-14 liquid discharge from Sellafield and concentrations in plaice, lobsters and winkles near Sellafield, 2003-2012

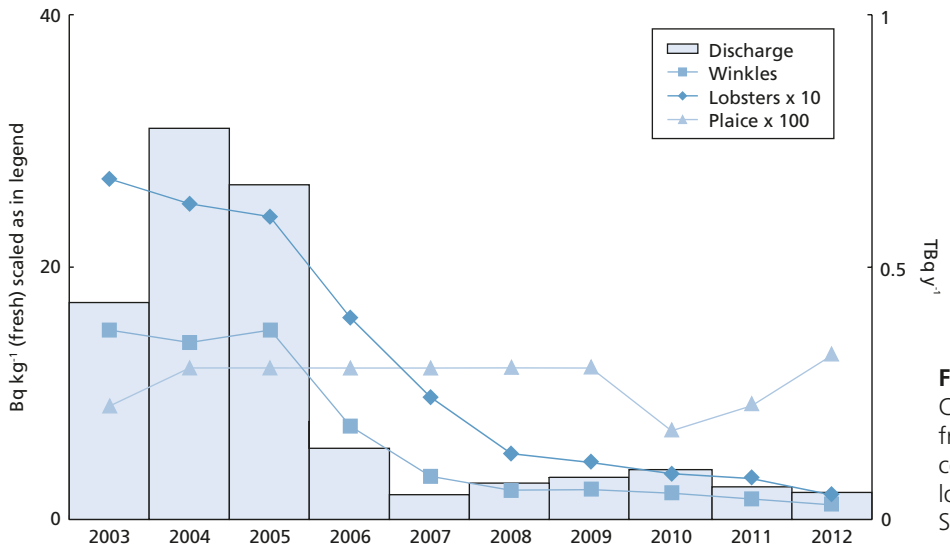


Figure 2.12.
Cobalt-60 liquid discharge from Sellafield and concentrations in plaice, lobsters and winkles near Sellafield, 2003-2012

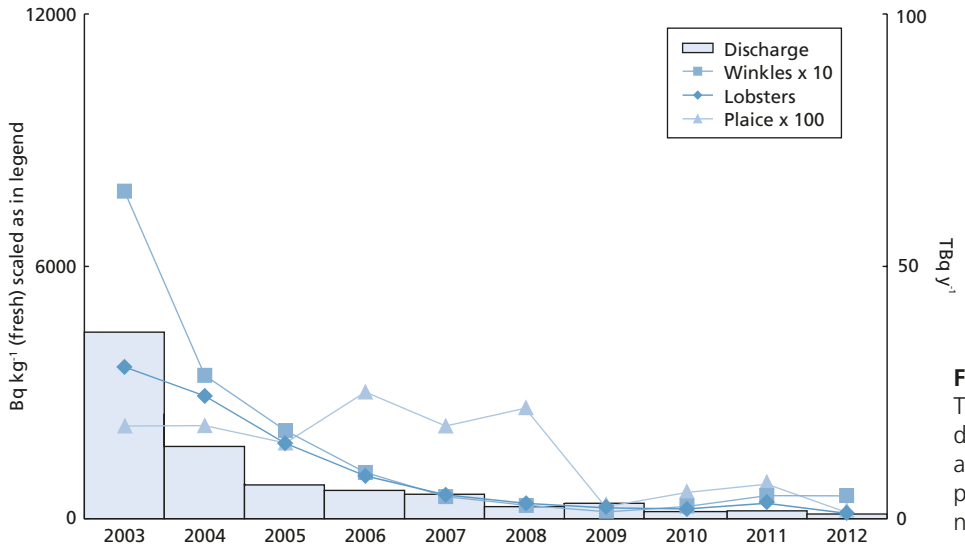


Figure 2.13.
Technetium-99 liquid discharge from Sellafield and concentrations in plaice, lobsters and winkles near Sellafield, 2003-2012

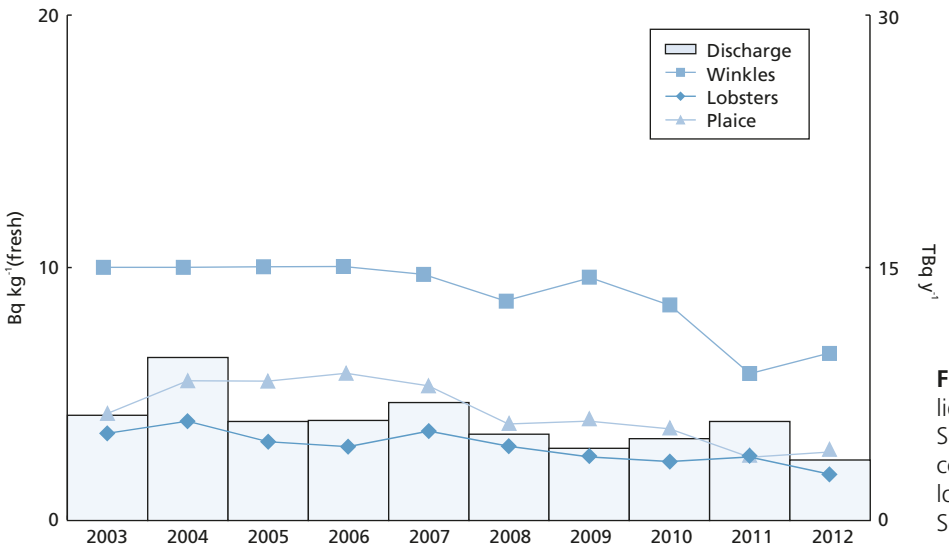


Figure 2.14. Caesium-137 liquid discharge from Sellafield and concentrations in plaice, lobsters and winkles near Sellafield, 2003-2012

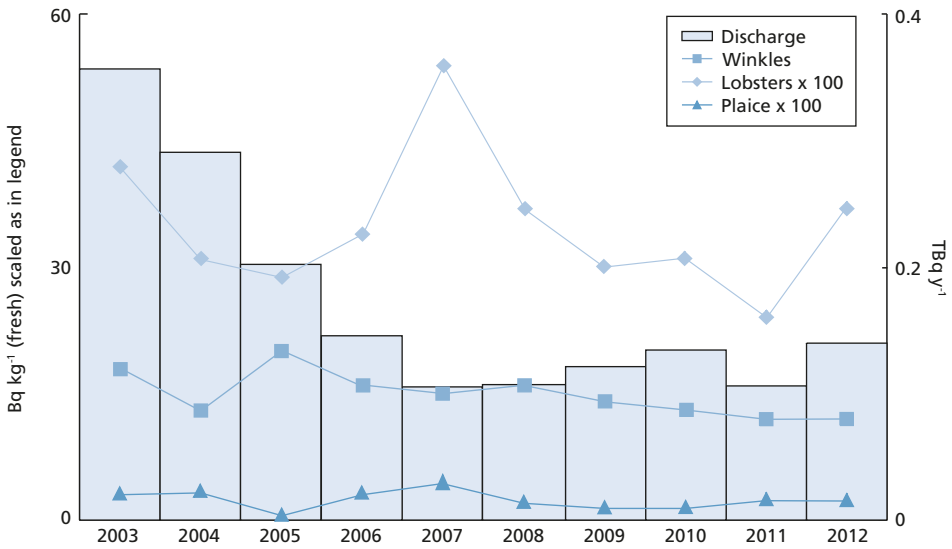


Figure 2.15. Plutonium-239+240 liquid discharge from Sellafield and concentrations in plaice, lobsters and winkles near Sellafield, 2003-2012

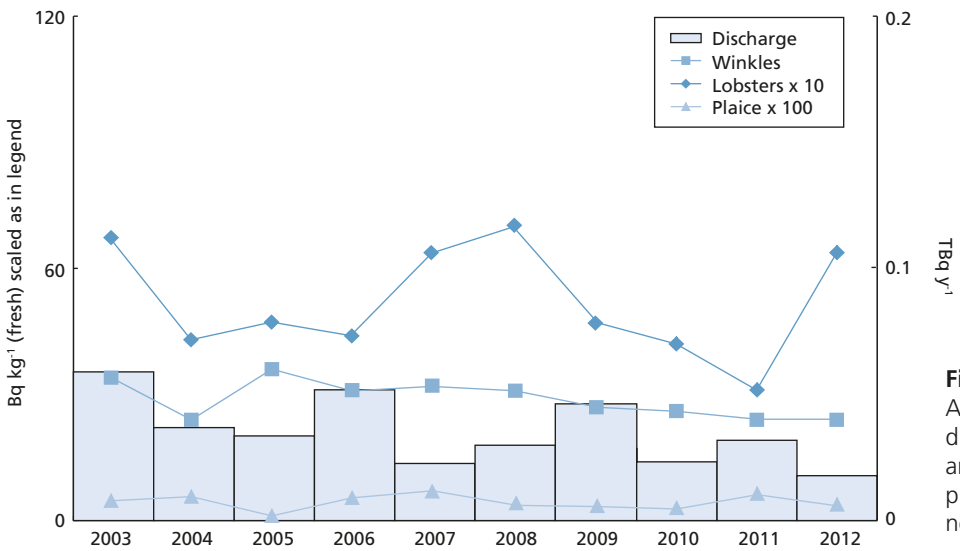


Figure 2.16. Americium-241 liquid discharge from Sellafield and concentrations in plaice, lobsters and winkles near Sellafield, 2003-2012

Beta/gamma-emitting radionuclides detected in fish included: tritium, carbon-14, strontium-90 and caesium-137 (Table 2.5). Overall, concentrations of caesium-137 in fish species were generally similar in comparison to those in 2011. 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 some years ago. There was therefore a greater contribution from historical sources.

As in previous years, brown trout was sampled for analysis from the River Calder, which flows through the Sellafield site. The long-term trend for concentrations of caesium-137 over time (1977 – 2012) is shown in Figure 2.17. The caesium-137 concentration in brown trout was 37 Bq kg^{-1} in 2012 and significantly lower than those in 2011 and 2009 (360 Bq kg^{-1} and 300 Bq kg^{-1}, respectively), but similar to that in 2010 (33 Bq kg^{-1}). Additional enhanced activity concentrations in fish were also detected periodically in earlier decades. The changes in concentrations were likely to be due the combined effects of Sellafield discharges and fallout from Chernobyl, accentuated by the movement of such fish in the Calder river system.

Concentrations of caesium-137 in fish from the Baltic Sea originate from the Chernobyl accident. Caesium-137 in fish, known to have been caught in Icelandic waters, remained typical of those from weapons test fallout, at ~ 0.1 – 0.2 Bq kg^{-1} for caesium-137 in cod. Data for the Barents Sea were similar.

Other artificial beta/gamma-emitting radionuclides detected in fish included carbon-14 and tritium. With an expected carbon-14 concentration from natural sources ~ 25 Bq kg^{-1}, the data suggest a continued local enhancement of carbon-14 due to discharges from Sellafield. In 2012, carbon-14 provided the highest activity concentration in marine fish (plaice, 240 Bq kg^{-1}), with slightly lower levels of tritium (total) and organically bound tritium (OBT). The limited tritium results suggest that virtually all of the total tritium in marine samples was associated with organic matter, although due to the low toxicity of this isotope of hydrogen and the low concentrations observed, the dose implication was very small.

For shellfish, a wide range of radionuclides is detectable, owing to generally greater uptake of radioactivity by these organisms from sediments. Generally, molluscs tend to contain higher concentrations than crustaceans and both contain higher concentrations than fish. Concentrations of beta/gamma-emitting radionuclides are shown in Table 2.6 (Table 2.7 for plutonium-241). Consumers who collect seafood in the Sellafield coastal area provided some of the winkles, mussels and limpets sampled. There can be substantial variations between species; for example, lobsters tend to concentrate more technetium-99 than crabs (see also Knowles *et al.,* 1998; Swift and Nicholson, 2001). The highest concentrations from Sellafield discharges were of tritium, carbon-14, and technetium-99. Comparing 2012 and 2011 data across a wide range of sampling locations and shellfish species, technetium-99 concentrations decreased in lobsters. Other concentrations of technetium-99 in shellfish were generally similar, but reduced in comparison to those years prior to 2011 due to the progressive reductions in discharges of this radionuclide. Concentrations of other radionuclides in 2012 were broadly similar to those in 2011.

Transuranic radionuclide data for fish and shellfish samples (chosen on the basis of potential radiological significance) in 2012 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 2012 and 2011 data across a wide range of sampling locations and shellfish species further afield from Sellafield, concentrations in shellfish were generally similar. Those from the north-eastern Irish Sea were the highest transuranic concentrations found in foodstuffs in the UK. In comparison to 2011 data, the concentrations in shellfish were generally similar for plutonium radionuclides and americium-241 at most of the north-eastern Irish Sea locations in 2012, with a small increase in activity concentrations in lobsters (Sellafield Coastal Area). 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.

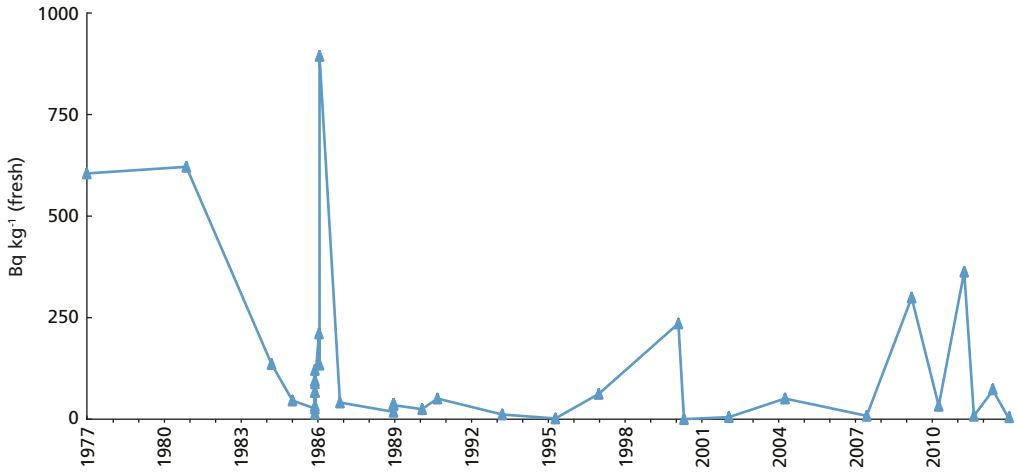


Figure 2.17. Concentration of caesium-137 in River Calder brown trout, 1977-2012

Monitoring of sediments

Radionuclides in Sellafield liquid discharges are taken up into sediments along the Cumbrian Coast in particular in more muddy (fine grained) areas such as estuaries. Some of these areas are used by the public. Levels of radionuclides are regularly monitored, both because of their relevance to exposure and in order to keep distributions of radioactivity under review. The results for 2012 are shown in Table 2.8. Radionuclides detected include cobalt-60, strontium-90, caesium-137 and transuranic elements. The highest concentrations found are close to the site and in fine particulate materials in estuaries and harbours, rather than the coarser-grained sands on open beaches. The concentrations of long-lived radionuclides, particularly caesium-137 and the transuranic elements, reflect past discharges from Sellafield, which were considerably higher than in recent years. Over the last 30 years discharges have fallen significantly as the site provided enhanced treatment to remove radionuclides prior to discharge. Overall, concentrations in sediments in 2012 were generally similar to those in recent years.

The trends over time (1988 – 2012) for concentrations in mud from Ravenglass with discharges from Sellafield are shown in Figures 2.18 – 2.21. The concentrations of most radionuclides have decreased over the past 25 years in response to decreases in discharges, with sustained reductions in discharges of caesium-137 and transuranic elements. Discharges of cobalt-60 have been variable in 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 2.20). Over the last decade, caesium-137 and transuranic concentrations in sediments have remained relatively constant (Figures 2.18, 2.19 and 2.21). Since the mid 1990s, discharges of caesium-137, plutonium isotopes and americium-241 have remained at low levels, but there has been some variability, and even a suggestion of small progressive increases in caesium-137 and transuranic elements activities in sediments (peaking over the period, ~2003 – 2006), and americium-241 increasing over recent years. The likely explanation is that changes in these concentrations are due to remobilisation and subsequent accretion of fine-grained sediments containing higher activity concentrations. For americium-241, there is also an additional contribution due to radioactive in-growth from the parent plutonium-241 already present in the environment. The effect is less apparent in fish and shellfish (Figures 2.14 – 2.16) and will continue to be monitored.

Concentrations of caesium-137 and americium-241 in sediments from coastal locations of the north-east Irish Sea are also shown in Figure 2.22. Concentrations of both radionuclides diminish with distance from Sellafield. Overall, concentrations in 2012 at a given location were generally similar to those in 2011, and any fluctuations were most likely due to normal variability in the environment. Limited evidence suggests that small progressive increases in the concentrations in sediments at some locations at distance from Sellafield were evident in most recent years, but these are still below peak values reported over the whole period of time (except at Carsluith). The effect appears to be more pronounced for americium-241 and is likely to be due to the spreading of activity away from Sellafield combined with the effect of grow-in from plutonium-241 (Hunt *et al.*, 2013).

A research study, commissioned by the Food Standards Agency, determined the depth distributions of technetium-99 concentrations in sea-bed cores to produce an estimate of the total inventory residing in the sub-tidal sediments of the Irish Sea (Jenkinson *et al.*, 2013). The study concluded that the inventory of technetium-99 was estimated to have been of the order of 30 TBq (or approximately 2 per cent of the total cumulative Sellafield discharge), with approximately 8 TBq present in surface material and thereby potentially most susceptible to re-dissolution or re-suspension.

Monitoring of dose rates

Dose rates are regularly monitored, both in the Sellafield vicinity and further afield, using environmental radiation dosemeters. Table 2.9 lists the locations monitored by the

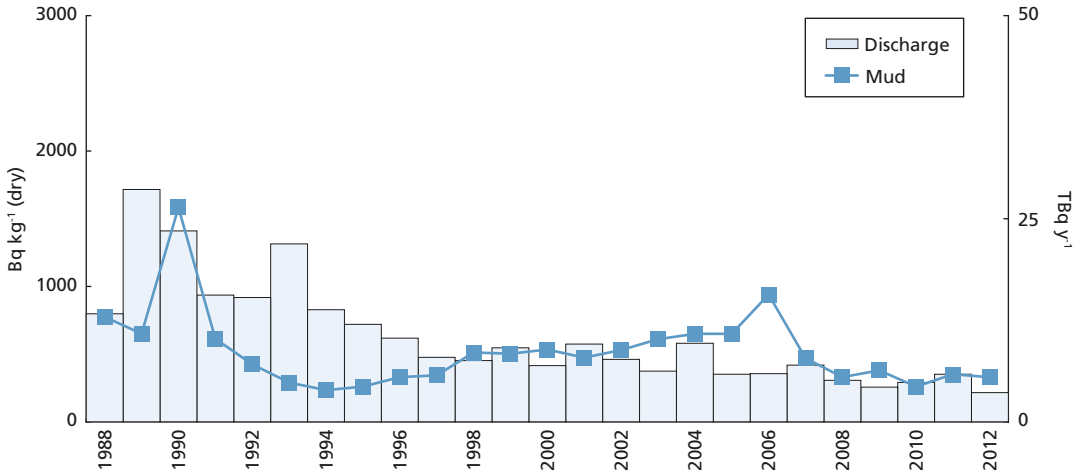


Figure 2.18. Caesium-137 liquid discharge from Sellafield and concentration in mud at Ravenglass, 1988-2012

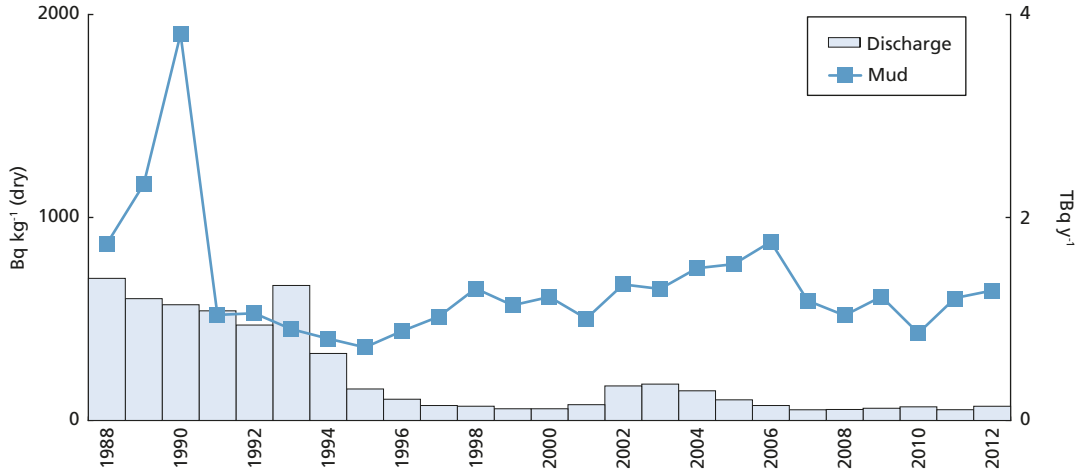


Figure 2.19. Plutonium-alpha liquid discharge from Sellafield and plutonium-239+240 concentration in mud at Ravenglass, 1988-2012

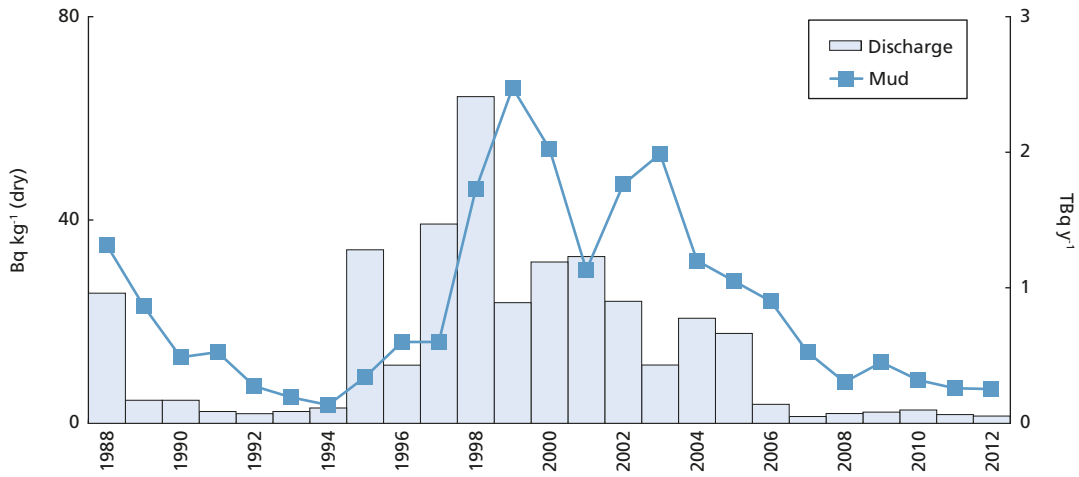


Figure 2.20. Cobalt-60 liquid discharge from Sellafield and concentration in mud at Ravenglass, 1988-2012

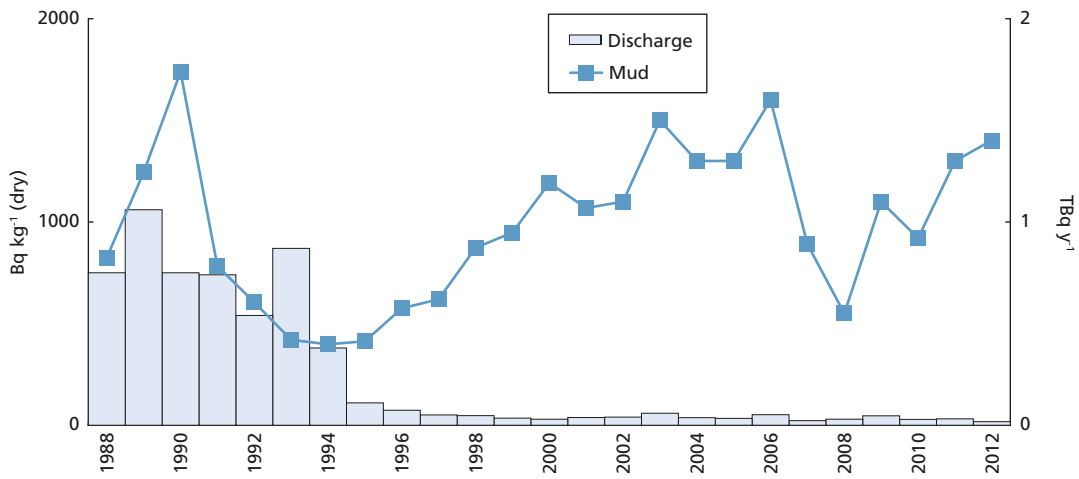


Figure 2.21. Americium-241 liquid discharge from Sellafield and concentration in mud at Ravenglass, 1988-2012

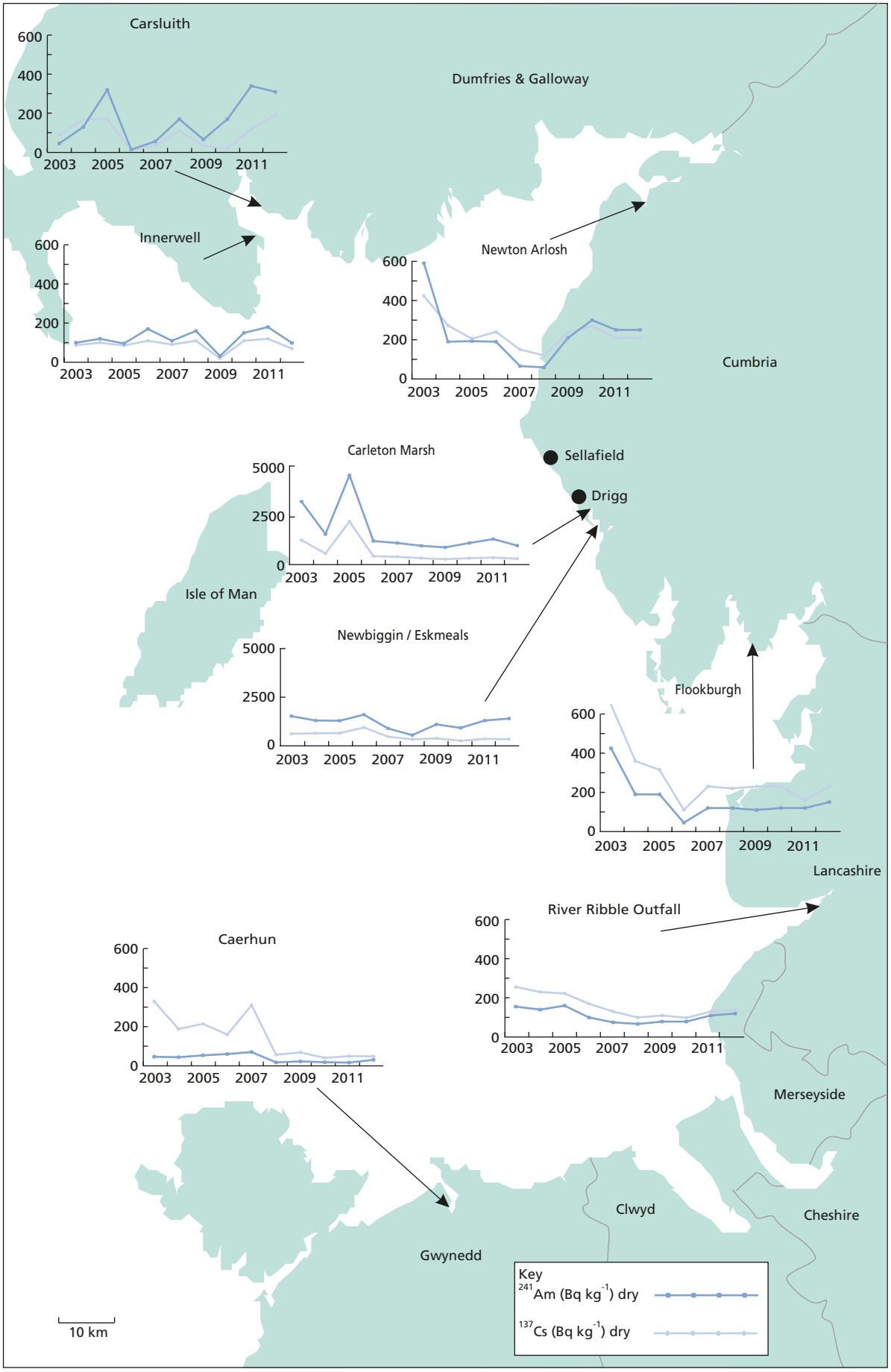


Figure 2.22. Concentrations of americium-241 and caesium-137 in coastal sediments in North West England and South West Scotland between 2003-2012 (Note different scales used for Newbiggin and Carleton Marsh)

environment agencies and the gamma dose rates in air at 1 m above ground. Where comparisons can be made from similar ground types and locations, dose rates over intertidal areas throughout the Irish Sea in 2012 were generally similar to those in recent years. Any variations between years are likely to have been due to normal variability in the environment. As in 2011, gamma dose rates measured on the banks of the River Calder, which flows through the Sellafield site, continued to show significant excess above natural background downstream of the site (of approximately 0.04 μGy h^{-1}). Although the dose rates were locally enhanced, 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 were 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 2.23. The general decrease in dose rates with increasing distance from Sellafield, which was apparent under conditions of higher discharges several decades ago, is no longer so prominent in recent years. Spatial variability of dose rates is expected, depending on ground type; generally higher dose rates being recorded over areas with finely divided sediments. For each location, there has been variation over time. Close to Sellafield (at Carleton Marsh and Newbiggin), there was limited evidence to suggest that dose rates were slowly declining over the whole period, with the lowest reported values in 2012. Locations that are further afield from Sellafield show dose rate values that only marginally exceeded average UK natural background rates.

Over the last 30 years, levels of radioactivity in the environment around Sellafield have declined as a result of reduced discharges. In more recent years the levels in the Esk have shown a less clear trend, with concentrations of some radionuclides fluctuating from year to year (for example, see Figure 2.19). This effect could be due to the dynamic nature of the sediment in the estuary, which is eroded and transported by tide and freshwater, periodically exposing older deeper sediment containing radioactivity from historical discharges. Due to the variations seen in recent years and local concerns, the Environment Agency initiated a more detailed study of dose rates in the Esk Estuary in 2007. The objectives of the study were to assess the current level of external gamma radiation exposure in the estuary, and changes in the measured dose rates, relative to a more detailed survey of the estuary undertaken in 1989 (Kelly and Emptage, 1991). A six week survey of gamma dose rates was undertaken at a total of 576 locations in the Esk Estuary. The University of Liverpool (Institute for Sustainable Water Integrated Management and Ecosystem Research (SWIMMER)) undertook the study.

The mean dose rate across all 576 locations was 0.14 μGy h^{-1}, with a range of 0.07 – 0.28 μGy h^{-1}. This indicates a significant decrease compared to the mean dose rate reported in 1989 (at similar locations) of 0.23 μGy h^{-1} (range 0.07 – 0.61 μGy h^{-1}). The highest gamma dose rates measured in both surveys were from comparable locations within the estuary. The reduced dose rates in the 2007 survey were due to the effects of reductions in radionuclide discharges from the Sellafield site and also radioactive decay of the inventory within the Esk Estuary sediments and soils since 1989. The full report on this study has been published by the Environment Agency (Wood *et al*., 2011).

Monitoring of fishing gear

During immersion in seawater, particles of sediment on which radioactivity is adsorbed may become trapped on fishing gear. Fishermen handling this gear may be exposed to external radiation, mainly to skin from beta particles. Fishing gear is regularly monitored using surface contamination monitors. Results for 2012 are given in Table 2.10. Overall, measured dose rates decreased in comparison to those rates in 2011.

Contact dose-rate monitoring of intertidal areas

Results from measurements of beta dose rates on shoreline sediments (using contamination monitors), to allow estimation of exposure of people who handle sediments regularly, are given in Table 2.11. Positively detected dose rates in 2012 were generally similar in comparison to those in 2011 (where comparisons can be made from similar ground types and locations), with some measurements either below the LoD or not detecting beta activity. Overall in 2012, beta dose rates were higher in sand at Whitehaven (outer harbour) than in most recent years.

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 2012, no material was found using these probes in excess of the action level equivalent to 0.01 mSv h^{-1}.

In 2008, the Environment Agency published a formal programme of work for the assessment of contamination by radioactive particles on and around the west Cumbrian coastline. The assessment was focused on public protection from high activity discrete radioactive particles that have been released to the environment from activities at the Sellafield site (Environment Agency, 2008c). The work so far has included investigating the distribution and behaviour of Sellafield-related particles, particle analysis and identification, risks from particles, and a review of particle dispersion and transport models focused on the Eastern Irish Sea and Solway Firth.

Since vehicle-mounted beach survey work began in November 2006, and up to June 2013, approximately 1694 hectares of beach area has been surveyed by the Sellafield site operator's contractors, stretching from the north Solway coastline (at the request of SEPA), down to Silecroft (south of Drigg). The survey equipment used currently (since August 2009) is the Groundhog™ Synergy system, which is an improvement on the use of the original Groundhog™ Evolution system.

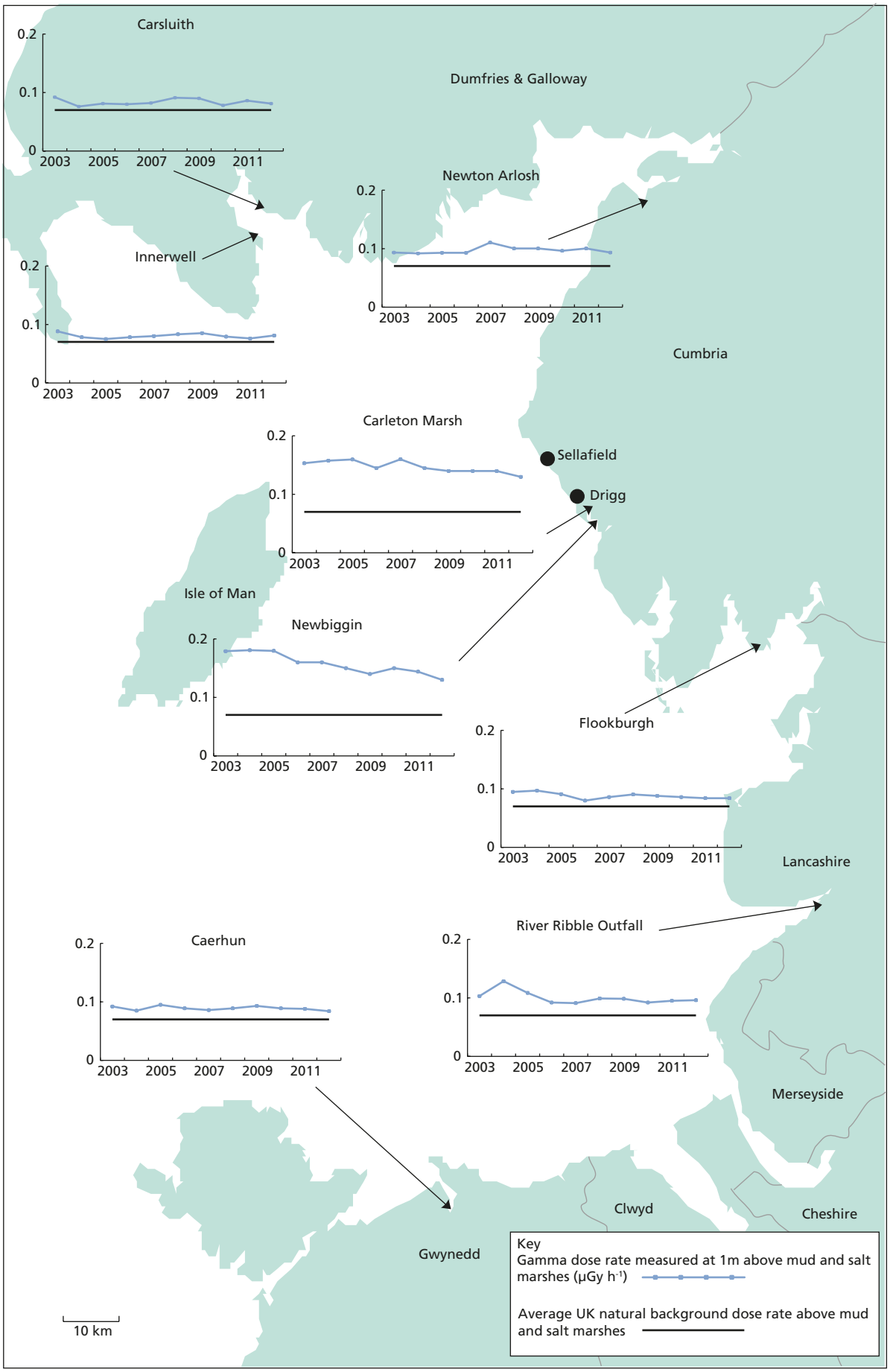


Figure 2.23. Gamma dose rates above fine coastal sediments (mud and salt marshes) in North West England and South West Scotland between 2003-2012

The Groundhog™ Synergy system has a specific capability in relation to the detection of medium/high energy gamma emitting radionuclides and also provides improved detection capability for low energy gamma emissions, increasing the detection of particles containing americium-241.

Up to June 2013, the total number of finds that have been identified since 2006 comprised 1777 stones, pebbles and particles, with around 73 per cent being less than 2 mm in diameter. All have been removed from the beaches. The number of radioactive finds identified in the period from April 2012 to March 2013 was 249 (compared with 267 in the previous year). The majority of the finds were concentrated on a 5 km stretch of beach running NW from the Sellafield site.

Monitoring along the Cumbrian coast will continue, with the current proposal being a further 150 hectares to be surveyed between April 2013 and March 2014, as part of the operator's routine environmental monitoring programme, and will include enhanced strandline and large area beach monitoring capability in relation to the detection of americium-241, strontium-90 and plutonium isotopes.

In August 2011, the Environment Agency conducted a trial programme of seabed sediment sampling along the west Cumbrian coastline in the vicinity of Sellafield. This programme was supported by on-vessel survey monitoring of the sediment to look for the presence of radioactive particles of the sort being detected and removed routinely from nearby beaches. The trial was successful in demonstrating the technique, and in retrieving samples, to allow sediment characteristics to be better understood. The outputs from the exercise were used to inform an offshore sampling and monitoring exercise undertaken by Sellafield Limited in 2012. So far, only a single radioactive particle has been identified by these offshore surveys and two further campaigns are programmed to take place in 2013.

In 2012, Public Health England (PHE) reported their review of the results and position on risk following the introduction of the improved Synergy™ monitoring system. The report concluded that the increase in particle finds following the introduction of this system was a result of its improved capability and also that advice previously given by PHE to the Environment Agency following a detailed assessment of risks in 2010 remained valid (Brown and Etherington, 2011; Etherington *et al*., 2012). The report restated the conclusion that based on the currently available information, the overall health risks to beach users are very low and significantly lower than other risks people accept when using the beaches. As such the PHE advice remained that no special precautionary actions were required to limit access to or use of the beaches.

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

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

In 2010 and 2011, the Environment Agency provided updates on further progress of the enhanced beach monitoring (Environment Agency, 2010; 2011b) with work prior to 2010 described elsewhere (Environment Agency, Food Standards Agency, Northern Ireland Environment Agency and Scottish Environment Protection Agency, 2010a). It is expected that a further update will be published in 2013. Further detail on the monitoring data compiled so far can be obtained from Sellafield Limited: http://sustainability.sellafieldsites.com/environment/environment-page/particles-in-the-environment/

Monitoring of seaweed

In addition to occasional use in foods and as fertilisers, seaweeds are useful environmental indicator materials (as radionuclides are concentrated by seaweeds), facilitating assessments and assisting the tracing of these radionuclides in the environment. Table 2.12 gives the results of measurements in 2012 of seaweeds from shorelines of the Cumbrian coast and further afield.

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, between 1989 and 2012, are shown in Figure 2.8. In the north-east Irish Sea there has been a continued decrease in technetium-99 levels, over the last few years, in response to the reduction in discharges; the highest concentrations which were found near Sellafield were much less than those in the mid 1990s. In general, there was 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 *Fucus* were broadly similar to those in 2011, and this included a specific location (Cemaes Bay, Wales) previously known to have had fluctuating levels over recent years. However in 2012, activity concentrations in seaweed (*Fucus* and *ascophyllum*) were lower at other locations (Carlingford Lough and Ardglass, Northern Ireland) compared with seaweed concentrations in previous years. Variations in levels in the past were most likely the result of complex hydrographic transport patterns in the Irish Sea, with technetium-99 being dispersed to a variable degree before arriving at distant

locations (Leonard *et al.,* 2004). It may also be noted that as the effects of the high technetium discharges of the 1990's continue to disperse, there is the potential for areas distant from Sellafield to exhibit concentrations greater than those in closer proximity, such as Auchencairn, and as observed in seawater in Liverpool Bay for 1998 (McCubbin *et al.*, 2002).

Seaweeds are sometimes used as fertilisers and soil conditioners and this potential pathway for the transfer of radionuclides into the food chain continues to be investigated. The results in 2012 are shown in Table 2.13. The study comprises a survey of the extent of the use of seaweed as a fertiliser in the Sellafield area, collection and analysis of samples and assessments of radiation exposures based on the consumption of crops grown on land to which seaweed, or its compost, had been added (Camplin *et al.*, 2000). Although seaweed harvesting in the Sellafield area continues to be rare, several plots of land were identified and investigated further. Samples of soil were analysed by gamma-ray spectrometry and for technetium-99. The Sellafield soil (compost) data showed enhanced concentrations of technetium-99 and small amounts of caesium-137, as would be expected from the activity initially present in the seaweed. Where comparisons can be made, technetium-99 concentrations in edible parts of the vegetables grown in these soils were lower in 2012 in comparison to those in 2011. These activity concentrations in vegetables provide no evidence for significant uptake. Concentrations of gamma-emitting radionuclides in vegetables were small or below the LoD.

No harvesting of *Porphyra* in west Cumbria, for consumption in the form of laverbread, was reported in 2012; this pathway has therefore remained dormant. However, monitoring of *Porphyra* has continued in view of its potential importance, historical significance and the value of *Porphyra* as an environmental indicator material. Samples of *Porphyra* are regularly collected from selected locations along UK shorelines of the Irish Sea. Results of analyses for 2012 are given in Table 2.12. In 2012, ruthenium-106 concentrations in *Porphyra* from the Cumbrian coast (Seascale and St Bees) were below the LoD, and reduced in comparison to those in earlier years (due to the decreased discharges of this radionuclide in 2005 and 2006). Results for analyses of samples of the major manufacturers' laverbread that are regularly collected from markets in South Wales, are also given in Table 2.12. In 2012, activity concentrations in laverbread were below the LoD, with the exception of small concentrations of americium-241.

Monitoring of seawashed pasture

The potential transfer of technetium-99 to milk, meat and offal from animals grazing tide-washed pasture was considered using a modelling approach in the report for 1997 (Ministry of Agriculture, Fisheries and Food and Scottish Environment Protection Agency, 1998). The maximum potential dose was calculated to be 0.009 mSv at that time. Follow-up sampling of tide-washed pastures at Newton Arlosh, Cumbria and Hutton Marsh, Lancashire in 2006 suggested that this dose estimate remains valid (Environment Agency, Environment and Heritage Service, Food Standards Agency and Scottish Environment Protection Agency, 2007).

Monitoring of sea to land transfer

Terrestrial foodstuffs are monitored near Ravenglass to check on the extent of transfer of radionuclides from sea to land in this area. Samples of milk, crops, fruit, livestock and environmental indicator materials were collected and analysed for radionuclides, which were released in liquid effluent discharges from Sellafield.

The results of measurements in 2012 are given in Table 2.14. In general, the data are similar to those for 2011 and, where detectable, show lower concentrations than are found in the immediate vicinity of Sellafield. As in previous years, the evidence for sea to land transfer was very limited in 2012. Positively detected technetium-99 concentrations were few, and measured just above the LoD. Small concentrations of artificial nuclides were detected in some samples but the concentrations were very low. Where detectable, observed isotopic ratios of ^{238}Pu:$^{239+240}Pu$ concentrations were somewhat higher than 0.025, a value which might be expected if the source was only (or entirely) due to fallout. This may suggest a Sellafield influence.

Monitoring of fishmeal

Low concentrations of man-made radioactivity were found in fishmeal, which is fed to farmed fish, poultry, pigs, cows and sheep. A theoretical study has established that any indirect onward transmission of radioactivity into human diet as a result of this pathway is unlikely to be of radiological significance (Smith and Jeffs, 1999). A detailed survey was undertaken in 2003 to confirm these findings. Samples were obtained from 14 fish farms in Scotland and three in Northern Ireland. They demonstrated that concentrations of radionuclides are indeed very low, most being less than the limits of detection, and the few that were positively determined were all less than 1 Bq kg^{-1} (Food Standards Agency, 2003). Results obtained in farmed salmon from the west of Scotland in 2012 in Tables 2.5 and 2.7 confirm the findings of the 2003 study.

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 9.

Sampling of fresh water 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 2012 are included in

Table 2.15. The gross alpha and beta activities for drinking waters were below the World Health Organisation (WHO) recommended values of 0.5 Bq l^{-1} and 1.0 Bq l^{-1} respectively.

Small amounts of activity 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. Unlike some previous years, there was no evidence of tritium 100m downstream of the outfall in 2012 (Table 2.15). These waters are not potable and any low concentrations observed previously are of no radiological significance. Table 2.15 also includes the results of monitoring from the Ehen Spit (Figure 2.10) near Sellafield where water issues from the ground at low tide. This release is not due to regulated discharges of liquid wastes but to ground water migration from the Sellafield site. The water is brackish so it will not be used as a drinking water source and therefore the only consumption would be inadvertent. Enhanced gross beta and tritium concentrations were observed in 2012 with concentrations similar to those in recent years. The dose from inadvertent consumption of water from Ehen Spit has been shown to be insignificant (Environment Agency, 2002a).

2.3.4 Monitoring of unusual pathways

In 1998, high concentrations of caesium-137 (of up to 110,000 Bq kg^{-1}) were found in feral pigeons sampled in Seascale by the Ministry of Agriculture, Fisheries and Food (MAFF). Consumption of the breast meat of only 20 birds contaminated at the highest concentration would have given a dose of 1 mSv to high-rate consumers. Advice issued by MAFF in 1998 was that people should not handle, slaughter or consume pigeons within a 10 mile radius of the site. A full review of the incident was published in 1999 (Copeland Borough Council *et al.*, 1999). It was found that pigeons had access to the roof spaces in buildings on the Sellafield site and had become contaminated with radionuclides including caesium-137. The pigeons were also congregating in large numbers at a bird sanctuary in Seascale village and the environment around had become contaminated. Since then, the site operator has undertaken remedial measures, including a substantial cull of feral pigeons in the area and preventing access to the loft spaces in buildings on the Sellafield site. Results of the analysis of a wood pigeon sample collected in 2012 are included in Table 2.4. The total caesium activity concentration in the muscle of wood pigeon (0.067 Bq kg^{-1}) in 2012 was generally similar to the maximum value reported in 2011 (0.29 Bq kg^{-1}). These total caesium concentrations have had fluctuating levels in recent years prior to 2011. Concentrations of artificial radionuclides were low and would add little to the exposure of local consumers. The Food Standards Agency will continue to monitor this pathway.

Following the review of the pigeon incident, the Environment Agency began to sample and analyse sediments from road drains (gully pots) in Seascale and Whitehaven in 1999. Gully pots in road drains collect sediments washed off road surfaces and provide good indicators of contamination of urban environments. The results of analyses in 2012 are shown in Table 2.16, and were generally similar to those in previous years. In 2010, elevated concentrations (of strontium-90, caesium-137, americium-241 and plutonium radionuclides) in sediments were reported for one of the five Seascale road drains (Seascale SS 233). Investigations, including monitoring of additional Seascale road drains, were conducted in 2011 to confirm that the elevation had ceased or to inform appropriate action. The results indicate that the elevated levels in 2010 were not sustained in 2011 and 2012 and that results were mostly consistent with other road drains sampled. The enhancements may have arisen from unusual weather conditions in that year, releasing radioactivity trapped within the drainage path. Generally, over a longer period, activity concentrations in road drains have fallen significantly since remedial measures to reduce contamination were taken.

2.4 Windscale, Cumbria

Windscale is a separate licensed site located at Sellafield. The NDA has ownership of the site. In 2008, the Windscale permit was transferred from UKAEA to Sellafield Limited, and combined with the Sellafield site permit. At Windscale there are three nuclear reactors, two of which were shut down in 1957 and the third in 1981. Most of the radioactive wastes derive from decontamination and decommissioning operations, some of which are of the early Windscale reactor buildings. Decommissioning activities began in the mid 1980s but have recently been subject to deferrals in order to release resources for high hazard work. However, the reactor decommissioning of the Windscale Advanced Gas Cooled Reactor was completed in 2011. Facilities which were undergoing decommissioning will be placed in a safe state until decommissioning work resumes. Gaseous wastes are regulated from specific stacks on the Windscale site; liquid radioactive wastes are disposed of, after appropriate treatment, to the Irish Sea via the Sellafield site pipelines. Both gaseous and liquid discharges are included as part of the regulated Sellafield discharges (Appendix 2). Discharges of both gaseous and liquid radioactive wastes are minor compared to those from the Sellafield nuclear licensed site.

Regular monitoring of the environment by the Environment Agency and the Food Standards Agency is conducted as part of the overall programme for the Sellafield site. The results of this monitoring and the implications in terms of dose to people in Cumbria are described in Section 2.3.

Table 2.1. Individual doses – Capenhurst and Springfields, 2012

Site	Exposed population[a]	Exposure, mSv per year						
		All pathways	Seafood	Other local food	External radiation from intertidal areas, river banks or fishing gear	Intakes of sediment and water	Gaseous plume related pathways	Direct radiation from site
Capenhurst								
Total dose – all sources	**Local inhabitants aged 10 yr (0-0.25km)**	**0.085**	**–**	**<0.005**	**–**	**–**	**<0.005**	**0.085**
Source specific doses	Infant consumers of locally grown food[d]	<0.005	–	<0.005	–	–	<0.005	–
	Children playing at Rivacre Brook[c,d]	0.009	–	–	0.009	<0.005	–	–
Springfields								
***Total dose* – all sources**	**Adult occupants on houseboats**	**0.068**	**–**	**–**	**0.068**	**–**	**–**	**–**
Source specific doses	Seafood consumers	0.022	<0.005	–	0.020	–	–	–
	Houseboat occupants	0.083	–	–	0.083	–	–	–
	Fishermen handling nets or pots[b]	0.054	–	–	0.054	–	–	–
	Children playing at Lower Penwortham[c,d]	<0.005	–	–	<0.005	<0.005	–	–
	Farmers	0.034	–	–	0.034	–	–	–
	Wildfowl consumption	0.006	–	<0.005	0.005	–	–	–
	Consumers of locally grown food	<0.005	–	<0.005	–	–	<0.005	–

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

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

[c] *Children aged 10y*

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

Table 2.2(a). Concentrations of radionuclides in food and the environment near Capenhurst, 2012

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	^{237}Np
Marine samples										
Plaice	Liverpool Bay	2	<25							
Flounder	Mersey Estuary	1	<25							
Shrimps	Wirral	2	<35	0.36	1.0	*				
Mussels	Liverpool Bay	2	<25							
Mussels	Mersey Estuary	2	<25							
Cockles	Dee Estuary	4		2.3	1.1	<4.3				
Sediment	Rivacre Brook	2[E]		55	1.8	50	71	3.4	39	<4.0
Sediment	Rivacre Brook (1.5 km downstream)	2[E]		34	1.7	22	33	<1.9	22	<4.0
Sediment	Rossmore (3.1 km downstream)	2[E]		27	1.2	21	17	<1.4	12	<4.0
Sediment	Rivacre Brook (4.3 km downstream)	2[E]		14	0.72	<8.3	11	<1.6	7.3	<4.0
Freshwater	Rivacre Brook	2[E]	<4.7	0.36			0.10	<0.0072	0.045	<0.10
Freshwater	Rivacre Brook (1.5 km downstream)	2[E]	<4.0	<0.062			0.032	<0.0064	0.017	<0.10
Freshwater	Rossmore (3.1 km downstream)	2[E]	<3.2	<0.15			0.029	<0.0041	0.016	<0.10
Freshwater	Rivacre Brook (4.3 km downstream)	2[E]	<3.1	<0.16			0.027	<0.0040	0.015	<0.10

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									
Shrimps	Wirral	2			<0.05				
Cockles	Dee Estuary	4	0.11	0.67	1.4	*	*		
Sediment	Rivacre Brook	2[E]						230	690
Sediment	Rivacre Brook (1.5 km downstream)	2[E]						140	380
Sediment	Rossmore (3.1 km downstream)	2[E]						<110	410
Sediment	Rivacre Brook (4.3 km downstream)	2[E]						<100	370
Freshwater	Rivacre Brook	2[E]						<0.15	0.56
Freshwater	Rivacre Brook (1.5 km downstream)	2[E]						<0.061	0.33
Freshwater	Rossmore (3.1 km downstream)	2[E]						<0.064	0.31
Freshwater	Rivacre Brook (4.3 km downstream)	2[E]						<0.046	0.28

Table 2.2(a). continued

Material	Location or selection[b]	No. of sampling observ-ations[d]	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}				
			^{3}H[c]	^{99}Tc	^{234}U	^{235}U	^{238}U
Terrestrial samples							
Milk		5	<3.2	<0.0040	0.0012	<0.00044	<0.0010
Milk	max		<3.5		0.0015	0.00070	0.0014
Cabbage		1			0.0011	<0.00030	0.00080
Gooseberries		1		0.037	0.00090	<0.00030	0.00080
Potatoes		1		<0.032	0.0053	0.00070	0.0028
Grass		4		<0.010	0.0082	<0.00055	0.0068
Grass	max			0.014	0.013	0.00070	0.013
Grass/herbage	North of Ledsham	1[E]		<0.43	<0.36	<0.37	<0.50
Grass/herbage	South of Capenhurst	1[E]		<0.38	<0.37	<0.20	<0.37
Grass/herbage	Off lane from Capenhurst to Dunkirk	1[E]		<0.28	<0.40	<0.22	<0.34
Grass/herbage	East of station	1[E]		<0.25	<0.34	<0.39	<0.36
Silage		2		<0.010	0.014	0.00060	0.014
Silage	max				0.015	0.00080	0.015
Soil		1[#]			6.9	0.28	7.1
Soil	North of Ledsham	1[E]		<1.6	17	<1.7	19
Soil	South of Capenhurst	1[E]		<2.2	16	<2.4	16
Soil	Off lane from Capenhurst to Dunkirk	1[E]		5.6	17	<3.5	16
Soil	East of station	1[E]		<1.9	17	<1.3	16

* *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 (except for those soil samples marked with a # which are fresh concentrations)*

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

[c] *In distillate fraction of sample*

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

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

Table 2.2(b). Monitoring of radiation dose rates near Capenhurst, 2012

Location	Ground type	No. of sampling observa-tions	μGy h^{-1}
Mean gamma dose rates at 1m over substrate			
Rivacre Brook Plant outlet	Grass and mud	1	0.093
Rivacre Brook Plant outlet	Grass	1	0.089
Rivacre Brook 1.5 km downstream	Grass	2	0.080
Rossmore Road West 3.1 km downstream	Grass and mud	1	0.075
Rossmore Road West 3.1 km downstream	Grass	1	0.080
Rivacre Brook 4.3 km downstream	Grass	1	0.079
Rivacre Brook 4.3 km downstream	Vegetation	1	0.077

Table 2.3(a). Concentrations of radionuclides in food and the environment near Springfields, 2012

Material	Location	No. of sampling observ-ations	Mean radioactivity concentration (fresh)[b], Bq kg^{-1}							
			^{3}H	^{14}C	^{60}Co	^{90}Sr	^{99}Tc	^{129}I	^{137}Cs	^{228}Th
Marine samples										
Grey mullet	Ribble Estuary	2			<0.10				2.2	
Sole	Ribble Estuary	1			<0.12				1.5	
Bass	Ribble Estuary	1			<0.15				3.9	
Salmon	Ribble Estuary	1			<0.07				0.20	
Shrimps	Ribble Estuary	2		44	<0.05		0.48		1.7	0.0084
Cockles	Ribble Estuary	2			<0.12				1.4	0.39
Wildfowl	Ribble Estuary	1	<25	21	<0.08	<0.076		<1.8	2.2	0.0057
Samphire	Marshside Sands	1			<0.10				0.98	
Sediment	River Ribble outfall	4[E]			<0.53				140	30
Sediment	Savick Brook	2[E]			<0.49				140	36
Sediment	Lea Gate	2[E]			<0.50				110	30
Sediment	Lower Penwortham Park	4[E]			<0.41				97	35
Sediment	Penwortham rail bridge	3[E]			<0.39				14	17
Sediment	Penwortham rail bridge – West bank	1[E]			<0.41				82	24
Sediment	Penwortham position 1	4[E]			<0.79				70	22
Sediment	Penwortham position 2	1[E]			<0.38				32	15
Sediment	Lytham Yacht Club	1[E]			<0.53				230	42
Sediment	Becconsall	4[E]			<0.51				120	31
Sediment	Freckleton	1[E]			<0.69				200	48
Sediment	Hutton Marsh	1[E]			<1.6				410	50
Sediment	Longton Marsh	1[E]			<0.56				470	44
Grass (washed)	Hutton Marsh	1[E]					<0.36			
Grass (unwashed)	Hutton Marsh	1[E]					<2.1			
Soil	Hutton Marsh	1[E]					33			

Material	Location	No. of sampling observ-ations	Mean radioactivity concentration (fresh)[b], Bq kg^{-1}							
			^{230}Th	^{232}Th	^{234}Th	^{234}U	^{235}U	^{238}U	^{237}Np	^{238}Pu
Marine samples										
Grey mullet	Ribble Estuary	2			*					
Sole	Ribble Estuary	1			*					
Bass	Ribble Estuary	1			*					
Salmon	Ribble Estuary	1			*					
Shrimps	Ribble Estuary	2	0.0042	0.0026	*				0.00015	0.0015
Cockles	Ribble Estuary	2	0.42	0.20	<5.1					0.14
Wildfowl	Ribble Estuary	1	0.0045	0.0026	*					0.0010
Sediment	River Ribble outfall	4[E]	54	28	230	21	<1.5	22		
Sediment	Savick Brook	2[E]	71	30	1300	32	<2.3	28		
Sediment	Lea Gate	2[E]	87	29	1300	42	2.1	38		
Sediment	Lower Penwortham Park	4[E]	100	32	280	19	<1.8	19		
Sediment	Penwortham rail bridge	3[E]	20	16	75	12	<1.5	12		
Sediment	Penwortham rail bridge – West bank	1[E]	44	23	830	19	0.96	20		
Sediment	Penwortham position 1	4[E]	38	20	<460	17	<2.0	17		
Sediment	Penwortham position 2	1[E]	20	14	370	11	<1.3	10		
Sediment	Lytham Yacht Club	1[E]	81	39	560	28	<2.0	28		
Sediment	Becconsall	4[E]	52	28	180	20	<1.7	21		
Sediment	Freckleton	1[E]	80	44	420	29	<3.5	28		
Sediment	Hutton Marsh	1[E]	170	41	150	26	<2.6	30		
Sediment	Longton Marsh	1[E]	240	41	58	30	<1.9	31		

Table 2.3(a). continued

Material	Location	No. of sampling observ-ations	Mean radioactivity concentration (fresh)[b], Bq kg^{-1}					
			^{239}Pu+ ^{240}Pu	^{241}Am	^{242}Cm	^{243}Cm+ ^{244}Cm	Gross alpha	Gross beta
Marine samples								
Grey mullet	Ribble Estuary	2		<0.17				
Sole	Ribble Estuary	1		<0.08				
Bass	Ribble Estuary	1		<0.31				
Salmon	Ribble Estuary	1		<0.07				
Shrimps	Ribble Estuary	2	0.0091	0.018	*	*		
Cockles	Ribble Estuary	2	0.86	2.3	*	*		
Wildfowl	Ribble Estuary	1	0.0056	0.0095	0.000040	*		
Samphire	Marshside Sands	1		0.40				
Sediment	River Ribble outfall	4[E]		120			410	1200
Sediment	Savick Brook	2[E]		110			430	1400
Sediment	Lea Gate	2[E]		89			410	1700
Sediment	Lower Penwortham Park	4[E]		79			440	820
Sediment	Penwortham rail bridge	3[E]		10			130	370
Sediment	Penwortham rail bridge							
	– West bank	1[E]		70			340	600
Sediment	Penwortham position 1	4[E]		<53			<230	670
Sediment	Penwortham position 2	1[E]		27			170	440
Sediment	Lytham Yacht Club	1[E]		200			600	1700
Sediment	Becconsall	4[E]		110			400	830
Sediment	Freckleton	1[E]		170			610	1400
Sediment	Hutton Marsh	1[E]		330			940	1500
Sediment	Longton Marsh	1[E]		290			980	1500

Material	Location or selection[a]	No. of sampling observ-ations[c]	Mean radioactivity concentration (fresh)[b], Bq kg^{-1}					
			^{3}H	^{14}C	^{90}Sr	^{129}I	^{137}Cs	Total Cs
Terrestrial samples								
Apples		1	<4.0	17	0.082	<0.020		0.074
Beetroot		1	<4.0	10	0.042	<0.028		0.093
Blackberries		1	<4.0	17	0.14	<0.027		0.19
Cabbage		1	11	7.0	0.098	<0.029		0.121
Potatoes		1	<5.0	22	0.038	<0.025		0.11
Rabbit		1	<6.0	45	<0.010	<0.041		0.064
Runner beans		1	9.0	11	0.089	<0.030		0.059
Sediment	Deepdale Brook	2[E]					1.4	
Grass		1					0.20	

Table 2.3(a). continued

Material	Location or selection[a]	No. of sampling observ-ations[c]	Mean radioactivity concentration (fresh)[b], Bq kg^{-1}					
			^{230}Th	^{232}Th	^{234}Th	^{234}U	^{235}U	^{238}U
Terrestrial samples								
Milk		5				0.0010	<0.00036	<0.0010
Milk	max					0.0016	0.00050	0.0020
Apples		1	0.0023	0.0017		0.0016	0.00030	0.0012
Beetroot		1	0.015	0.0084		0.0091	0.00080	0.0085
Blackberries		1	0.0053	0.0022		0.0013	<0.00030	0.00060
Cabbage		1	0.0071	0.0011		0.0017	<0.00030	0.00070
Potatoes		1	0.0092	0.0069		0.0049	0.00030	0.0048
Rabbit		1	0.0038	<0.0010		0.0020	0.00020	0.00090
Runner beans		1	0.0032	0.0031		0.0020	0.00030	0.00090
Sediment	Deepdale Brook	2[E]			76	57	2.9	58
Grass		1				0.037	0.0018	0.029
Grass	Site fence	1[E]				<0.61	<0.58	<0.29
Grass	Opposite site entrance	1[E]				<0.72	<0.48	<0.68
Grass	Opposite windmill	1[E]				1.2	<0.18	0.88
Grass	Deepdale Brook	1[E]				<0.78	<0.32	0.70
Grass	Lea Town	1[E]				<0.61	<0.66	<0.67
Grass	N of Lea Town	1[E]				<0.18	<0.15	0.18
Silage		1				0.30	0.011	0.27
Soil		1[#]				17	0.71	17
Soil	Site fence	1[E]				87	3.0	78
Soil	Opposite site entrance	1[E]				96	6.1	86
Soil	Opposite windmill	1[E]				95	4.3	88
Soil	Deepdale Brook	1[E]				99	4.9	96
Soil	Lea Town	1[E]				33	1.9	35
Soil	N of Lea Town	1[E]				57	<3.3	59
Freshwater	Deepdale Brook	4[E]				0.57	0.026	0.55

Material	Location or selection[a]	No. of sampling observ-ations[c]	Mean radioactivity concentration (fresh)[b], Bq kg^{-1}					
			^{238}Pu	^{239}Pu + ^{240}Pu	^{241}Pu	^{241}Am	Gross alpha	Gross beta
Terrestrial samples								
Apples		1	<0.00020	<0.00030	<0.076	0.00020		
Beetroot		1	0.00030	<0.00030	<0.073	0.00020		
Blackberries		1	<0.00020	<0.00030	0.12	0.00060		
Cabbage		1	<0.00020	<0.00030	<0.079	0.00010		
Potatoes		1	<0.00010	<0.00030	<0.072	0.00020		
Rabbit		1	0.00010	<0.00020	0.11	0.00030		
Runner beans		1	0.00020	<0.00030	<0.083	0.00020		
Sediment	Deepdale Brook	2[E]					430	890
Grass		1				<0.00020		
Freshwater	Deepdale Brook	4[E]					0.84	0.80

* *Not detected by the method used*

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

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

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

[E] *Measurements are made on behalf of the Food Standards Agency unless labelled "E". In that case they are made on behalf of the Environment Agency*

[#] *Fresh concentrations*

Table 2.3(b). Monitoring of radiation dose rates near Springfields, 2012

Location	Material or ground type	No. of sampling observations	μGy h^{-1}
Mean gamma dose rates at 1m over substrate			
Lytham Yacht Club	Grass	1	0.098
Warton Mud Marsh	Grass	2	0.12
Warton Mud Marsh	Grass[a]	2	0.13
Warton Salt Marsh	Grass	2	0.096
Freckleton	Grass	1	0.098
Naze Point	Grass	2	0.11
Banks Marsh	Grass	2	0.11
Banks Marsh	Grass[a]	2	0.12
Hesketh Bank	Grass	2	0.11
Becconsall Boatyard	Mud[b]	17	0.086
Becconsall Boatyard	Grass and mud	2	0.084
Becconsall Boatyard	Grass	2	0.089
Becconsall (vicinity of houseboats)	Asphalt	2	0.077
Longton Marsh	Grass and salt marsh	1	0.11
Hutton Marsh	Grass	1	0.11
River Ribble outfall	Mud	2	0.095
River Ribble outfall	Mud and sand	2	0.096
Savick Brook, confluence with Ribble	Grass and mud	1	0.088
Savick Brook, confluence with Ribble	Grass	1	0.090
Savick Brook, tidal limit	Grass and mud	1	0.093
Savick Brook, tidal limit	Grass	1	0.099
Savick Brook, Lea Gate	Grass and mud	1	0.095
Savick Brook, Lea Gate	Grass	1	0.098
South bank opposite outfall	Grass	1	0.11
Penwortham Bridge cadet hut	Mud and sand	1	0.087
Penwortham Bridge cadet hut	Sand and stones	1	0.083
Lower Penwortham Park	Grass	4	0.079
Lower Penwortham Railway Bridge	Grass and mud	1	0.079
Lower Penwortham Railway Bridge	Pebbles and stones	3	0.082
River Darwen	Grass	4	0.082
Riverbank Angler location 1	Grass and mud	1	0.079
Riverbank Angler location 1	Grass	3	0.077
Riverbank Angler location 2	Mud	1	0.078
Ulnes Walton, BNFL area survey	Grass	3	0.079
Mean beta dose rates			μSv h^{-1}
Lytham – Granny's Bay	Mud and sand	1	0.020
Ribble Estuary	Gill net	2	0.12
Ribble Estuary	Shrimp net	2	0.19
Banks Marsh	Grass	2	0.030
Warton Mud Marsh	Grass	2	0.040
Warton Salt Marsh	Grass	2	0.040

[a] *15cm above substrate*
[b] *Data collected during survey of occupancies, 2012*

Table 2.4. Concentrations of radionuclides in terrestrial food and the environment near Sellafield, 2012

Material	Selection[a]	No. of sampling observ-ations[c]	Mean radioactivity concentration (fresh)[b], Bq kg^{-1}									
			Organic ^{3}H	^{3}H	^{14}C	^{60}Co	^{90}Sr	^{99}Tc	^{106}Ru	^{125}Sb	^{129}I	^{131}I
Milk		16	<4.4	<4.5	20	<0.18	0.040	<0.0050	<1.1	<0.35	<0.0081	<0.0053
Milk	max		<5.0	<5.3	22	<0.20	0.067		<1.3	<0.38	0.023	<0.0068
Apples		2	<4.5	<4.0	14	<0.20	0.11	0.17	<1.4	<0.35	<0.023	
Apples	max		<5.0		15		0.12			<0.40		
Barley		1		<8.0	75	<0.30	1.0		<1.7	<0.30	<0.041	
Beef kidney		1	<22	22	35	<0.20	0.79	<0.025	<0.80	<0.50	<0.032	
Beef liver		1	<21	21	59	<0.20	0.21	<0.026	<0.90	<0.20	<0.037	
Beef muscle		1	<11	11	40	<0.20	<0.0070	<0.026	<1.4	<0.40	<0.036	
Blackberries		2	<5.0	<4.0	13	<0.20	0.79		<1.3	<0.35	<0.033	
Blackberries	max		<6.0	4.0			0.93			<0.40		
Blackcurrants		1	<4.0	<4.0	17	<0.20	0.076		<1.2	<0.30	<0.022	
Cabbage		1	<4.0	<4.0	13	<0.20	0.20		<1.4	<0.40	<0.029	
Carrots		1	<4.0	<4.0	9.0	<0.20	0.39	<0.029	<1.1	<0.30	<0.027	
Duck		1	<6.0	<6.0	39	<0.20	0.020	<0.030	<1.0	<0.40	<0.022	
Eggs		1	<6.0	<6.0	36	<0.20	0.011		<1.2	<0.50	<0.025	
Honey		1		<8.0	71	<0.20	0.035		<0.80	<0.40	<0.013	
Mushrooms		1	<4.0	<4.0	5.0	<0.20	1.3		<1.2	<0.50	<0.034	
Oats		1		<7.0	87	<0.20	0.99		<0.60	<0.60	<0.031	
Onions		1	<4.0	<4.0	16	<0.20	0.20		<0.70	<0.40	<0.023	
Pheasants		1	<5.0	<5.0	52	<0.10	0.052	<0.027	<1.2	<0.30	<0.052	
Potatoes		2	<5.5	<5.5	15	<0.20	0.042		<1.5	<0.50	<0.041	
Potatoes	max		<6.0	6.0	22				<1.8	<0.60	<0.042	
Rabbit		1	<5.0	<5.0	23	<0.20	0.025	<0.026	<1.1	<0.30	<0.049	
Runner beans		1	<5.0	5.0	10	<0.20	0.29		<0.90	<0.40	<0.061	
Sheep muscle		2	<6.0	<6.0	54	<0.20	0.022	<0.025	<1.1	<0.40	<0.035	
Sheep muscle	max				56		0.024		<1.2		<0.045	
Sheep offal		2	<8.0	<8.0	34	<0.15	0.44	<0.035	<1.2	<0.30	<0.036	
Sheep offal	max				43	<0.20	0.45	0.041				
Swede		1	<4.0	<4.0	14	<0.30	0.61		<1.4	<0.50	<0.026	
Turnips		1	<4.0	<4.0	10	<0.20	0.48		<1.0	<0.40	<0.037	
Wood pigeon muscle		1	<5.0	<5.0	49	<0.20	0.047		<1.0	<0.40	<0.039	
Grass		5				<0.14		<0.17	<0.60	<0.32		
Grass	max					<0.20		0.30	<0.80	0.60		
Soil		3				<0.20			<1.0	<0.47		
Soil	max								<1.3	<0.50		

Table 2.4. continued

Material	Selection[a]	No. of sampling observ-ations[c]	Mean radioactivity concentration (fresh)[b], Bq kg^{-1}									
			^{134}Cs	^{137}Cs	Total Cs	^{234}U	^{235}U	^{238}U	^{238}Pu	^{239}Pu + ^{240}Pu	^{241}Pu	^{241}Am
Milk		16	<0.19	<0.19	0.13				<0.00011	<0.00016	<0.038	<0.00011
Milk	max		<0.20	<0.20	0.23				<0.00013	<0.00018	<0.042	<0.00013
Apples		2			0.12				<0.00020	0.00060	<0.081	0.00095
Apples	max				0.14					0.00080	<0.083	0.0010
Barley		1			0.58				0.00040	0.0035	<0.081	0.00029
Beef kidney		1			1.5	0.012	<0.00040	0.011				
Beef liver		1			1.0				0.00020	0.0035	0.10	0.0023
Beef muscle		1			0.87				<0.00020	<0.00040	<0.093	0.00050
Blackberries		2			0.20				<0.00020	0.00070	<0.082	0.0012
Blackberries	max				0.28					0.0012	<0.088	0.0015
Blackcurrants		1			0.11				0.00020	0.00050	<0.082	0.0023
Cabbage		1			0.25				0.00010	<0.00020	<0.063	0.00030
Carrots		1			0.21							
Duck		1			0.11				<0.00020	0.00030	0.10	0.00030
Eggs		1			0.093				<0.00010	<0.00030	<0.065	0.00040
Honey		1			0.067				<0.00010	<0.00020	<0.084	<0.00010
Mushrooms		1			0.26				0.0021	0.015	<0.084	0.027
Oats		1			1.5				0.00090	0.011	<0.088	0.0070
Onions		1			0.17							
Pheasants		1			0.60				0.00020	<0.00030	<0.14	<0.00020
Potatoes		2			0.13	0.0024	<0.00030	0.0021	<0.00020	<0.00020	<0.085	0.00020
Potatoes	max				0.14							
Rabbit		1			2.8				0.00020	<0.00030	<0.13	<0.00020
Runner beans		1			0.13				0.00020	0.00030	<0.080	0.00060
Sheep muscle		2			1.7				<0.00025	<0.00045	<0.11	0.00030
Sheep muscle	max				1.8				<0.00030	<0.00050	<0.12	
Sheep offal		2			0.63	0.0028	0.00030	0.0027	0.00035	0.0036	<0.16	0.0027
Sheep offal	max				0.73	0.0039		0.0035	0.00040	0.0041	<0.19	0.0030
Swede		1			0.27							
Turnips		1			0.22	0.0031	0.00030	0.0019				
Wood pigeon muscle		1			0.067				<0.00020	<0.00040	<0.092	0.00020
Grass		5	<0.10	0.88								<0.23
Grass	max			1.9								0.30
Soil		3	<0.20	49								5.6
Soil	max			57		9.8	0.42	9.3				7.1

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

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

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

Table 2.5. Beta/gamma radioactivity in fish from the Irish Sea vicinity and further afield, 2012

Location	Material	No. of sampling observ-ations	Mean radioactivity concentration (fresh), Bq kg^{-1}							
			Organic ^{3}H	^{3}H	^{14}C	^{60}Co	^{90}Sr	^{95}Zr	^{95}Nb	^{99}Tc
Cumbria										
Maryport	Plaice	4				<0.07		<0.16	<0.14	
Parton	Cod	4				<0.09		<0.19	<0.17	
Whitehaven	Cod	4			80	<0.09	0.029	<0.20	<0.18	
Whitehaven	Plaice	4				<0.10	0.026	<0.24	<0.24	
Whitehaven	Skates / rays	4				<0.15		<0.44	<0.49	
Whitehaven	Sole	4				<0.11		<0.40	<0.56	
Sellafield coastal area	Cod	8				<0.11		<0.39	<0.53	
Sellafield coastal area	Plaice	4	110	130		<0.10		<0.35	<0.51	
Sellafield coastal area	Bass	1				<0.09		<0.29	<0.35	
Sellafield coastal area	Grey mullet	1				<0.09		<0.31	<0.33	
Sellafield offshore area	Cod	2			130	<0.11	0.069	<0.24	<0.21	0.17
Sellafield offshore area	Dab	2				<0.25		<0.78	<1.0	
Sellafield offshore area	Plaice[a]	2			240	<0.13	<0.17	<0.28	<0.28	2.0
Sellafield offshore area	Lesser spotted dogfish	1				<0.08		<0.21	<0.18	
Sellafield offshore area	Gurnard	1				<0.14		<0.44	<0.58	
Sellafield offshore area	Skates / rays	1				<0.11		<0.19	<0.16	
Sellafield offshore area	Spurdog	1				<0.10		<0.44	<0.65	
River Calder	Brown trout	2				<0.11		<0.41	<0.54	
Ravenglass	Cod	6				<0.07		<0.24	<0.31	
Ravenglass	Plaice	4	150	180		<0.08		<0.22	<0.23	
Morecambe Bay (Flookburgh)	Flounder	4			72	<0.13		<0.54	<0.82	
Lancashire and Merseyside										
Morecambe Bay (Morecambe)	Whiting	4				<0.07		<0.23	<0.27	
Morecambe Bay (Morecambe)	Bass	2				<0.08		<0.33	<0.47	
Morecambe Bay (Morecambe)	Flounder	4	28	<25		<0.10	0.040	<0.29	<0.31	0.31
Morecambe Bay (Sunderland Point)	Whitebait	1				<0.10	0.050	<0.23	<0.19	
Fleetwood	Plaice	4				<0.05		<0.17	<0.19	
Fleetwood	Cod	4			36	<0.06	<0.054	<0.12	<0.10	<0.24
Ribble Estuary	Grey mullet	2				<0.10		<0.35	<0.39	
Ribble Estuary	Sole	1				<0.12		<0.45	<0.58	
Ribble Estuary	Bass	1				<0.15		<0.36	<0.34	
Ribble Estuary	Salmon	1				<0.07		<0.22	<0.26	
Liverpool Bay	Plaice	2		<25						
Mersey Estuary	Flounder	1		<25						
Scotland										
Shetland	Fish meal (herring)	1[S]				<0.10		<0.22	<0.16	
Shetland	Fish meal (salmon)	1[S]				<0.10		<0.21	<0.16	
Shetland	Fish oil (herring)	1[S]				<0.10		<0.54	<0.81	
Shetland	Fish oil (salmon)	1[S]				<0.10		<0.50	<0.75	
Minch	Herring	1[S]				<0.10		<0.16	<0.17	
West of Scotland	Mackerel	1[S]				<0.10		<0.23	<0.40	
West of Scotland	Salmon	1[S]				<0.10		<0.25	<0.47	
Kirkcudbright	Plaice	4[S]			<15	<0.11		<0.43	<0.64	0.30
Inner Solway	Flounder	2[S]			28	<0.13	<0.10	<0.55	<0.81	5.6
Inner Solway	Salmon	1[S]		<5.0		<0.10		<0.46	<0.66	
Inner Solway	Sea trout	1[S]		<5.0		<0.10		<0.84	<1.8	
Isle of Man										
Isle of Man	Cod	4				<0.06		<0.15	<0.13	
Isle of Man	Herring	4				<0.09		<0.49	<0.13	
Wales										
North Anglesey	Skates / rays	1				<0.04		<0.17	<0.24	
North Anglesey	Lesser spotted dogfish	3				<0.12		<0.43	<0.54	
North Anglesey	Plaice	2	<25	<25	45	<0.06		<0.18	<0.24	
North Anglesey	Bass	1				<0.04		<0.22	<0.34	

Table 2.5. continued

Location	Material	No. of sampling observ-ations	Mean radioactivity concentration (fresh), Bq kg^{-1}						
			^{106}Ru	^{125}Sb	^{134}Cs	^{137}Cs	^{144}Ce	^{155}Eu	Gross beta
Cumbria									
Maryport	Plaice	4	<0.61	<0.17	<0.07	2.2	<0.32	<0.15	
Parton	Cod	4	<0.80	<0.22	<0.09	4.8	<0.45	<0.22	
Whitehaven	Cod	4	<0.78	<0.22	<0.09	4.4	<0.41	<0.20	
Whitehaven	Plaice	4	<0.85	<0.22	<0.10	3.0	<0.40	<0.19	
Whitehaven	Skates / rays	4	<1.5	<0.35	<0.16	4.9	<0.60	<0.27	
Whitehaven	Sole	4	<1.1	<0.25	<0.11	2.4	<0.48	<0.20	
Sellafield coastal area	Cod	8	<1.0	<0.28	<0.11	7.0	<0.55	<0.26	220
Sellafield coastal area	Plaice	4	<0.88	<0.22	<0.09	3.0	<0.44	<0.19	170
Sellafield coastal area	Bass	1	<0.89	<0.25	<0.09	9.3	<0.58	<0.25	
Sellafield coastal area	Grey mullet	1	<0.90	<0.23	<0.10	4.6	<0.54	<0.24	
Sellafield offshore area	Cod	2	<0.96	<0.24	<0.10	5.3	<0.38	<0.17	
Sellafield offshore area	Dab	2	<2.3	<0.49	<0.22	3.3	<0.77	<0.32	
Sellafield offshore area	Plaice[a]	2	<0.99	<0.25	<0.11	2.8	<0.40	<0.18	
Sellafield offshore area	Lesser spotted dogfish	1	<0.86	<0.25	<0.10	5.9	<0.54	<0.26	
Sellafield offshore area	Gurnard	1	<1.3	<0.27	<0.12	2.8	<0.49	<0.19	
Sellafield offshore area	Skates / rays	1	<0.94	<0.27	<0.11	3.6	<0.47	<0.27	
Sellafield offshore area	Spurdog	1	<1.1	<0.29	<0.10	7.2	<0.56	<0.26	
River Calder	Brown trout	2	<1.2	<0.39	<0.11	37	<0.63	<0.25	
Ravenglass	Cod	6	<0.66	<0.18	<0.07	3.6	<0.37	<0.16	
Ravenglass	Plaice	4	<0.72	<0.19	<0.08	3.2	<0.36	<0.16	
Morecambe Bay (Flookburgh)	Flounder	4	<1.2	<0.32	<0.13	9.1	<0.56	<0.25	
Lancashire and Merseyside									
Morecambe Bay (Morecambe)	Whiting	4	<0.67	<0.18	<0.07	5.8	<0.38	<0.16	
Morecambe Bay (Morecambe)	Bass	2	<0.85	<0.24	<0.08	11	<0.56	<0.24	
Morecambe Bay (Morecambe)	Flounder	4	<0.95	<0.23	<0.10	5.1	<0.41	<0.18	
Morecambe Bay (Sunderland Point)	Whitebait	1	<0.84	<0.22	<0.10	2.6	<0.35	<0.16	
Fleetwood	Plaice	4	<0.51	<0.13	<0.06	1.0	<0.26	<0.12	
Fleetwood	Cod	4	<0.52	<0.14	<0.06	2.4	<0.25	<0.13	
Ribble Estuary	Grey mullet	2	<0.97	<0.24	<0.11	2.2	<0.48	<0.21	
Ribble Estuary	Sole	1	<1.3	<0.26	<0.12	1.5	<0.44	<0.16	
Ribble Estuary	Bass	1	<1.6	<0.37	<0.16	3.9	<0.75	<0.34	
Ribble Estuary	Salmon	1	<0.67	<0.15	<0.07	0.20	<0.29	<0.12	
Scotland									
Shetland	Fish meal (herring)	1^{S}	<0.84	<0.25	<0.10	0.44	<0.55	<0.25	
Shetland	Fish meal (salmon)	1^{S}	<0.85	<0.25	<0.10	0.47	<0.52	<0.23	
Shetland	Fish oil (herring)	1^{S}	<1.1	<0.29	<0.11	<0.10	<0.73	<0.28	
Shetland	Fish oil (salmon)	1^{S}	<0.99	<0.27	<0.10	<0.10	<0.68	<0.24	
Minch	Herring	1^{S}	<0.40	<0.11	<0.10	0.29	<0.26	<0.12	
West of Scotland	Mackerel	1^{S}	<0.36	<0.10	<0.10	0.78	<0.26	<0.12	
West of Scotland	Farmed salmon	1^{S}	<0.41	<0.10	<0.10	0.17	<0.29	<0.12	
Kirkcudbright	Plaice	4^{S}	<0.91	<0.24	<0.10	<0.10	<0.55	<0.21	
Inner Solway	Flounder	2^{S}	<1.2	<0.33	<0.13	11	<0.66	<0.26	
Inner Solway	Salmon	1^{S}	<0.97	<0.26	<0.10	0.36	<0.58	<0.22	
Inner Solway	Sea trout	1^{S}	<1.2	<0.28	<0.11	0.13	<0.73	<0.25	
Isle of Man									
Isle of Man	Cod	4	<0.54	<0.14	<0.06	1.2	<0.26	<0.13	
Isle of Man	Herring	4	<0.89	<0.21	<0.10	0.38	<0.41	<0.17	
Wales									
North Anglesey	Skates / rays	1	<0.37	<0.09	<0.04	0.53	<0.19	<0.08	
North Anglesey	Lesser spotted dogfish	3	<1.3	<0.28	<0.12	0.91	<0.54	<0.23	
North Anglesey	Plaice	2	<0.53	<0.13	<0.06	1.0	<0.24	<0.10	
North Anglesey	Bass	1	<0.45	<0.12	<0.05	1.7	<0.29	<0.12	

Table 2.5. continued

Location	Material	No. of sampling observ-ations	Mean radioactivity concentration (fresh), Bq kg^{-1}					
			^{14}C	^{60}Co	^{90}Sr	^{95}Zr	^{95}Nb	^{99}Tc
Northern Ireland								
North coast	Skates / rays	1[N]		<0.07		<0.19	<0.18	
North coast	Lesser spotted dogfish	2[N]		<0.08		<0.24	<0.28	
North coast	Spurdog	1[N]		<0.17		<1.1	<2.3	
Ardglass	Herring	2[N]		<0.10		<0.52	<0.85	
Kilkeel	Cod	4[N]	31	<0.06		<0.24	<0.36	
Kilkeel	Plaice	4[N]		<0.05		<0.17	<0.19	
Kilkeel	Skates / rays	3[N]		<0.11		<0.75	<0.31	
Kilkeel	Lesser spotted dogfish	1[N]		<0.21		<0.50	<0.49	
Kilkeel	Haddock	4[N]		<0.06		<0.17	<0.18	
Glenarm	Brown trout	1		<0.06		<0.20	<0.20	<0.35
Further afield								
Baltic Sea	Cod	2		<0.06		<0.15	<0.14	
Baltic Sea	Herring	2		<0.09		<0.25	<0.25	
Barents Sea	Cod	2		<0.06		<0.27	<0.41	
Norwegian Sea	Herring	1		<0.09		<0.97	*	
Norwegian Sea	Mackerel	1		<0.11		<1.3	*	
Norwegian Sea	Saithe	2		<0.06		<0.27	<0.41	
Norwegian processed	Cod	1	17	<0.04		<0.25	<0.48	
Iceland area	Cod	1		<0.06		<0.17	<0.17	
Skagerrak	Cod	1		<0.06		<0.27	<0.40	
Skagerrak	Herring	2		<0.08		<0.28	<0.35	
Skagerrak	Haddock	1		<0.07		<0.15	<0.13	
Mid North Sea	Cod	2	20	<0.05	<0.051	<0.10	<0.07	
Mid North Sea	Plaice	1		<0.05		<0.12	<0.09	
Mid North Sea	Flounder	1	20	<0.04	<0.054	<0.09	<0.09	
Gt Yarmouth (retail shop)	Cod	2		<0.04		<0.08	<0.05	
Gt Yarmouth (retail shop)	Plaice	2		<0.04		<0.09	<0.08	
Southern North Sea	Cod	2		<0.06	<0.050	<0.12	<0.08	
Southern North Sea	Plaice	2		<0.04	<0.050	<0.08	<0.06	
Southern North Sea	Herring	1		<0.06		<0.11	<0.07	
English Channel-East	Plaice	1		<0.04		<0.07	<0.05	
English Channel-East	Whiting	2		<0.05		<0.13	<0.12	
English Channel-East	Dab	1		<0.05		<0.16	<0.19	
English Channel-West	Mackerel	2		<0.07		<0.14	<0.11	
English Channel-West	Plaice	2	24	<0.07		<0.15	<0.13	
English Channel-West	Whiting	2		<0.06		<0.13	<0.12	
Celtic Sea	Plaice	1		<0.06		<0.23	<0.31	
Celtic Sea	Whiting	1		<0.06		<0.22	<0.26	
Celtic Sea	Dab	1		<0.07		<0.27	<0.34	
Celtic Sea	Gurnards	1	23	<0.07	<0.027	<0.29	<0.37	
Northern Irish Sea	Dab	1		<0.08		<0.25	<0.29	
Northern Irish Sea	Lesser spotted dogfish	1		<0.21		<0.76	<1.0	
Northern Irish Sea	Skates / rays	1		<0.08		<0.31	<0.32	

Table 2.5. continued

Location	Material	No. of sampling observ-ations	Mean radioactivity concentration (fresh), Bq kg^{-1}					
			^{106}Ru	^{125}Sb	^{134}Cs	^{137}Cs	^{144}Ce	^{155}Eu
Northern Ireland								
North coast	Skates / rays	1[N]	<0.68	<0.17	<0.07	1.5	<0.34	<0.17
North coast	Lesser spotted dogfish	2[N]	<0.77	<0.20	<0.08	1.6	<0.40	<0.20
North coast	Spurdog	1[N]	<2.0	<0.36	<0.18	1.8	<0.66	<0.24
Ardglass	Herring	2[N]	<1.0	<0.25	<0.11	1.1	<0.50	<0.22
Kilkeel	Cod	4[N]	<0.60	<0.14	<0.06	1.3	<0.26	<0.12
Kilkeel	Plaice	4[N]	<0.50	<0.12	<0.06	0.61	<0.26	<0.12
Kilkeel	Skates / rays	3[N]	<1.3	<0.26	<0.11	0.72	<0.59	<0.22
Kilkeel	Lesser spotted dogfish	1[N]	<2.0	<0.42	<0.20	1.1	<0.63	<0.28
Kilkeel	Haddock	4[N]	<0.55	<0.13	<0.06	0.58	<0.26	<0.12
Glenarm	Brown trout	1	<0.60	<0.14	<0.07	0.15	<0.25	<0.12
Further afield								
Baltic Sea	Cod	2	<0.58	<0.16	<0.06	5.6	<0.31	<0.15
Baltic Sea	Herring	2	<0.92	<0.24	<0.09	4.1	<0.46	<0.21
Barents Sea	Cod	2	<0.57	<0.14	<0.06	0.15	<0.30	<0.14
Norwegian Sea	Herring	1	<1.1	<0.21	<0.10	<0.09	<0.46	<0.16
Norwegian Sea	Mackerel	1	<1.2	<0.25	<0.12	<0.10	<0.52	<0.18
Norwegian Sea	Saithe	2	<0.56	<0.13	<0.06	0.18	<0.30	<0.14
Norwegian processed	Cod	1	<0.37	<0.08	<0.04	0.19	<0.18	<0.07
Iceland area	Cod	1	<0.55	<0.13	<0.06	0.13	<0.27	<0.14
Skagerrak	Cod	1	<0.57	<0.14	<0.06	0.20	<0.38	<0.16
Skagerrak	Herring	2	<0.78	<0.19	<0.08	0.30	<0.37	<0.17
Skagerrak	Haddock	1	<0.59	<0.16	<0.07	0.12	<0.30	<0.16
Mid North Sea	Cod	2	<0.42	<0.10	<0.05	0.32	<0.18	<0.09
Mid North Sea	Plaice	1	<0.47	<0.12	<0.05	0.17	<0.23	<0.12
Mid North Sea	Flounder	1	<0.29	<0.06	<0.03	0.16	<0.09	<0.04
Gt Yarmouth (retail shop)	Cod	2	<0.37	<0.09	<0.04	0.13	<0.16	<0.09
Gt Yarmouth (retail shop)	Plaice	2	<0.34	<0.08	<0.04	0.07	<0.15	<0.07
Southern North Sea	Cod	2	<0.54	<0.14	<0.06	0.31	<0.27	<0.15
Southern North Sea	Plaice	2	<0.37	<0.09	<0.04	<0.10	<0.15	<0.07
Southern North Sea	Herring	1	<0.53	<0.13	<0.06	0.18	<0.20	<0.10
English Channel-East	Plaice	1	<0.38	<0.09	<0.04	0.09	<0.17	<0.08
English Channel-East	Whiting	2	<0.42	<0.10	<0.05	0.23	<0.18	<0.09
English Channel-East	Dab	1	<0.47	<0.11	<0.05	0.10	<0.22	<0.09
English Channel-West	Mackerel	2	<0.60	<0.14	<0.07	0.22	<0.27	<0.13
English Channel-West	Plaice	2	<0.59	<0.14	<0.06	<0.09	<0.24	<0.10
English Channel-West	Whiting	2	<0.49	<0.12	<0.06	0.26	<0.22	<0.11
Celtic Sea	Plaice	1	<0.57	<0.13	<0.06	0.22	<0.24	<0.10
Celtic Sea	Whiting	1	<0.57	<0.14	<0.06	0.11	<0.30	<0.15
Celtic Sea	Dab	1	<0.68	<0.15	<0.07	<0.07	<0.26	<0.12
Celtic Sea	Gurnards	1	<0.73	<0.17	<0.08	0.22	<0.37	<0.18
Northern Irish Sea	Dab	1	<0.75	<0.18	<0.08	0.82	<0.32	<0.13
Northern Irish Sea	Lesser spotted dogfish	1	<1.9	<0.39	<0.19	0.76	<0.65	<0.26
Northern Irish Sea	Skates / rays	1	<0.81	<0.20	<0.09	0.96	<0.44	<0.20

* *Not detected by the method used*

[a] *The concentrations of ^{129}I and ^{147}Pm were <1.7 and <0.076 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, 2012

Location	Material	No. of sampling observ-ations	Mean radioactivity concentration (fresh), Bq kg^{-1}								
			Organic ^{3}H	^{3}H	^{14}C	^{60}Co	^{90}Sr	^{95}Zr	^{95}Nb	^{99}Tc	^{106}Ru
Cumbria											
Silloth	Shrimps	4				<0.08		<0.19	<0.15		<0.77
Silloth	Winkles	4		<25		<0.27		<0.32	<0.30		<1.3
Parton	Crabs	4				<0.25		<0.33	<0.45		<1.1
Parton	Lobsters	4				<0.07		<0.10	<0.08		<0.44
Parton	Winkles	4				0.60		<0.15	<0.12		<2.0
Whitehaven	*Nephrops*	4			81	<0.17	0.10	<0.56	<0.77	31	<1.6
Whitehaven	Cockles	2				<0.08		<0.18	<0.14		<0.80
Whitehaven	Mussels	2				<0.05	<0.056	<0.12	<0.10		<0.54
Whitehaven outer harbour	Mussels	2				0.37		<0.14	<0.11		1.4
Saltom Bay	Winkles	4				<0.54		<0.32	<0.25		<1.6
St Bees	Winkles[a]	4			97	0.96	2.2	<0.23	<0.24	57	<2.8
St Bees	Mussels	4				0.64		<0.19	<0.15		4.0
St Bees	Limpets	4				0.51		<0.16	<0.12		<2.5
Nethertown	Winkles	12	<25	<25	130	1.2	3.1	<0.28	<0.24	55	6.2
Nethertown	Mussels	4	67	80	130	0.76		<0.15	<0.11	46	4.4
Sellafield coastal area	Crabs[b]	8			150	0.45	0.15	<0.35	<0.50	8.7	<0.94
Sellafield coastal area	Lobsters	8			200	<0.20	<0.27	<0.26	<0.35	140	<0.70
Sellafield coastal area	*Nephrops*	1				<0.06		<0.17	<0.18	27	<0.55
Sellafield coastal area	Winkles[c]	5			140	1.5	2.9	<0.25	<0.22	25	6.1
Sellafield coastal area	Mussels[c]	1				0.48	0.56	<0.17	<0.15		2.3
Sellafield coastal area	Limpets[c]	1			84	0.44	0.88	<0.31	<0.31	100	4.8
Whitriggs	Shrimps	1				<0.19		<0.54	<0.62		<1.9
Drigg	Winkles	4			160	1.3		<0.23	<0.19	52	<6.0
Ravenglass	Crabs	4				0.17	0.12	<0.21	<0.19	5.8	<0.76
Ravenglass	Lobsters	6				<0.14	0.30	<0.24	<0.31	88	<0.68
Ravenglass	Winkles	2				0.72		<0.18	<0.16		3.1
Ravenglass	Cockles	4			150	1.5	0.58	<0.13	<0.09	3.9	2.5
Ravenglass	Mussels	4		64		0.66		<0.17	<0.12	75	<2.1
Tarn Bay	Winkles	4				0.82		<0.18	<0.14		<3.6
Haverigg	Winkles	2				0.35		<0.17	<0.13		<1.5
Millom	Mussels	4				<0.22		<0.15	<0.11		<0.88
Barrow	Crabs	4				<0.08		<0.31	<0.48		<0.69
Barrow	Lobsters	4				<0.06		<0.21	<0.30	93	<0.56
Roosebeck	Pacific oysters	2				<0.07		<0.16	<0.14		<0.69
Morecambe Bay (Flookburgh)	Shrimps	4			79	<0.08		<0.30	<0.44	0.63	<0.80
Morecambe Bay (Flookburgh)	Cockles	4			69	<0.17	0.14	<0.18	<0.21	3.3	<0.59
Lancashire and Merseyside											
Morecambe Bay (Morecambe)	Shrimps	2				<0.08		<0.22	<0.20		<0.76
Morecambe Bay (Morecambe)	Mussels	4	32	<31	70	<0.07		<0.16	<0.15	56	<0.61
Red Nab Point	Winkles	4				<0.09		<0.16	<0.15		<0.59
Morecambe Bay (Middleton Sands)	Cockles	2				0.18		<0.18	<0.15		<0.72
Knott End	Mussels	2				<0.17		<0.38	<0.37		<1.5
Fleetwood	Whelks	1				<0.04		<0.07	<0.05		<0.29
Ribble Estuary	Shrimps	2			44	<0.05		<0.12	<0.11	0.48	<0.47
Ribble Estuary	Cockles	2				<0.12		<0.32	<0.31		<1.1
Liverpool Bay	Mussels	2		<25							
Mersey Estuary	Mussels	2		<25							
Dee Estuary	Cockles	4				<0.12		<0.27	<0.22	2.3	<1.2
Wirral	Shrimps	2		<35		<0.04		<0.10	<0.09	0.36	<0.40

Table 2.6. continued

Location	Material	No. of sampling observ-ations	Mean radioactivity concentration (fresh), Bq kg^{-1}							
			^{110m}Ag	^{125}Sb	^{134}Cs	^{137}Cs	^{144}Ce	^{147}Pm	^{155}Eu	Gross beta
Cumbria										
Silloth	Shrimps	4	<0.15	<0.21	<0.08	3.1	<0.39		<0.19	
Silloth	Winkles	4	<0.22	<0.34	<0.13	6.2	<0.61		<0.29	
Parton	Crabs	4	<0.20	<0.24	<0.11	1.3	<0.40		<0.17	
Parton	Lobsters	4	<0.09	<0.11	<0.05	0.83	<0.20		<0.09	
Parton	Winkles	4	<0.13	<0.32	<0.08	5.0	<0.33		<0.17	
Whitehaven	*Nephrops*	4	<0.29	<0.34	<0.17	2.7	<0.58		<0.24	160
Whitehaven	Cockles	2	<0.14	<0.19	<0.08	0.11	<0.32		<0.15	
Whitehaven	Mussels	2	<0.09	<0.14	<0.06	<0.06	<0.28		<0.14	
Whitehaven outer harbour	Mussels	2	<0.10	0.47	<0.06	2.2	<0.32		<0.15	
Saltom Bay	Winkles	4	<0.28	<0.45	<0.16	4.0	<0.61		<0.31	
St Bees	Winkles[a]	4	<0.17	0.59	<0.09	4.4	<0.50	0.42	<0.23	
St Bees	Mussels	4	<0.15	0.68	<0.09	2.4	<0.43		<0.20	
St Bees	Limpets	4	<0.15	0.96	<0.08	4.4	<0.43		<0.21	
Nethertown	Winkles	12	<0.23	<0.64	<0.13	6.6	<0.50	1.5	<0.23	260
Nethertown	Mussels	4	<0.12	0.91	<0.07	2.4	<0.40		<0.20	190
Sellafield coastal area	Crabs[b]	8	<0.18	<0.26	<0.09	1.2	<0.48	0.088	<0.20	130
Sellafield coastal area	Lobsters	8	<0.16	<0.21	<0.07	1.8	<0.38	0.32	<0.16	330
Sellafield coastal area	*Nephrops*	1	<0.11	<0.14	<0.06	2.1	<0.26		<0.10	
Sellafield coastal area	Winkles[c]	5	<0.22	<0.75	<0.12	8.0	<0.57	0.46	<0.28	
Sellafield coastal area	Mussels[c]	1	<0.12	0.69	<0.08	2.5	<0.44		<0.21	
Sellafield coastal area	Limpets[c]	1	<0.22	2.1	<0.12	3.4	<0.47		<0.21	
Whitriggs	Shrimps	1	<0.32	<0.40	<0.18	2.3	<0.65		<0.24	
Drigg	Winkles	4	<0.25	<0.56	<0.11	4.6	<0.53	0.53	<0.26	270
Ravenglass	Crabs	4	<0.14	<0.20	<0.08	1.1	<0.35		<0.15	140
Ravenglass	Lobsters	6	<0.15	<0.18	<0.07	1.3	<0.35		<0.17	220
Ravenglass	Winkles	2	<0.16	<0.45	<0.09	4.5	<0.43		<0.20	
Ravenglass	Cockles	4	<0.12	<0.44	<0.07	2.6	<0.30		<0.14	160
Ravenglass	Mussels	4	<0.15	0.78	<0.09	0.98	<0.32		<0.15	
Tarn Bay	Winkles	4	<0.16	<0.46	<0.09	4.9	<0.46		<0.23	
Haverigg	Winkles	2	<0.13	<0.22	<0.08	4.2	<0.37		<0.18	
Millom	Mussels	4	<0.12	<0.22	<0.07	1.1	<0.32		<0.17	
Barrow	Crabs	4	<0.14	<0.17	<0.07	0.76	<0.31		<0.12	
Barrow	Lobsters	4	<0.11	<0.14	<0.06	1.2	<0.28		<0.12	180
Roosebeck	Pacific oysters	2	<0.12	<0.17	<0.07	1.0	<0.36		<0.17	
Morecambe Bay (Flookburgh)	Shrimps	4	<0.15	<0.22	<0.08	4.5	<0.47		<0.21	
Morecambe Bay (Flookburgh)	Cockles	4	<0.11	<0.21	<0.06	2.9	<0.32		<0.15	
Lancashire and Merseyside										
Morecambe Bay (Morecambe)	Shrimps	2	<0.15	<0.21	<0.08	4.5	<0.36		<0.18	
Morecambe Bay (Morecambe)	Mussels	4	<0.11	<0.22	<0.07	2.2	<0.31		<0.15	
Red Nab Point	Winkles	4	<0.10	<0.17	<0.06	4.3	<0.31		<0.16	
Morecambe Bay (Middleton Sands)	Cockles	2	<0.12	<0.17	<0.08	2.1	<0.29		<0.13	
Knott End	Mussels	2	<0.25	<0.32	<0.15	1.1	<0.49		<0.21	
Fleetwood	Whelks	1	<0.07	<0.07	<0.04	0.39	<0.09		<0.04	
Ribble Estuary	Shrimps	2	<0.09	<0.13	<0.05	1.7	<0.23		<0.10	
Ribble Estuary	Cockles	2	<0.20	<0.26	<0.11	1.4	<0.50		<0.21	
Dee Estuary	Cockles	4	<0.20	<0.28	<0.13	1.1	<0.49		<0.23	
Wirral	Shrimps	2	<0.07	<0.10	<0.04	1.0	<0.18		<0.08	

Table 2.6. continued

Location	Material	No. of sampling observ-ations	Mean radioactivity concentration (fresh), Bq kg^{-1}							
			^{3}H	^{14}C	^{60}Co	^{90}Sr	^{95}Zr	^{95}Nb	^{99}Tc	^{106}Ru
Scotland										
Lewis	Mussels	1^{S}			<0.10		<0.31	<0.38		<0.78
Skye	Lobsters	1^{S}			<0.10		<0.31	<0.39	8.2	<0.73
Skye	Mussels	1^{S}			<0.10		<0.26	<0.29		<0.72
Islay	Crabs	1^{S}			<0.10		<0.14	<0.11		<0.59
Islay	Scallops	1^{S}			<0.10		<0.10	<0.10		<0.28
Kirkcudbright	Scallops	4^{S}			<0.10		<0.19	<0.29	0.44	<0.45
Kirkcudbright	Queens	4^{S}			<0.10		<0.33	<0.52	0.44	<0.80
Kirkcudbright	Limpets	1^{S}			<0.10		<0.35	<0.52		<0.72
Southerness	Winkles	4^{S}	<5.0		<0.12	0.21	<0.25	<0.26	16	<0.70
North Solway coast	Crabs	4^{S}		59	<0.13	0.19	<0.25	<0.26	5.8	<0.83
North Solway coast	Lobsters	4^{S}		57	<0.10	<0.10	<0.23	<0.24	26	<0.69
North Solway coast	Winkles	4^{S}			<0.14	0.15	<0.23	<0.25	22	<0.68
North Solway coast	Cockles	1^{S}			0.25		<0.10	<0.10		<0.31
North Solway coast	Mussels	4^{S}	<4.8	48	<0.15	0.42	<0.23	<0.26	15	<0.68
Inner Solway	Shrimps	2^{S}	4.9		<0.11	<0.10	<0.58	<1.3	2.7	<1.1
Isle of Man										
Isle of Man	Lobsters	4			<0.07		<0.15	<0.12	24	<0.67
Isle of Man	Scallops	4			<0.07		<0.19	<0.24		<0.61
Wales										
Conwy	Mussels	2		41	<0.05		<0.09	<0.07		<0.43
North Anglesey	Crabs	2			<0.05		<0.11	<0.09	1.2	<0.51
North Anglesey	Lobsters	2			<0.04		<0.09	<0.07	20	<0.35
Northern Ireland										
Ballycastle	Lobsters	2^{N}			<0.04		<0.08	<0.06	25	<0.39
County Down	Scallops	2^{N}			<0.06		<0.14	<0.12		<0.51
Kilkeel	Crabs	4^{N}			<0.07		<0.26	<0.34		<0.71
Kilkeel	Lobsters	4^{N}			<0.06		<0.24	<0.48	19	<0.55
Kilkeel	*Nephrops*	4^{N}			<0.12		<0.47	<0.82	5.0	<1.2
Minerstown	Winkles	4^{N}			<0.05		<0.10	<0.08		<0.43
Carlingford Lough	Mussels	2^{N}			<0.10		<0.59	<1.4	6.1	<1.2
Further afield										
Cromer	Crabs	1			<0.05		<0.10	<0.06		<0.47
Southern North Sea	Cockles	1			<0.06		<0.16	<0.14		<0.53
Southern North Sea	Mussels	2			<0.10		<0.27	<0.31	0.96	<0.97
Southern North Sea	Cockles^{d}	1			<0.03		<0.10	<0.12	<0.25	<0.31
Southern North Sea	Mussels^{d}	1			<0.06		<0.21	<0.22		<0.62
English Channel-East	Scallops	2		19	<0.08		<0.48	<1.2		<0.80
English Channel-West	Crabs	2		28	<0.06		<0.15	<0.13		<0.58
English Channel-West	Lobsters	2			<0.05		<0.10	<0.08	0.38	<0.43
English Channel-West	Scallops	2		18	<0.10		<0.18	<0.14		<0.86
Northern Irish Sea	Crabs	1			<0.09		<0.34	<0.43		<0.96
Northern Irish Sea	Octopuses	1			<0.14		<0.53	<0.72		<1.5

Table 2.6. continued

Location	Material	No. of sampling observ-ations	Mean radioactivity concentration (fresh), Bq kg^{-1}						
			^{110m}Ag	^{125}Sb	^{134}Cs	^{137}Cs	^{144}Ce	^{155}Eu	Gross beta
Scotland									
Lewis	Mussels	1[S]	<0.10	<0.22	<0.10	<0.10	<0.52	<0.21	
Skye	Lobsters	1[S]	<0.10	<0.20	<0.10	<0.10	<0.42	<0.16	
Skye	Mussels	1[S]	<0.10	<0.20	<0.10	<0.10	<0.41	<0.16	
Islay	Crabs	1[S]	<0.10	<0.16	<0.10	0.12	<0.33	<0.14	
Islay	Scallops	1[S]	<0.10	<0.10	<0.10	<0.10	<0.19	<0.10	
Kirkcudbright	Scallops	4[S]	<0.10	<0.13	<0.10	<0.17	<0.30	<0.14	
Kirkcudbright	Queens	4[S]	<0.11	<0.23	<0.10	0.22	<0.50	<0.20	
Kirkcudbright	Limpets	1[S]	<0.12	<0.16	<0.10	5.5	<0.51	<0.20	
Southerness	Winkles	4[S]	<0.12	<0.20	<0.10	1.0	<0.44	<0.18	
North Solway coast	Crabs	4[S]	<0.13	<0.23	<0.12	0.92	<0.45	<0.18	
North Solway coast	Lobsters	4[S]	<0.12	<0.20	<0.10	1.6	<0.42	<0.17	
North Solway coast	Winkles	4[S]	<0.12	<0.20	<0.10	0.99	<0.41	<0.17	
North Solway coast	Cockles	1[S]	<0.10	<0.10	<0.10	2.1	<0.21	0.14	
North Solway coast	Mussels	4[S]	<0.13	<0.20	<0.11	2.5	<0.40	<0.17	
Inner Solway	Shrimps	2[S]	<0.18	<0.30	<0.11	1.9	<0.62	<0.24	
Isle of Man									
Isle of Man	Lobsters	4	<0.12	<0.16	<0.07	0.28	<0.29	<0.13	130
Isle of Man	Scallops	4	<0.12	<0.14	<0.06	<0.26	<0.25	<0.12	
Wales									
Conwy	Mussels	2	<0.08	<0.11	<0.05	0.68	<0.17	<0.08	
North Anglesey	Crabs	2	<0.09	<0.13	<0.05	0.52	<0.26	<0.12	
North Anglesey	Lobsters	2	<0.07	<0.09	<0.04	0.42	<0.17	<0.08	120
Northern Ireland									
Ballycastle	Lobsters	2[N]	<0.07	<0.10	<0.04	0.17	<0.20	<0.11	
County Down	Scallops	2[N]	<0.10	<0.13	<0.06	0.28	<0.26	<0.14	
Kilkeel	Crabs	4[N]	<0.13	<0.16	<0.07	0.16	<0.33	<0.14	
Kilkeel	Lobsters	4[N]	<0.11	<0.14	<0.06	0.23	<0.27	<0.12	
Kilkeel	*Nephrops*	4[N]	<0.22	<0.26	<0.12	0.51	<0.49	<0.20	
Minerstown	Winkles	4[N]	<0.08	<0.11	<0.05	0.17	<0.21	<0.11	
Carlingford Lough	Mussels	2[N]	<0.20	<0.23	<0.10	<0.31	<0.42	<0.14	
Further afield									
Cromer	Crabs	1	<0.09	<0.12	<0.05	<0.05	<0.22	<0.10	
Southern North Sea	Cockles	1	<0.11	<0.14	<0.06	<0.06	<0.29	<0.14	
Southern North Sea	Mussels	2	<0.17	<0.21	<0.10	<0.14	<0.35	<0.15	
Southern North Sea	Cockles[d]	1	<0.06	<0.08	<0.03	0.06	<0.21	<0.09	
Southern North Sea	Mussels[d]	1	<0.12	<0.16	<0.06	<0.06	<0.34	<0.16	25
English Channel-East	Scallops	2	<0.16	<0.17	<0.08	<0.07	<0.34	<0.14	
English Channel-West	Crabs	2	<0.11	<0.14	<0.06	<0.06	<0.26	<0.11	
English Channel-West	Lobsters	2	<0.08	<0.11	<0.05	<0.05	<0.21	<0.11	
English Channel-West	Scallops	2	<0.16	<0.20	<0.10	<0.08	<0.32	<0.16	
Northern Irish Sea	Crabs	1	<0.17	<0.19	<0.09	0.16	<0.36	<0.14	
Northern Irish Sea	Octopuses	1	<0.25	<0.29	<0.13	0.17	<0.50	<0.19	

[a] *The concentration of ^{129}I was <2.0 Bq kg^{-1}*
[b] *The concentration of ^{129}I was <1.5 Bq kg^{-1}*
[c] *Samples collected by Consumer 971*
[d] *Landed in Holland or Denmark*
[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, 2012

Location	Material	No. of sampling observ-ations	Mean radioactivity concentration (fresh), Bq kg^{-1}						
			^{237}Np	^{238}Pu	^{239}Pu+ ^{240}Pu	^{241}Pu	^{241}Am	^{242}Cm	^{243}Cm+ ^{244}Cm
Cumbria									
Silloth	Shrimps	1		0.0024	0.014	<0.75	0.030	*	*
Silloth	Winkles	1		0.95	5.3		11	*	0.018
Maryport	Plaice	4					<0.18		
Parton	Cod	4					<0.25		
Parton	Crabs	4					1.3		
Parton	Lobsters	4					<1.3		
Parton	Winkles	1		1.3	6.5	41	14	*	*
Whitehaven	Cod	1		0.00047	0.0025		0.0049	*	0.000030
Whitehaven	Plaice	1		0.0030	0.017		0.040	*	0.000058
Whitehaven	Skates / rays	1		0.00014	0.00088		0.0021	*	*
Whitehaven	Sole	1		0.00049	0.0029		0.0050	*	0.0000077
Whitehaven	Nephrops	1		0.075	0.42		1.9	*	*
Whitehaven	Cockles	1		0.0013	0.011		0.014	*	0.000061
Whitehaven	Mussels	1		0.000091	0.0015	<0.47	0.0011	*	0.000020
Whitehaven outer harbour	Mussels	2					8.4		
Saltom Bay	Winkles	4					12		
St Bees	Winkles	1	0.0098	1.4	7.3	46	14	*	0.018
St Bees	Mussels	2		1.1	5.5	40	11	<0.016	0.023
St Bees	Limpets	1		1.7	8.9		17	*	0.028
Nethertown	Winkles	4	0.039	2.2	12	78	24	<0.012	0.031
Nethertown	Mussels	4		1.1	5.2		11	*	<0.010
Sellafield coastal area	Cod	2		0.00042	0.0020		0.0043	*	*
Sellafield coastal area	Plaice	1		0.0043	0.022		0.048	0.000067	0.000058
Sellafield coastal area	Bass	1					<0.25		
Sellafield coastal area	Grey mullet	1					<0.21		
Sellafield coastal area	Crabs	2	0.0012	0.083	0.42	2.0	1.7	*	*
Sellafield coastal area	Lobsters	2	0.017	0.079	0.37	3.7	6.4	*	<0.0058
Sellafield coastal area	Nephrops	1		0.035	0.21		0.79	*	*
Sellafield coastal area[a]	Winkles	2	0.023	2.2	12	82	25	*	0.029
Sellafield coastal area[a]	Mussels	1		0.83	4.8	32	10	*	0.014
Sellafield coastal area[a]	Limpets	1		1.2	6.5	49	13	0.027	0.011
Sellafield offshore area	Cod	1		0.00070	0.0038		0.0082	*	0.000022
Sellafield offshore area	Dab	2					<0.20		
Sellafield offshore area	Plaice	1	0.00017	0.0022	0.016		0.035	*	*
Sellafield offshore area	Lesser spotted dogfish	1					<0.25		
Sellafield offshore area	Gurnard	1					<0.10		
Sellafield offshore area	Skates / rays	1					<0.32		
Sellafield offshore area	Spurdog	1					<0.31		
River Calder	Brown trout	2					<0.14		
Whitriggs	Shrimps	1					<0.13		
Drigg	Winkles	1	0.016	1.7	8.3	53	17	0.012	0.020
Ravenglass	Cod	1		0.00022	0.0013		0.0027	*	*
Ravenglass	Plaice	1		0.0085	0.046		0.091	0.00011	0.000067
Ravenglass	Crabs	1		0.056	0.30	2.1	1.2	*	*
Ravenglass	Lobsters	1		0.039	0.21	1.4	4.2	*	*
Ravenglass	Winkles	2					17		
Ravenglass	Cockles	1		1.1	5.9	40	19	*	0.026
Ravenglass	Mussels	1		0.72	3.7	28	9.3	*	0.010
Tarn Bay	Winkles	1		1.6	8.7	59	17	*	*
Haverigg	Winkles	2					11		
Millom	Mussels	1		0.20	1.2		2.8	*	0.0036
Barrow	Crabs	1		0.019	0.10		0.72	*	*
Barrow	Lobsters	4					1.0		
Roosebeck	Pacific oysters	1		0.11	0.62		0.69	*	0.00091
Morecambe Bay (Flookburgh)	Flounder	1		0.00039	0.0025		0.0049	*	*
Morecambe Bay (Flookburgh)	Shrimps	1		0.0046	0.026	<0.25	0.041	*	*
Morecambe Bay (Flookburgh)	Cockles	1		0.24	1.7	8.8	4.3	*	*

Table 2.7. continued

Location	Material	No. of sampling observ-ations	Mean radioactivity concentration (fresh), Bq kg^{-1}						
			^{237}Np	^{238}Pu	^{239}Pu+ ^{240}Pu	^{241}Pu	^{241}Am	^{242}Cm	^{243}Cm+ ^{244}Cm
Lancashire and Merseyside									
Morecambe Bay (Morecambe)	Whiting	4					<0.13		
Morecambe Bay (Morecambe)	Bass	2					<0.22		
Morecambe Bay (Morecambe)	Flounder	4					<0.12		
Morecambe Bay (Morecambe)	Shrimps	2					<0.16		
Morecambe Bay (Morecambe)	Mussels	1		0.28	1.7		2.9	*	*
Red Nab Point	Winkles	1		0.29	1.6		3.3	*	*
Morecambe Bay (Middleton Sands)	Cockles	1		0.29	1.7		4.7	*	*
Morecambe Bay (Sunderland Point)	Whitebait	1		0.029	0.17	<1.1	0.31	*	0.00022
Knott End	Mussels	1		0.20	1.2		1.6	*	*
Fleetwood	Plaice	1		0.00018	0.00088		0.0016	*	*
Fleetwood	Cod	1		0.000032	0.00023		0.00050	0.000045	*
Fleetwood	Whelks	1					0.11		
Ribble Estuary	Grey mullet	2					<0.17		
Ribble Estuary	Sole	1					<0.08		
Ribble Estuary	Bass	1					<0.31		
Ribble Estuary	Salmon	1					<0.07		
Ribble Estuary	Shrimps	1	0.00015	0.0015	0.0091		0.018	*	*
Ribble Estuary	Cockles	1		0.14	0.86		2.3	*	*
Dee Estuary	Cockles	1		0.11	0.67		1.4	*	*
Wirral	Shrimps	2					<0.05		
Scotland									
Shetland	Fish meal (herring)	1^{S}		0.0058	<0.0033		<0.14		
Shetland	Fish meal (salmon)	1^{S}		0.0088	0.0077		<0.14		
Shetland	Fish oil (herring)	1^{S}		<0.0063	<0.0063		0.017		
Shetland	Fish oil (salmon)	1^{S}		<0.0060	<0.0060		<0.070		
Minch	Herring	1^{S}		<0.0016	<0.0016		0.0040		
West of Scotland	Mackerel	1^{S}		0.0040	<0.0038		0.0066		
West of Scotland	Farmed salmon	1^{S}		0.0017	<0.0013		<0.0027		
Lewis	Mussels	1^{S}					<0.11		
Skye	Lobsters	1^{S}					<0.10		
Skye	Mussels	1^{S}					<0.10		
Islay	Crabs	1^{S}					0.20		
Islay	Scallops	1^{S}					<0.10		
Kirkcudbright	Plaice	1^{S}		0.00070	0.0023		0.0054		
Kirkcudbright	Scallops	1^{S}		0.0057	0.036		0.025		
Kirkcudbright	Queens	1^{S}		0.0071	0.038		0.035		
Kirkcudbright	Limpets	1^{S}					8.8		
Southerness	Winkles	1^{S}		0.12	0.64	3.1	1.4		
North Solway coast	Crabs	1^{S}		0.015	0.095	0.43	0.64		
North Solway coast	Lobsters	1^{S}		0.013	0.066	0.32	0.45		
North Solway coast	Winkles	1^{S}		0.20	1.2		2.1		
North Solway coast	Cockles	1^{S}		0.47	2.8		8.9		
North Solway coast	Mussels	1^{S}		0.38	2.1	11	4.2		
Inner Solway	Flounder	1^{S}		<0.0011	0.0027		0.0051		
Inner Solway	Salmon	1^{S}					<0.14		
Inner Solway	Sea trout	1^{S}					<0.15		
Inner Solway	Shrimps	1^{S}		0.0039	0.019		0.037		
Isle of Man									
Isle of Man	Cod	1		0.00032	0.0019		0.0041	*	*
Isle of Man	Herring	1		0.000029	0.00018		0.00031	*	*
Isle of Man	Lobsters	4					<0.10		
Isle of Man	Scallops	1		0.015	0.086		0.031	*	*

Table 2.7. continued

Location	Material	No. of sampling observ-ations	Mean radioactivity concentration (fresh), Bq kg^{-1}				
			^{238}Pu	^{239}Pu+ ^{240}Pu	^{241}Am	^{242}Cm	^{243}Cm+ ^{244}Cm
Wales							
Conwy	Mussels	1	0.056	0.33	0.49	*	0.00076
North Anglesey	Skates / rays	1			<0.04		
North Anglesey	Lesser spotted dogfish	1	0.00010	0.00062	0.0014	*	*
North Anglesey	Plaice	2			<0.05		
North Anglesey	Bass	1			<0.11		
North Anglesey	Crabs	1	0.0036	0.021	0.096	*	0.00017
North Anglesey	Lobsters	2			0.06		
Northern Ireland							
North coast	Skates / rays	1^{N}			<0.20		
North coast	Lesser spotted dogfish	2^{N}			<0.23		
North coast	Spurdog	1^{N}			<0.12		
Ballycastle	Lobsters	2^{N}			<0.24		
County Down	Scallops	2^{N}			<0.17		
Ardglass	Herring	2^{N}			<0.20		
Kilkeel	Cod	4^{N}			<0.09		
Kilkeel	Plaice	4^{N}			<0.09		
Kilkeel	Skates / rays	3^{N}			<0.19		
Kilkeel	Lesser spotted dogfish	1^{N}			<0.15		
Kilkeel	Haddock	4^{N}			<0.12		
Kilkeel	Crabs	4^{N}			<0.10		
Kilkeel	Lobsters	4^{N}			<0.12		
Kilkeel	Nephrops	1^{N}	0.0016	0.0098	0.028	*	*
Minerstown	Winkles	1^{N}	0.028	0.17	0.10	*	*
Carlingford Lough	Mussels	2^{N}			<0.11		
Glenarm	Brown trout	1			<0.07		
Further afield							
Baltic Sea	Cod	2			<0.12		
Baltic Sea	Herring	2			<0.16		
Barents Sea	Cod	2			<0.16		
Norwegian Sea	Herring	1			<0.08		
Norwegian Sea	Mackerel	1			<0.09		
Norwegian Sea	Saithe	2			<0.16		
Norwegian processed	Cod	1	<0.00023	0.000038	0.00013	*	*
Iceland area	Cod	1			<0.16		
Skagerrak	Cod	1			<0.15		
Skagerrak	Herring	2			<0.16		
Skagerrak	Haddock	1			<0.19		
Mid North Sea	Cod	2			<0.05		
Mid North Sea	Plaice	1			<0.14		
Mid North Sea	Flounder	1			<0.02		
Cromer	Crabs	1			<0.06		
Gt Yarmouth (retail shop)	Cod	2			<0.08		
Gt Yarmouth (retail shop)	Plaice	2			<0.06		
Southern North Sea	Cod	2			<0.18		
Southern North Sea	Plaice	2			<0.04		
Southern North Sea	Herring	1			<0.06		
Southern North Sea	Cockles	1	0.0018	0.013	0.0071	*	*
Southern North Sea	Mussels	1	0.0035	0.026	0.011	*	*
Southern North Sea	Cockles[b]	1	0.00042	0.0039	0.0033	*	0.000055
Southern North Sea	Mussels[b]	1	0.000068	0.0011	0.00070	*	*
English Channel-East	Plaice	1			<0.05		
English Channel-East	Whiting	2			<0.09		
English Channel-East	Dab	1			<0.05		
English Channel-East	Scallops	1	0.00031	0.0014	0.00041	*	0.000016

Table 2.7. continued

Location	Material	No. of sampling observ-ations	Mean radioactivity concentration (fresh), Bq kg^{-1}				
			^{238}Pu	^{239}Pu+ ^{240}Pu	^{241}Am	^{242}Cm	^{243}Cm+ ^{244}Cm
English Channel-West	Mackerel	2			<0.10		
English Channel-West	Plaice	2			<0.05		
English Channel-West	Whiting	2			<0.10		
English Channel-West	Crabs	1	0.000033	0.00072	0.00083	*	0.000036
English Channel-West	Lobsters	2			<0.10		
English Channel-West	Scallops	1	0.00015	0.0036	0.00011	*	*
Celtic Sea	Plaice	1			<0.06		
Celtic Sea	Whiting	1			<0.18		
Celtic Sea	Dab	1			<0.07		
Celtic Sea	Gurnards	1			<0.21		
Northern Irish Sea	Dab	1			<0.07		
Northern Irish Sea	Lesser spotted dogfish	1			<0.14		
Northern Irish Sea	Skates / rays	1			<0.25		
Northern Irish Sea	Crabs	1			<0.07		
Northern Irish Sea	Octopuses	1			<0.09		

* *Not detected by the method used*
[a] *Samples collected by consumer 971*
[b] *Landed in Holland or Denmark*
[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, 2012

Location	Material	No. of sampling observ-ations	Mean radioactivity concentration (dry), Bq kg^{-1}								
			^{60}Co	^{90}Sr	^{95}Zr	^{95}Nb	^{106}Ru	^{125}Sb	^{134}Cs	^{137}Cs	^{144}Ce
Cumbria											
Newton Arlosh	Sediment	4	<0.85		<2.8	<0.59	<6.4	<3.2	<0.84	210	<3.5
Maryport Outer Harbour	Sediment	2	<1.1	7.8	<2.2	<0.57	<5.7	<3.0	<0.73	85	<2.8
Workington Harbour	Sediment	2	<0.37		<0.97	<0.33	<2.4	<1.3	<0.35	50	<1.8
Harrington Harbour	Sediment	2	<0.41		<1.1	<0.35	<2.9	<1.5	<0.38	120	<2.1
Whitehaven Outer Harbour	Sediment	4	<0.88	<4.5	<1.8	<0.42	<4.0	<2.1	<0.49	83	<2.2
St Bees beach	Sediment	4	1.2		<0.89	<0.21	<2.1	<1.1	<0.27	59	<1.4
Sellafield beach, S of former pipeline	Sediment	2	0.99		<0.87	<0.22	<2.2	<1.1	<0.30	39	<1.3
River Calder – downstream	Sediment	2	<0.46		<0.96	<0.31	<2.9	<1.5	<0.38	78	<1.6
River Calder – upstream	Sediment	2	<0.48		<1.2	<0.39	<2.9	<1.5	<0.43	34	<2.2
Seascale beach	Sediment	4	0.71		<0.87	<0.21	<2.0	<1.0	<0.27	31	<1.3
Ravenglass – Carleton Marsh	Sediment	4	4.0		<1.8	<0.49	<20	<3.2	<0.59	300	<3.1
River Mite Estuary (erosional)	Sediment	4	4.1	65	<2.8	<0.69	<12	<3.9	<0.88	450	<4.8
Ravenglass – Raven Villa	Sediment	4	2.5		<1.5	<0.39	<8.9	<1.9	<0.48	150	<2.2
Newbiggin (Eskmeals)	Sediment	4	6.8	65	<2.9	<0.73	<12	<3.9	<0.85	340	<3.9
Haverigg	Sediment	2	1.6		<1.0	<0.31	<4.9	<1.4	<0.36	68	<1.8
Millom	Sediment	2	1.3		<1.2	<0.36	<7.0	<1.6	<0.41	130	<2.1
Low Shaw	Sediment	2	<0.38		<1.0	<0.23	<2.4	<1.3	<0.33	64	<1.6
Walney Channel – N of discharge point	Sediment	2	0.87		<1.1	<0.34	<5.8	<1.6	<0.39	100	<1.9
Walney Channel – S of discharge point	Sediment	2	0.76		<1.0	<0.32	<2.9	<1.4	<0.36	88	<1.8
Sand Gate Marsh	Sediment	4	<0.65		<2.1	<0.44	<4.5	<2.3	<0.60	83	<2.6
Kents Bank	Sediment	4	<0.66		<2.2	<0.48	<5.2	<2.7	<0.65	230	<3.0
Lancashire											
Morecambe	Sediment	2	<0.61							8.9	
Half Moon Bay	Sediment	2	<0.34							47	
Red Nab Point	Sediment	2	<0.34							18	
Potts Corner	Sediment	2	<0.62							18	
Sunderland Point	Sediment	4	<0.88		<2.4	<0.70	<6.1	<3.2	<0.81	68	<3.2
Conder Green	Sediment	4	<0.92		<2.5	<0.70	<6.6	<3.4	<0.85	82	<3.3
Hambleton	Sediment	4	<1.1		<2.9	<0.84	<8.9	<4.6	<1.1	270	<4.7
Skippool Creek	Sediment	4	<0.86		<2.1	<0.68	<6.3	<3.3	<0.83	210	<3.2
Fleetwood	Sediment	4	<0.41		<1.1	<0.28	<2.5	<1.3	<0.37	12	<1.3
Blackpool	Sediment	4	<0.27		<0.77	<0.19	<1.8	<0.92	<0.26	2.8	<1.2
Crossens Marsh	Sediment	4	<1.1		<2.8	<0.75	<7.8	<4.0	<0.98	210	<3.8
Ainsdale	Sediment	4	<0.26		<0.71	<0.18	<1.7	<0.87	<0.25	4.0	<1.1
Rock Ferry	Sediment	4	<0.45		<1.2	<0.31	<2.9	<1.5	<0.40	71	<1.8
New Brighton	Sediment	4	<0.26		<0.65	<0.17	<1.6	<0.82	<0.23	3.2	<1.1
Scotland											
Campbeltown	Sediment	1^{S}	<0.10		<0.25	<0.26	<0.66	<0.21	<0.10	8.1	<0.64
Garlieston	Sediment	1^{S}	0.14		<0.31	<0.38	<0.80	<0.27	<0.10	29	<0.77
Innerwell	Sediment	1^{S}	0.42		<0.26	<0.37	<0.92	<0.26	<0.12	70	<0.92
Carsluith	Sediment	1^{S}	1.3		<0.36	<0.60	3.3	1.2	<0.16	190	<1.3
Skyreburn	Sediment	1^{S}	2.3		<0.38	<0.50	<3.2	<1.3	<0.38	270	<2.6
Kirkcudbright	Sediment	1^{S}	1.5		<0.18	<0.17	<1.1	0.85	<0.13	140	<0.95
Rascarrel Bay	Sediment	1^{S}	<0.10		<0.21	<0.19	<0.78	<0.26	<0.11	25	<0.72
Palnackie Harbour	Sediment	1^{S}	0.67		<0.26	<0.51	<0.62	0.93	<0.12	100	<0.90
Gardenburn	Sediment	1^{S}	0.81		<0.55	<1.6	<1.3	0.65	<0.14	140	<1.3
Kippford Slipway	Sediment	1^{S}	0.56		<0.21	<0.34	<0.96	0.55	<0.11	95	<0.91
Kippford Merse	Sediment	1^{S}	0.87		<0.37	<0.67	<1.3	0.55	<0.16	130	<1.2
Southerness	Sediment	1^{S}	<0.10		<0.21	<0.43	<0.73	<0.24	<0.10	19	<0.70
Kirkconnell Merse	Sediment	1^{S}	0.61		<0.27	<0.41	<1.3	<0.56	<0.14	280	<1.3

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}Pu	^{241}Am	Gross alpha	Gross beta
Cumbria										
Newton Arlosh	Sediment	4	<2.0	<1.5				250	560	780
Maryport Outer Harbour	Sediment	2	<2.0	<1.2	15	86	490	170	390	590
Workington Harbour	Sediment	2	<0.83	<0.75				33	400	650
Harrington Harbour	Sediment	2	<0.92	<0.85				56	330	800
Whitehaven Outer Harbour	Sediment	4	<1.3	<0.93	15	85	460	150	270	640
St Bees beach	Sediment	4	<0.72	<0.58				160	260	360
Sellafield beach, S of former pipeline	Sediment	2	<0.84	<0.54				150	120	450
River Calder – downstream	Sediment	2	<1.1	<0.69				72	<200	570
River Calder – upstream	Sediment	2	<1.2	<1.7					250	1000
Seascale beach	Sediment	4	<0.71	<0.55				130	220	390
Ravenglass – Carleton Marsh	Sediment	4	3.2	<1.3				970	1200	1100
River Mite Estuary (erosional)	Sediment	4	4.8	<2.7	130	800	4300	1800	2000	1400
Ravenglass – Raven Villa	Sediment	4	1.7	<1.6				570	790	880
Newbiggin (Eskmeals)	Sediment	4	4.2	<2.9	110	640	3800	1400	1800	1100
Haverigg	Sediment	2	<0.84	<0.73				240	460	670
Millom	Sediment	2	<1.3	<0.88				350	520	870
Low Shaw	Sediment	2	<0.89	<0.67				110	180	500
Walney Channel – N of discharge point	Sediment	2	<0.93	<0.81				240	510	740
Walney Channel – S of discharge point	Sediment	2	<1.0	<1.8				210	320	640
Sand Gate Marsh	Sediment	4	<1.5	<1.1				60	<150	550
Kents Bank	Sediment	4	<1.6	<2.1				150	440	810
Lancashire										
Morecambe	Sediment	2						<7.0		
Half Moon Bay	Sediment	2			6.3	38		65		
Red Nab Point	Sediment	2						23		
Potts Corner	Sediment	2						16		
Sunderland Point	Sediment	4	<2.2	<2.0				72	250	590
Conder Green	Sediment	4	<2.2	<2.2				91	340	790
Hambleton	Sediment	4	<2.8	<2.0				280	530	1100
Skippool Creek	Sediment	4	<2.1	<1.4				230	490	1000
Fleetwood	Sediment	4	<1.0	<0.56				16	<110	390
Blackpool	Sediment	4	<0.66	<0.49				4.1	<100	190
Crossens Marsh	Sediment	4	<2.5	<1.7				190	490	1200
Ainsdale	Sediment	4	<0.62	<0.49				2.8	<110	240
Rock Ferry	Sediment	4	<1.1	<0.75				52	<240	730
New Brighton	Sediment	4	<0.62	<0.45				2.6	<120	240
Scotland										
Campbeltown	Sediment	1^{S}	<0.15	0.86				1.1		
Garlieston	Sediment	1^{S}	<0.17	1.2	3.2	25		41	200	2200
Innerwell	Sediment	1^{S}	<0.21	1.2	9.8	60		99		
Carsluith	Sediment	1^{S}	0.85	1.3	25	150		310	140	430
Skyreburn	Sediment	1^{S}	1.6	<1.3				430		
Kirkcudbright	Sediment	1^{S}	0.87	1.2	24	140		280		
Rascarrel Bay	Sediment	1^{S}	<0.17	0.85	3.6	20		36		
Palnackie Harbour	Sediment	1^{S}	0.62	0.94	15	96		160		
Gardenburn	Sediment	1^{S}	0.62	<0.56	19	110		220		
Kippford Slipway	Sediment	1^{S}	0.42	0.85	12	70		130		
Kippford Merse	Sediment	1^{S}	0.69	1.7	24	130		260		
Southerness	Sediment	1^{S}	<0.15	0.65	3.6	18		34		
Kirkconnell Merse	Sediment	1^{S}	0.83	1.3	17	110		220		

Table 2.8. continued

Location	Material	No. of sampling observ-ations	Mean radioactivity concentration (dry), Bq kg^{-1}								
			^{60}Co	^{95}Zr	^{95}Nb	^{106}Ru	^{125}Sb	^{134}Cs	^{137}Cs	^{144}Ce	^{154}Eu
Isle of Man											
Ramsey	Sediment	1	<0.34	<0.97	<0.26	<2.2	<1.1	<0.33	7.0	<1.5	<0.80
Wales											
Rhyl	Sediment	2	<0.89	<2.3	<0.68	<6.2	<3.2	<0.83	70	<3.1	<2.3
Llandudno	Sediment	2	<0.26	<0.74	<0.20	<1.8	<0.95	<0.26	2.1	<1.2	<0.62
Caerhun	Sediment	2	<0.82	<2.5	<0.61	<5.7	<3.0	<0.76	49	<2.9	<2.0
Llanfairfechan	Sediment	2	<0.72	<2.2	<0.50	<4.9	<2.6	<0.71	19	<2.4	<1.7
Northern Ireland											
Carrichue	Mud and sand	1^{N}	<0.32	<1.3	<1.6	<3.5	<1.0	<0.48	1.4	<3.0	<0.96
Carrichue	Mud, sand and stones	1^{N}	<0.42	<1.6	<1.6	<4.8	<1.3	<0.63	4.1	<3.6	<1.3
Portrush	Sand	2^{N}	<0.32	<1.0	<1.1	<3.5	<0.96	<0.40	0.53	<2.3	<1.1
Oldmill Bay	Mud	2^{N}	<0.50	<2.7	<4.3	<6.0	<1.7	<0.74	35	<4.1	<1.6
Ballymacormick	Mud	1^{N}	<0.39	<1.3	<1.4	<3.8	<1.1	<0.48	14	<2.4	<1.1
Ballymacormick	Mud and sand	1^{N}	<0.36	<5.1	*	<4.5	<1.2	<0.52	12	<4.0	<1.1
Strangford Lough – Nicky's Point	Mud	2^{N}	<0.58	<2.0	<2.2	<5.6	<1.6	<0.73	22	<3.4	<1.8
Dundrum Bay	Mud	1^{N}	<0.56	<2.1	<2.5	<5.7	<1.7	<0.84	32	<4.6	<1.6
Dundrum Bay	Mud and sand	1^{N}	<0.47	<2.0	<1.9	<5.3	<1.5	<0.71	4.5	<4.4	<1.7
Carlingford Lough	Mud	2^{N}	<0.70	<2.2	<2.4	<6.6	<2.0	<0.88	58	<4.0	<2.0

Location	Material	No. of sampling observ-ations	Mean radioactivity concentration (dry), Bq kg^{-1}							
			^{155}Eu	^{238}Pu	^{239}Pu + ^{240}Pu	^{241}Am	^{242}Cm	^{243}Cm+ ^{244}Cm	Gross alpha	Gross beta
Isle of Man										
Ramsey	Sediment	1	<0.60			<0.55			<110	630
Wales										
Rhyl	Sediment	2	<1.4			56			480	910
Llandudno	Sediment	2	<0.53			1.7			<130	160
Caerhun	Sediment	2	<1.3			31			220	710
Llanfairfechan	Sediment	2	<1.1			15			<270	410
Northern Ireland										
Carrichue	Mud and sand	1^{N}	<1.4	0.12	0.81	1.3	*	*		
Carrichue	Mud, sand and stones	1^{N}	<1.9			<2.4				
Portrush	Sand	2^{N}	<1.1			<1.0				
Oldmill Bay	Mud	2^{N}	<1.8			14				
Ballymacormick	Mud	1^{N}	<1.1			12				
Ballymacormick	Mud and sand	1^{N}	<1.5			10				
Strangford Lough – Nicky's Point	Mud	2^{N}	<1.7			<4.3				
Dundrum Bay	Mud	1^{N}	<2.2			8.9				
Dundrum Bay	Mud and sand	1^{N}	<2.1			<2.7				
Carlingford Lough	Mud	2^{N}	<1.8	2.3	15	12	*	*		

* *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

Table 2.9. Gamma radiation dose rates over areas of the Cumbrian coast and further afield, 2012

Location	Ground type	No. of sampling observations	Mean gamma dose rate in air at 1m, μGy h^{-1}
Cumbria, Rockcliffe-Harrington			
Rockcliffe Marsh	Grass	2	0.080
Burgh Marsh	Grass	2	0.080
Port Carlisle 1	Mud	1	0.082
Port Carlisle 1	Mud and sand	3	0.081
Port Carlisle 2	Grass	4	0.085
Greenend 1	Mud	1	0.090
Greenend 1	Mud and sand	2	0.086
Greenend 1	Sand and stones	1	0.093
Greenend 2	Grass	4	0.087
Cardurnock Marsh	Grass	4	0.076
Newton Arlosh	Grass	4	0.093
Silloth harbour	Mud and sand	2	0.10
Silloth harbour	Mud and stones	2	0.098
Silloth silt pond	Grass	4	0.079
Allonby	Sand	4	0.082
Maryport harbour	Mud and sand	1	0.089
Maryport harbour	Sand	1	0.083
Workington harbour	Pebbles and stones	2	0.12
Harrington harbour	Pebbles and sand	2	0.11
Cumbria, Whitehaven-Drigg			
Whitehaven – outer harbour	Sand	1	0.083
Whitehaven – outer harbour	Pebbles and sand	2	0.098
Whitehaven – outer harbour	Sand and stones	1	0.10
St Bees	Sand	4	0.074
Nethertown beach	Pebbles and stones	1	0.12
Nethertown beach	Stones	1	0.12
Braystones	Pebbles and stones	2	0.11
Sellafield dunes	Grass	2	0.11
North of former pipeline on foreshore	Sand	2	0.078
South of former pipeline on foreshore	Sand	2	0.083
River Calder downstream of factory sewer	Grass	2	0.090
River Calder upstream of factory sewer	Grass	2	0.095
Seascale beach	Sand	3	0.081
Seascale beach	Pebbles and sand	1	0.10
Seascale	Grass	4	0.083
Cumbria, Ravenglass-Askam			
Ravenglass – Carleton Marsh	Grass and mud	1	0.13
Ravenglass – Carleton Marsh	Grass	3	0.14
Ravenglass – River Mite estuary (erosional)	Grass and salt marsh	1	0.15
Ravenglass – River Mite estuary (erosional)	Grass	3	0.15
Ravenglass – Raven Villa	Salt marsh	4	0.14
Ravenglass – boat area	Pebbles and sand	1	0.10
Ravenglass – boat area	Sand and stones	1	0.11
Ravenglass – boat area	Pebbles	1	0.11
Ravenglass – boat area	Pebbles and stones	1	0.10
Ravenglass – ford	Mud	1	0.10
Ravenglass – ford	Mud and sand	2	0.11
Ravenglass – ford	Mud and pebbles	1	0.11
Muncaster Bridge	Grass	4	0.12
Ravenglass – salmon garth	Mud and stones	1	0.11
Ravenglass – salmon garth	Pebbles and sand	2	0.11
Ravenglass – salmon garth	Sand and stones	1	0.11
Ravenglass – Eskmeals Nature Reserve	Mud	1	0.12
Ravenglass – Eskmeals Nature Reserve	Salt marsh	3	0.12
Newbiggin/Eskmeals viaduct	Mud	1	0.11
Newbiggin/Eskmeals viaduct	Mud and pebbles	2	0.11
Newbiggin/Eskmeals viaduct	Salt marsh	1	0.12
Newbiggin/Eskmeals Bridge	Salt marsh	3	0.13
Newbiggin/Eskmeals Bridge	Grass and salt marsh	1	0.13
Tarn Bay	Salt marsh	1	0.098
Tarn Bay	Sand	1	0.086
Silecroft	Pebbles and stones	2	0.11
Haverigg	Mud and sand	2	0.090
Millom	Mud and stones	2	0.10
Low Shaw	Grass	2	0.081
Askam	Sand	2	0.070

Table 2.9. continued

Location	Ground type	No. of sampling observations	Mean gamma dose rate in air at 1m, μGy h^{-1}
Cumbria, Walney-Arnside			
Walney Channel, N of discharge point	Mud and sand	2	0.084
Walney Channel, S of discharge point	Mud and salt marsh	1	0.093
Walney Channel, S of discharge point	Mud and sand	1	0.092
Tummer Hill Marsh	Salt marsh	2	0.11
Roa Island	Mud	1	0.092
Roa Island	Mud and sand	1	0.087
Greenodd Salt Marsh	Grass	2	0.081
Sand Gate Marsh	Grass	4	0.084
Kents Bank 2	Grass	4	0.088
High Foulshaw	Grass and mud	2	0.082
High Foulshaw	Grass	2	0.080
Arnside 1	Mud and salt marsh	1	0.085
Arnside 1	Mud and sand	3	0.082
Arnside 2	Salt marsh	1	0.094
Arnside 2	Grass	3	0.091
Lancashire and Merseyside			
Morecambe Central Pier	Sand	1	0.067
Morecambe Central Pier	Pebbles and sand	1	0.077
Half Moon Bay	Sand	1	0.081
Half Moon Bay	Pebbles and stones	1	0.078
Red Nab Point	Sand	1	0.082
Red Nab Point	Pebbles and sand	1	0.094
Middleton Sands	Sand	2	0.080
Sunderland Point	Mud and sand	4	0.093
Sunderland	Salt marsh	4	0.091
Colloway Marsh	Grass and salt marsh	1	0.13
Colloway Marsh	Grass	3	0.12
Lancaster	Grass	4	0.080
Aldcliffe Marsh	Grass	4	0.095
Conder Green	Mud	2	0.091
Conder Green	Mud and sand	1	0.087
Conder Green	Grass and mud	1	0.087
Pilling Marsh	Grass	4	0.096
Knott End	Sand	2	0.074
Heads – River Wyre	Grass and mud	4	0.10
Height o' th' hill – River Wyre	Salt marsh	3	0.11
Height o' th' hill – River Wyre	Grass	1	0.10
Hambleton	Grass and mud	1	0.10
Hambleton	Grass	3	0.10
Skippool Creek 1	Salt marsh	3	0.11
Skippool Creek 1	Grass	1	0.11
Skippool Creek 2	Salt marsh	4	0.10
Skippool Creek 3	Wood	4	0.096
Skippool Creek boat 2	Wood	4	0.093
Skippool Creek boat 2 – in vicinity of boats	Mud	3	0.086
Skippool Creek boat 2 – in vicinity of boats	Mud and sand	1	0.084
Fleetwood Marsh Nature Park	Salt marsh	4	0.11
Fleetwood shore 1	Sand	4	0.073
Blackpool	Sand	4	0.066
Crossens Marsh	Salt marsh	4	0.093
Ainsdale	Sand	4	0.062
Rock Ferry	Mud and sand	4	0.090
New Brighton	Sand	4	0.067
West Kirby	Sand	4	0.069
Little Neston Marsh 1	Mud and grass	1	0.090
Little Neston Marsh 1	Grass and salt marsh	1	0.095
Little Neston Marsh 2	Grass	2	0.074
Flint 1	Mud	2	0.085
Flint 2	Salt marsh	2	0.10

Table 2.9. continued

Location	Ground type	No. of sampling observations	Mean gamma dose rate in air at 1m, μGy h^{-1}
Scotland			
Piltanton Burn	Salt marsh	4^S	0.055
Garlieston	Mud	4^S	0.077
Innerwell	Mud	4^S	0.081
Bladnoch	Mud	4^S	0.078
Carsluith	Mud	4^S	0.081
Skyreburn Bay (Water of Fleet)	Salt marsh	4^S	0.068
Kirkcudbright	Salt marsh	4^S	0.066
Cutters Pool	Winkle bed	4^S	0.084
Rascarrel Bay	Winkle bed	4^S	0.090
Gardenburn	Salt marsh	1^S	0.095
Palnackie Harbour	Mud	1^S	0.084
Kippford – Slipway	Mud	4^S	0.090
Kippford – Merse	Salt marsh	1^S	0.10
Southerness	Winkle bed	4^S	0.063
Kirkconnell Marsh	Salt marsh	1^S	0.096
Isle of Man			
Ramsey	Pebbles and sand	1	0.084
Wales			
Prestatyn	Sand	2	0.060
Rhyl	Salt marsh	2	0.083
Llandudno	Pebbles and sand	2	0.088
Caerhun	Grass	2	0.084
Llanfairfechan	Sand	1	0.071
Llanfairfechan	Sand and shells	1	0.078

Table 2.9. continued

Location	Ground type	No. of sampling observations	Mean gamma dose rate in air at 1m, μGy h^{-1}
Northern Ireland			
Lishally	Mud	1[N]	0.061
Eglington	Shingle	1[N]	0.052
Carrichue	Mud	1[N]	0.068
Bellerena	Mud	1[N]	0.059
Benone	Sand	1[N]	0.059
Castlerock	Sand	1[N]	0.055
Portstewart	Sand	1[N]	0.061
Portrush, Blue Pool	Sand	1[N]	0.059
Portrush, White Rocks	Sand	1[N]	0.055
Portballintrae	Sand	1[N]	0.064
Giant's Causeway	Sand	1[N]	0.057
Ballycastle	Sand	1[N]	0.055
Cushendun	Sand	1[N]	0.059
Cushendall	Sand and stones	1[N]	0.061
Red Bay	Sand	1[N]	0.064
Carnlough	Sand	1[N]	0.061
Glenarm	Sand	1[N]	0.053
Half Way House	Sand	1[N]	0.055
Ballygally	Sand	1[N]	0.056
Drains Bay	Sand	1[N]	0.056
Larne	Sand	1[N]	0.057
Whitehead	Sand	1[N]	0.062
Carrickfergus	Sand	1[N]	0.059
Jordanstown	Sand	1[N]	0.056
Helen's Bay	Sand	1[N]	0.064
Groomsport	Sand	1[N]	0.062
Millisle	Sand	1[N]	0.064
Ballywalter	Sand	1[N]	0.065
Ballyhalbert	Sand	1[N]	0.064
Cloghy	Sand	1[N]	0.066
Portaferry	Shingle and stones	1[N]	0.087
Kircubbin	Sand	1[N]	0.075
Greyabbey	Sand	1[N]	0.074
Ards Maltings	Mud	1[N]	0.072
Island Hill	Mud	1[N]	0.066
Nicky's Point	Mud	1[N]	0.071
Strangford	Shingle and stones	1[N]	0.093
Kilclief	Sand	1[N]	0.073
Ardglass	Mud	1[N]	0.082
Killough	Mud	1[N]	0.083
Rocky Beach	Sand	1[N]	0.071
Tyrella	Sand	1[N]	0.076
Dundrum	Sand	1[N]	0.083
Newcastle	Sand	1[N]	0.092
Annalong	Sand	1[N]	0.11
Cranfield Bay	Sand	1[N]	0.088
Mill Bay	Sand	1[N]	0.11
Greencastle	Sand	1[N]	0.084
Rostrevor	Sand	1[N]	0.11
Narrow Water	Mud	1[N]	0.098

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

Table 2.10. Beta radiation dose rates on contact with fishing gear on vessels operating off Sellafield, 2012

Vessel	Type of gear	No. of sampling observations	Mean beta dose rate in tissue, μSv h^{-1}
A	Nets	1	0.015
	Rope	1	0.070
B	Nets	1	0.098
	Rope	1	0.035
C	Nets	2	0.11
	Rope	2	0.034
S	Gill nets	4	0.065
	Pots	4	0.058
T	Gill nets	4	0.035
	Pots	4	0.072
W	Gill nets	2	0.037
	Pots	2	0.023
X	Gill nets	4	0.020
	Pots	4	0.039
Z	Nets	4	0.045

Table 2.11. Beta radiation dose rates over intertidal areas of the Cumbrian coast, 2012

Location	Ground type	No. of sampling observations	Mean beta dose rate in tissue, mSv h^{-1}
Whitehaven – outer harbour	Sand	1	0.14
Whitehaven – outer harbour	Sand and stones	1	0.020
Whitehaven – outer harbour	Pebbles and sand	2	0.040
St Bees	Sand	4	0.095
Sellafield pipeline	Sand	1	*
Ravenglass - Raven Villa	Salt marsh	3	<0.073
Tarn Bay	Salt marsh	1	0.080
Tarn Bay	Sand	1	0.040

** Not detected by the method used*

Table 2.12. Concentrations of radionuclides in aquatic plants from the Cumbrian coast and further afield, 2012

Location	Material	No. of sampling observ-ations	Mean radioactivity concentration (fresh), Bq kg^{-1}					
			^{60}Co	^{90}Sr	^{95}Zr	^{95}Nb	^{99}Tc	^{106}Ru
Cumbria								
Silloth	Seaweed	2	<0.61		<0.83	<0.39	210	<3.8
Harrington Harbour	Seaweed	2	<0.57		<0.74	<0.38	170	<3.4
St Bees	*Porphyra*[a]	4[F]	<0.08	0.23	<0.18	<0.20	0.97	<2.1
St Bees	Seaweed	2	<0.74	<1.0	<0.82	<0.42	810	<3.8
Braystones South	*Porphyra*	4[F]	<0.09		<0.17	<0.18		2.4
Sellafield	*Rhodymenia* spp.	2[F]	<0.29		<0.47	<0.61		<4.9
Sellafield	Seaweed	2	1.6	0.83	<0.75	<0.40	1600	<3.7
Seascale	*Porphyra*[b]	53[F]	<0.35		<0.54	<0.31		<4.3
Ravenglass	Samphire	1[F]	<0.06		<0.20	<0.22	0.37	<0.67
Ravenglass	Seaweed	2	<0.81		<0.73	<0.36	140	<3.4
Lancashire								
Half Moon Bay	Seaweed	2	<0.67		<0.89	<0.48	400	<4.1
Marshside Sands	Samphire	1[F]	<0.10		<0.49	<0.88		<1.1
Cockerham Marsh	Samphire	1[F]	<0.09		<0.45	<0.72		<1.0
Scotland								
Aberdeen	*Fucus vesiculosus*	1[S]	<0.10		<0.35	<0.54	13	<0.64
Lerwick	*Fucus vesiculosus*	1[S]	<0.10		<0.10	<0.10	29	<0.21
Lewis	*Fucus vesiculosus*	1[S]	<0.10		<0.13	<0.15	16	<0.29
Islay	*Fucus vesiculosus*	1[S]	<0.10		<0.16	<0.15	32	<0.49
Campbeltown	*Fucus vesiculosus*	1[S]	<0.10		<0.10	<0.10	39	<0.30
Port William	*Fucus vesiculosus*	4[S]	<0.10		<0.20	<0.34	110	<0.40
Garlieston	*Fucus vesiculosus*	4[S]	<0.10		<0.17	<0.21	38	<0.38
Auchencairn	*Fucus vesiculosus*	4[S]	0.17		<0.14	<0.18	480	<0.34
Isle of Man	Seaweed	4	<0.76		<0.95	<0.50	94	<4.5
Wales								
Cemaes Bay	Seaweed	2	<0.65		<0.81	<0.41	51	<3.6
Porthmadog	Seaweed	2	<0.70		<0.90	<0.47	2.5	<4.2
Lavernock Point	Seaweed	2	<0.56		<0.64	<0.33	1.8	<3.0
Fishguard	Seaweed	2	<0.46		<0.78	<0.29	12	<3.0
South Wales, manufacturer A	Laverbread	1[F]	<0.06		<0.11	<0.08		<0.51
South Wales, manufacturer C	Laverbread	1[F]	<0.12		<0.32	<0.33		<1.0
South Wales, manufacturer D	Laverbread	1[F]	<0.13		<0.41	<0.45		<1.3
South Wales, manufacturer E	Laverbread	1[F]	<0.07		<0.16	<0.16		<0.62
Northern Ireland								
Portrush	*Fucus* spp.	4[N]	<0.05		<0.11	<0.09		<0.42
Portaferry	*Rhodymenia* spp.	4[N]	<0.11		<0.29	<0.33	0.48	<0.91
Ardglass	*Fucus vesiculosus*	4[N]	<0.15		<0.41	<0.44	54	<1.4
Carlingford Lough	*Ascophyllum nodosum*	1[N]	<0.05		<0.08	<0.05		<0.34
Carlingford Lough	*Fucus* spp.	3[N]	<0.07		<0.21	<0.23	64	<0.65
Isles of Scilly	Seaweed	1	<1.3		<1.5	<0.83	2.4	<7.0

Table 2.12. continued

Location	Material	No. of sampling observ-ations	Mean radioactivity concentration (fresh), Bq kg^{-1}					
			^{125}Sb	^{134}Cs	^{137}Cs	^{144}Ce	^{155}Eu	^{238}Pu
Cumbria								
Silloth	Seaweed	2	<2.1	<0.53	4.6	<1.8		
Harrington Harbour	Seaweed	2	<1.9	<0.50	3.0	<1.5		
St Bees	*Porphyra*[a]	4[F]	<0.16	<0.07	1.1	<0.34	<0.15	0.29
St Bees	Seaweed	2	<2.1	<0.56	4.0	<1.6		1.8
Braystones South	*Porphyra*	4[F]	<0.15	<0.06	1.4	<0.31	<0.14	0.30
Sellafield	*Rhodymenia* spp.	2[F]	<0.39	<0.14	4.5	<0.59	<0.26	7.2
Sellafield	Seaweed	2	<2.1	<0.53	3.8	<1.7		2.3
Seascale	*Porphyra*[b]	53[F]	<0.90	<0.35	1.2	<1.7	<0.86	
Ravenglass	Samphire	1[F]	<0.16	<0.06	0.78	<0.34	<0.14	
Ravenglass	Seaweed	2	<2.0	<0.51	7.7	<1.6		
Lancashire								
Half Moon Bay	Seaweed	2	<2.4	<0.64	3.7	<1.9		
Marshside Sands	Samphire	1[F]	<0.21	<0.11	0.98	<0.35	<0.14	
Cockerham Marsh	Samphire	1[F]	<0.21	<0.09	1.5	<0.39	<0.15	
Scotland								
Aberdeen	*Fucus vesiculosus*	1[S]	<0.17	<0.10	<0.10	<0.40	<0.16	
Lerwick	*Fucus vesiculosus*	1[S]	<0.10	<0.10	<0.10	<0.14	<0.10	
Lewis	*Fucus vesiculosus*	1[S]	<0.10	<0.10	0.31	<0.21	<0.10	
Islay	*Fucus vesiculosus*	1[S]	<0.14	<0.10	0.21	<0.34	<0.15	
Campbeltown	*Fucus vesiculosus*	1[S]	<0.10	<0.10	0.40	<0.20	<0.10	
Port William	*Fucus vesiculosus*	4[S]	<0.13	<0.10	0.76	<0.28	<0.15	
Garlieston	*Fucus vesiculosus*	4[S]	<0.14	<0.10	2.4	<0.25	<0.14	
Auchencairn	*Fucus vesiculosus*	4[S]	<0.20	<0.10	2.7	<0.23	<0.11	
Isle of Man	Seaweed	4	<2.6	<0.65	<0.60	<2.2	<1.1	
Wales								
Cemaes Bay	Seaweed	2	<2.1	<0.55	1.2	<1.8		
Porthmadog	Seaweed	2	<2.5	<0.61	<0.51	<1.9		
Lavernock Point	Seaweed	2	<1.8	<0.47	<0.39	<1.4	<0.71	
Fishguard	Seaweed	2	<1.6	<0.42	<0.33	<1.6		
South Wales, manufacturer A	Laverbread	1[F]	<0.11	<0.05	<0.05	<0.18	<0.08	
South Wales, manufacturer C	Laverbread	1[F]	<0.21	<0.11	0.19	<0.34	<0.15	
South Wales, manufacturer D	Laverbread	1[F]	<0.26	<0.13	<0.12	<0.44	<0.18	
South Wales, manufacturer E	Laverbread	1[F]	<0.14	<0.07	<0.06	<0.24	<0.10	
Northern Ireland								
Portrush	*Fucus* spp.	4[N]	<0.10	<0.05	<0.13	<0.19	<0.10	
Portaferry	*Rhodymenia* spp.	4[N]	<0.19	<0.09	0.71	<0.32	<0.14	0.049
Ardglass	*Fucus vesiculosus*	4[N]	<0.30	<0.16	0.54	<0.49	<0.21	
Carlingford Lough	*Ascophyllum nodosum*	1[N]	<0.08	<0.05	0.30	<0.11	<0.06	
Carlingford Lough	*Fucus* spp.	3[N]	<0.15	<0.08	0.41	<0.32	<0.15	
Isles of Scilly	Seaweed	1	<3.7	<1.1	<0.82	<2.3	<1.1	

Table 2.12. continued

Location	Material	No. of sampling observ-ations	Mean radioactivity concentration (fresh), Bq kg^{-1}					
			^{239}Pu + ^{240}Pu	^{241}Pu	^{241}Am	^{242}Cm	^{243}Cm+ ^{244}Cm	Gross beta
Cumbria								
Silloth	Seaweed	2			<2.0			
Harrington Harbour	Seaweed	2			2.0			
St Bees	*Porphyra*[a]	4[F]	1.5	0.010	4.0	*	0.0058	240
St Bees	Seaweed	2	8.8		5.4			
Braystones South	*Porphyra*	4[F]	1.6	11	3.1	*	*	
Sellafield	*Rhodymenia* spp.	2[F]	38		10	*	*	
Sellafield	Seaweed	2	11		6.3			
Seascale	*Porphyra*[b]	53[F]			4.8			
Ravenglass	Samphire	1[F]			2.0			
Ravenglass	Seaweed	2			27			
Lancashire								
Half Moon Bay	Seaweed	2			<0.72			
Marshside Sands	Samphire	1[F]			0.40			
Cockerham Marsh	Samphire	1[F]			1.0			56
Scotland								
Aberdeen	*Fucus vesiculosus*	1[S]			<0.10			
Lerwick	*Fucus vesiculosus*	1[S]			<0.10			
Lewis	*Fucus vesiculosus*	1[S]			<0.10			
Islay	*Fucus vesiculosus*	1[S]			<0.10			
Campbeltown	*Fucus vesiculosus*	1[S]			<0.10			
Port William	*Fucus vesiculosus*	4[S]			0.47			
Garlieston	*Fucus vesiculosus*	4[S]			3.5			
Auchencairn	*Fucus vesiculosus*	4[S]			2.1			
Isle of Man	Seaweed	4			<0.83			
Wales								
Cemaes Bay	Seaweed	2			<0.66			
Porthmadog	Seaweed	2			<0.75			
Lavernock Point	Seaweed	2			<0.53			
Fishguard	Seaweed	2			<0.51			
South Wales, manufacturer A	Laverbread	1[F]			<0.05			
South Wales, manufacturer C	Laverbread	1[F]			0.15			
South Wales, manufacturer D	Laverbread	1[F]			0.17			120
South Wales, manufacturer E	Laverbread	1[F]			0.06			
Northern Ireland								
Portrush	*Fucus* spp.	4[N]			<0.10			
Portaferry	*Rhodymenia* spp.	4[N]	0.31		0.55	*	*	
Ardglass	*Fucus vesiculosus*	4[N]			0.38			
Carlingford Lough	*Ascophyllum nodosum*	1[N]			<0.04			
Carlingford Lough	*Fucus* spp.	3[N]			<0.16			
Isles of Scilly	Seaweed	1			<0.84			

* *Not detected by the method used*
[a] *The concentration of ^{14}C was 30 Bq kg^{-1}*
[b] *Counted fresh*
[F] *Measurements labelled "F" are made on behalf of the Food Standards Agency*
[N] *Measurements labelled "N" are made on behalf of the Northern Ireland Environment Agency*
[S] *Measurements labelled "S" are made on behalf of the Scottish Environment Protection Agency*
All other measurements are made on behalf of the Environment Agency

Table 2.13. Concentrations of radionuclides in vegetables, grass and soil measured to investigate the transfer of radionuclides from sea to land, 2012

Location	Material	No. of sampling observ-ations	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}									
			^{60}Co	^{95}Zr	^{95}Nb	^{99}Tc	^{106}Ru	^{125}Sb	^{134}Cs	^{137}Cs	^{144}Ce	^{241}Am
Sellafield 154[b]	Cabbage	1	<0.03	<0.13	<0.18	<0.059	<0.31	<0.06	<0.03	<0.03	<0.12	<0.02
Sellafield 154[b]	Onions	1	<0.04	<0.15	<0.19	<0.081	<0.44	<0.09	<0.04	<0.04	<0.15	<0.03
Sellafield 154[b]	Potatoes	1	<0.09	<0.23	<0.20	0.35	<0.95	<0.22	<0.10	0.16	<0.46	<0.19
Sellafield 154[b]	Swiss chard	1	<0.07	<0.24	<0.32	0.089	<0.67	<0.13	<0.07	<0.06	<0.21	<0.05
Sellafield 154[b]	Soil	1	<0.37	<2.0	<3.0	12	<4.2	<1.2	<0.52	48	<3.1	<1.5
Sellafield 474[b]	Beetroot	1	<0.03	<0.06	<0.05	<0.14	<0.24	<0.05	<0.03	<0.02	<0.10	<0.03
Sellafield 474[b]	French dwarf beans	1	<0.06	<0.18	<0.21	<0.083	<0.57	<0.12	<0.05	<0.05	<0.20	<0.04
Sellafield 474[b]	Onions	1	<0.06	<0.13	<0.09	<0.13	<0.58	<0.13	<0.06	<0.05	<0.22	<0.05
Sellafield 474[b]	Potatoes	1	<0.06	<0.13	<0.10	<0.25	<0.51	<0.13	<0.06	<0.05	<0.26	<0.17
Sellafield 474[b]	Swiss chard	1	<0.04	<0.11	<0.10	0.57	<0.35	<0.08	<0.04	<0.03	<0.13	<0.03
Sellafield 474[b]	Soil	1	<0.24	<1.2	<1.5	<1.3	<2.9	<0.74	<0.35	4.0	<2.2	<1.3

[a] *Except for soil where dry concentrations apply*
[b] *Consumer code number*

Table 2.14. Concentrations of radionuclides in terrestrial food and the environment near Ravenglass, 2012

Material and selection[a]		No. of sampling observ-ations[c]	Mean radioactivity concentration (fresh)[b], Bq kg^{-1}									
			^{3}H	^{14}C	^{60}Co	^{90}Sr	^{95}Zr	^{95}Nb	^{99}Tc	^{106}Ru	^{125}Sb	^{129}I
Milk[d]		4	<4.2	21	<0.18	0.038	<0.29	<0.23	<0.0045	<1.1	<0.38	<0.0082
Milk	max		<4.5	25		0.052	<0.32	<0.25		<1.2	<0.43	<0.0095
Apples		1	<4.0	17	<0.20	0.33	<0.30	<0.20	<0.025	<1.1	<0.40	<0.023
Barley		1	<7.0	95	<0.20	0.97	<0.30	<0.20	<0.026	<1.2	<0.40	<0.029
Beef kidney		1	13	31	<0.20	0.26	<0.40	<0.20	<0.022	<1.6	<0.60	<0.025
Beef liver		1	10	35	<0.20	0.23	<0.30	<0.20	<0.026	<1.0	<0.30	<0.026
Beef muscle		1	<6.0	13	<0.10	<0.0060	<0.30	<0.20	<0.023	<1.3	<0.40	<0.028
Beetroot		1							<0.027			
Blackberries		1	<4.0	18	<0.20	0.13	<0.30	<0.20	<0.029	<0.50	<0.30	<0.035
Cabbage		1	<4.0	9.0	<0.20	5.1	<0.30	<0.20	0.056	<1.2	<0.50	<0.026
Carrots		1	<4.0	7.0	<0.20	0.35	<0.30	<0.20	<0.035	<1.3	<0.40	<0.023
Honey		1	<7.0	92	<0.20	0.037	<0.30	<0.20	<0.025	<1.6	<0.40	<0.013
Lettuce		1							<0.035			
Mangetout		1	<4.0	11	<0.20	0.30	<0.30	<0.40	<0.049	<0.90	<0.70	
Pheasants		1	<5.0	26	<0.20	0.011	<0.20	<0.20	<0.030	<1.3	<0.40	<0.046
Potatoes		1	4.0	13	<0.20	0.044	<0.40	<0.30	<0.030	<1.3	<0.60	<0.032
Sheep muscle		2	<6.0	45	<0.20	0.027	<0.30	<0.20	<0.030	<1.3	<0.25	<0.022
Sheep muscle	max		6.0	56	<0.30	0.036			<0.031	<1.5	<0.30	<0.023
Sheep offal		2	<11	28	<0.20	0.37	<0.30	<0.20	<0.023	<1.4	<0.40	<0.029
Sheep offal	max		15			0.41			<0.025	<1.6	<0.50	<0.031
Grass		2							1.6			
Grass	max								3.1			

Material and selection[a]		No. of sampling observ-ations[c]	Mean radioactivity concentration (fresh)[b], Bq kg^{-1}								
			Total Cs	^{144}Ce	^{234}U	^{235}U	^{238}U	^{238}Pu	^{239}Pu + ^{240}Pu	^{241}Pu	^{241}Am
Milk[d]		4		<0.84				<0.00011	<0.00017	<0.039	<0.00014
Milk	max			<1.0				<0.00013	<0.00023	<0.043	0.00023
Apples		1	0.14	<0.60				<0.00020	0.00020	<0.087	0.00060
Barley		1	0.42	<0.60				0.0016	0.013	<0.12	0.020
Beef kidney		1	0.39	<1.2	0.012	<0.00040	0.011	<0.00020	<0.00040	<0.13	0.00040
Beef liver		1	0.46	<0.70				0.00020	0.0019	0.10	0.0015
Beef muscle		1	0.43	<0.70				<0.00030	<0.00040	<0.11	0.00030
Beetroot		1			0.0031	0.00040	0.0025				
Blackberries		1	0.18	<0.70				<0.00010	0.00040	<0.060	0.00070
Cabbage		1	0.23	<0.80				<0.00040	0.0026	<0.20	0.0026
Carrots		1	0.32	<0.90				0.00020	0.00070	<0.063	0.00080
Honey		1	0.16	<1.4				<0.00020	0.00020	<0.078	0.00020
Lettuce		1			0.026	0.0015	0.022				
Mangetout		1	0.17	<1.4				<0.00030	<0.00060	<0.14	0.00060
Pheasants		1	0.54	<0.70				<0.00020	<0.00030	<0.13	<0.00020
Potatoes		1	0.13	<1.4				<0.00020	<0.00030	<0.086	<0.00020
Sheep muscle		2	1.4	<0.65				<0.00020	<0.00040	<0.094	0.00030
Sheep muscle	max			<0.70				<0.00030	<0.00050	0.11	0.00040
Sheep offal		2	0.96	<1.0				<0.00025	<0.00050	<0.12	0.00055
Sheep offal	max		1.1	<1.4				<0.00030	<0.00060		0.00080
Soil		1			8.6	0.35	8.6				

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

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

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

[d] *The mean concentrations of ^{134}Cs and ^{137}Cs were <0.20 and <0.19 (max <0.20) Bq l^{-1}*

Table 2.15. Concentrations of radionuclides in surface waters from West Cumbria, 2012

Location	No. of sampling observ-ations	Mean radioactivity concentration, Bq l^{-1}								
		^{3}H	^{60}Co	^{90}Sr	^{134}Cs	^{137}Cs	^{238}Pu	^{239}Pu + ^{240}Pu	Gross alpha	Gross beta
Ehen Spit beach[a]	4	400	<0.26	<0.038	<0.26	<0.31	<0.0063	<0.0068	<2.4	12
River Ehen (100m downstream of sewer outfall)	4	<6.9	<0.23	<0.10	<0.24	<0.20	<0.0053	<0.0050	<0.041	0.38
River Calder (downstream)	4	<3.7	<0.27	<0.040	<0.28	<0.23	<0.0050	<0.0050	<0.035	0.11
River Calder (upstream)	4	<3.0	<0.27	<0.038	<0.29	<0.23	<0.0050	<0.0050	<0.025	<0.067
Wast Water	1	<3.2	<0.23			<0.19			<0.020	<0.10
Ennerdale Water	1	<3.3	<0.20		<0.21	<0.14			<0.030	<0.10
Devoke Water	1	<3.1	<0.16		<0.16	<0.14			<0.050	<0.10
Thirlmere	1	<3.2	<0.23			<0.20			<0.030	<0.10

[a] *The concentration of ^{99}Tc was <0.68 Bq l^{-1}*

Table 2.16. Concentrations of radionuclides in road drain sediments from Whitehaven and Seascale, 2012

Location	No. of sampling observ-ations	Mean radioactivity concentration (dry), Bq kg^{-1}						
		^{60}Co	^{90}Sr	^{134}Cs	^{137}Cs	^{238}Pu	^{239}Pu+ ^{240}Pu	^{241}Am
Seascale SS 204	1	<0.52	<2.0	<0.51	170	2.2	15	23
Seascale SS 233	1	<0.49	3.5	0.63	240	2.7	22	28
Seascale SS 209	1	<0.40	<2.0	<0.39	18	1.0	6.7	11
Seascale SS 232	1	<0.39	<2.0	<0.37	100	2.1	16	26
Seascale SS 231	1	<1.6	3.3	<1.6	54	4.0	21	44
Seascale SS 206	1	<2.9		<2.7	320			
Seascale SS 208	1	<0.42		<0.42	46			
Seascale SS 234	1	<1.6		<1.4	57			
Whitehaven SS 201	1	<1.7	<2.0	<2.0	29	<0.80	1.6	3.3

Table 2.17. Doses from artificial radionuclides in the Irish Sea, 2007-2012

Group	Exposure, mSv per year					
	2007	2008	2009	2010	2011	2012
Isle of Man	0.006	0.007	0.007	<0.005	<0.005	<0.005
Northern Ireland	0.015	0.017	0.012	0.010	0.010	0.011
Dumfries and Galloway	0.060	0.047	0.047	0.040	0.040	0.046
Whitehaven	0.009	0.009	0.011	0.010	0.010	0.013
Sellafield (5 year average consumption)	0.24	0.23	0.20	0.18	0.15	0.14
Morecambe Bay	0.037	0.042	0.041	0.046	0.034	0.034
Fleetwood	0.013	0.016	0.013	0.015	0.008	0.008
North Wales	0.014	0.018	0.015	0.013	0.014	0.014

Table 2.18. Individual radiation exposures, Sellafield, 2012

Exposed population[a]	Exposure, mSv per year							
	Total	Seafood (nuclear industry discharges)[i]	Seafood (other discharges)[h]	Other local food	External radiation from intertidal areas, river banks or fishing gear	Intakes of sediment and water	Gaseous plume related pathways	Direct radiation from site
***Total dose* – maximum effect of all sources**								
Adult mollucs consumers	**0.30[e]**	**0.066**	**0.22**	**–**	**0.016**	**–**	**–**	**–**
***Total dose* – maximum effect of gaseous release and direct radiation sources**								
Infant root vegetable consumers	**0.010**	**–**	**–**	**0.010**	**–**	**–**	**–**	**–**
***Total dose* – maximum effect of liquid release source**								
Adult mollusc consumers	**0.30[e]**	**0.066**	**0.22**	**–**	**0.016**	**–**	**–**	**–**
Source specfic doses								
Seafood consumers								
Local seafood consumers (habits averaged 2008-12)	0.33[f]	0.11	0.19	–	0.032	–	–	–
Local seafood consumers (habits for 2012)	0.32[g]	0.063	0.23	–	0.032	–	–	–
Whitehaven – seafood consumers	0.013	0.013	–	–	–	–	–	–
Dumfries and Galloway – seafood and wildfowl consumers	0.046	0.038	–	–	0.007	–	–	–
Morecambe Bay – seafood consumers	0.034	0.014	–	–	0.019	–	–	–
Fleetwood – seafood consumers	0.008	0.008	–	–	–	–	–	–
Isle of Man – seafood consumers	<0.005	<0.005	–	–	–	–	–	–
Northern Ireland – seafood consumers	0.011	0.008	–	–	<0.005	–	–	–
North Wales – seafood consumers	0.014	0.009	–	–	0.006	–	–	–
Other groups								
Ravenglass Estuary, marsh users	0.017	–	–	–	0.014	<0.005	–	–
Fishermen handling nets or pots[c]	0.060	–	–	–	0.060	–	–	–
Bait diggers and shellfish collectors[c]	0.040	–	–	–	0.040	–	–	–
Ribble Estuary houseboats	0.083	–	–	–	0.083	–	–	–
Local consumers at Ravenglass[b]	0.018	–	–	0.018	–	–	–	–
Local consumers of vegetables grown on land with seaweed added	0.008	–	–	0.008	–	–	–	–
Local consumers in the Isle of Man[b]	0.008	–	–	0.008	–	–	–	–
Consumers of laverbread in South Wales	<0.005	–	–	<0.005	–	–	–	–
Inhabitants and consumers of locally grown food[b]	0.016	–	–	0.015	–	–	<0.005	–
Groups with average consumption or exposure								
Average seafood consumer in Cumbria	<0.005	<0.005	–	–	–	–	–	–
Average consumer of locally grown food[d]	0.006	–	–	0.006	–	–	–	–
Typical visitor to Cumbria	<0.005	<0.005	<0.005	–	<0.005	–	–	–
Recreational user of beaches								
North Cumbria	0.010	–	–	–	0.010	–	–	–
Sellafield	0.010	–	–	–	0.010	–	–	–
Lancashire	0.006	–	–	–	0.006	–	–	–
North Wales	0.006	–	–	–	0.006	–	–	–
Isle of Man	0.006	–	–	–	0.006	–	–	–

Table 2.18. continued

Exposed population[a]	Exposure, mSv per year							
	Total	Seafood (nuclear industry discharges)[i]	Seafood (other discharges)[h]	Other local food	External radiation from intertidal areas, river banks or fishing gear	Intakes of sediment and water	Gaseous plume related pathways	Direct radiation from site
Recreational user of mud/saltmarsh areas								
Dumfries and Galloway	<0.005	–	–	–	<0.005	–	–	–
North Cumbria	0.006	–	–	–	0.006	–	–	–
Sellafield	0.014	–	–	–	0.014	–	–	–
Lancashire	0.008	–	–	–	0.008	–	–	–
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. Adults are the most exposed group unless otherwise stated

[b] *Infants*

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

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

[e] *The dose due to nuclear industry discharges was 0.082 mSv*

[f] *The dose due to nuclear industry discharges was 0.14 mSv*

[g] *The* total dose *due to nuclear industry discharges was 0.094 mSv*

[h] *Enhanced naturally occurring radionuclides from Whitehaven*

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

3. Research establishments

This section considers the results of monitoring by the Environment Agency, Food Standards Agency and SEPA near research establishments that hold nuclear site licences.

The NDA has ownership of the majority of such sites, with licensed nuclear sites at Harwell and Winfrith in England, and Dounreay in Scotland. The non-nuclear site at Culham, Oxfordshire is operated by UKAEA (under contract from Euratom) under the terms of the European Fusion Development Agreement. Previously Harwell, Winfrith and Dounreay sites were operated by UKAEA. In 2009, Research Sites Restoration Limited (RSRL) and Dounreay Site Restoration Limited (DSRL) (both wholly-owned subsidiaries of UKAEA) became the site licence companies for Harwell and Winfrith, and Dounreay respectively. UKAEA Limited itself was sold to Babcock International Group plc, including its subsidiary companies DSRL and RSRL, as a preliminary to NDA starting the Dounreay Parent Body Organisation competition. The NDA completed the Parent Body competition process and Babcock Dounreay Partnership was awarded the contract. All of the nuclear licensed sites have reactors that are at different stages of decommissioning. Discharges of radioactive waste are largely related to decommissioning and decontamination operations and the nuclear related research that is undertaken. Tenants, or contractors, such as Nuvia Limited carry out some of this work.

In April 2012, the NDA announced its competition for the Parent Body Organisation contracts for Research Sites Restoration Limited. More information can be found at: https://www.nda.gov.uk/contracts/competition/magnox-rsrl.cfm

Regular monitoring of the environment was undertaken in relation to all sites, which included the effects of discharges from neighbouring sites and tenants where appropriate, i.e. the Vulcan Naval Reactor Test Establishment (NRTE) adjacent to the Dounreay site, and GE Healthcare Limited at Harwell.

The medium-term trends in discharges, environmental concentrations and doses at Dounreay, Harwell and Winfrith were considered in a summary report (Environment Agency, Food Standards Agency, Northern Ireland Environment Agency and Scottish Environment Protection Agency, 2010b).

The remaining research site considered in this section is the Imperial College Reactor Centre near Ascot, Berkshire.

Key points

- Public radiation doses from all sources were less than 2 per cent of the dose limit at all those sites assessed
- Doses, discharges, environmental concentrations and dose rates in 2012 were broadly similar to those in 2011

Dounreay, Highland

- Babcock Dounreay Partnership became the Parent Body Organisation in 2012
- There were small decreases in public radiation doses in 2012
- Gaseous discharges of krypton-85 increased from the Fast Reactor and Prototype Fast Reactor in 2012

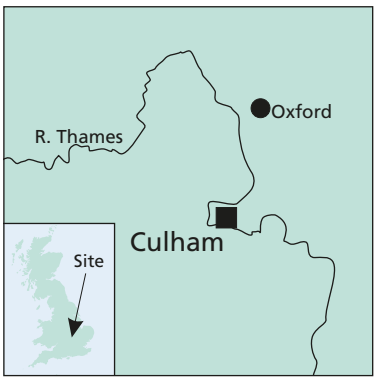
Harwell, Oxfordshire

- GE Healthcare Limited surrendered their permit and nuclear site licence at Harwell in 2012
- Liquid discharges from the Harwell site increased to the River Thames and Lydebank Brook in 2012

Winfrith, Dorset

- Gaseous and liquid discharges of tritium increased in 2012

3.1 Culham, Oxfordshire

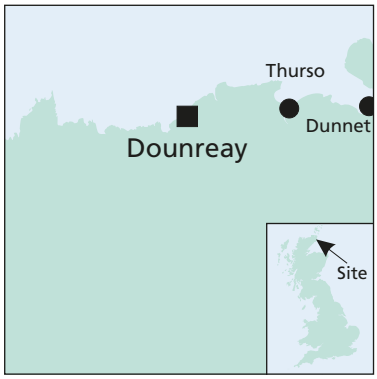


Culham Centre for Fusion Energy (CCFE), based at the Culham Science Centre, is the UK's national laboratory for fusion research. CCFE hosts an experimental fusion reactor, the Joint European Torus (JET), owned and operated by the UKAEA. Although not currently designated, the NDA understands that the intention of Government is to designate that part of the Culham Site occupied by the JET facilities as an NDA site at an appropriate time after JET operation ceases. The NDA would then take responsibility for the decommissioning programme.

Total dose is not determined at this site, in this report, because an integrated habits survey has not been undertaken. The source specific dose, from using the River Thames directly as drinking water downstream of the discharge point at Culham in 2012, was estimated to be much less than 0.005 mSv (Table 3.1).

Monitoring of soil and grass around Culham and of sediment and water from the River Thames was undertaken in 2012. Locations and data are shown in Figure 3.1 and Table 3.2, respectively. In previous years, the main effect of the site's operation was the increased tritium concentrations found in grass collected near the site perimeter. In 2012, measurements of tritium were less than the LoD. Overall, no effects due to site operation were detected. The measured concentrations of caesium-137 in the River Thames sediment are not attributable to Culham but were due to past discharges from Harwell, nuclear weapons testing fallout from the 1950's and 1960's and the Chernobyl reactor accident in 1986.

3.2 Dounreay, Highland



The Dounreay site was opened in 1955 to develop research reactors. Three reactors were built on the site; the Prototype Fast Reactor, the Dounreay Fast Reactor and the Dounreay Materials Test Reactor. All three are now closed and undergoing decommissioning.

From 2005, the NDA became responsible for the UK's civil nuclear liabilities which included those at UKAEA Dounreay, and UKAEA became a contractor to the NDA. In common with other NDA sites, UKAEA prepared a long term decommissioning plan known as the Lifetime Plan. The NDA's Strategy includes a summary of the Parent Body Organisation competition process. Part of this process required the transfer of the three existing radioactive waste disposal authorisations from UKAEA to a new site licence company (Dounreay Site Restoration Limited, DSRL), before DSRL took over the site management contract. The NDA completed the Parent Body competition process and Babcock Dounreay Partnership was awarded the contract on 2 April 2012.

SEPA is continuing to determine DSRL's application for a new authorisation for the disposal of radioactive waste arising from the decommissioning of the Dounreay site. The content of the application is based upon the predicted requirements of the decommissioning activities which are to be undertaken.

In August 2012, SEPA varied DSRL's gaseous authorisation (also reported in RIFE 17). The variation increased the Prototype Fast Reactor stack krypton-85 discharge limit to facilitate repackaging and movement of fuel to a dry storage environment and decreased the Fuel Cycle Area stack krypton-85 discharge limit, resulting in an overall reduction of the site's authorised krypton-85 discharge limit.

In 2012, SEPA granted DSRL's authorisation for a Low Level Radioactive Waste disposal facility adjacent to the site. The facility is currently under construction and is expected to begin accepting waste for disposal during 2014.

During 2012, DSRL completed the processing of the bulk of the Sodium/Potassium (NaK) liquid coolant through the NaK destruction plant in the Dounreay Fast Reactor.

During 2012, SEPA undertook a range of inspections which included the following topics:

- Key aspects of DSRL's management system for achieving compliance with the site's authorisations
- DSRL's processes for consigning Out of Scope waste and the implementation of changes to the Radioactive Substances Act regarding the revised exemption order
- DSRL's revised management structure
- Maintenance arrangements
- Decommissioning projects

In March 2012, DSRL notified SEPA of the identification of unauthorised disposals of radioactively contaminated effluent into the site's inactive drainage system, which is discharged to sea via an inactive outfall. The disposals related to effluent discharges from the environmental laboratories and involved very low levels of radioactivity. Although there was no discernible environmental impact as a result of the discharges, the discharges constituted a contravention of the limitations and conditions of the RSA 93 authorisation held by the operator. This resulted in SEPA issuing a warning letter to DSRL.

In July 2012, DSRL notified SEPA that a consignment of solid waste had been removed from site without it going through DSRL's due process for waste leaving site. The incident did not result in an unauthorised disposal of radioactive waste, as the waste was subsequently proven to be clean. However, as there was a failure in the arrangements in place to control the disposal of waste from the site, the event constituted a contravention of the limitations and conditions of the RSA 93 authorisation held by the operator. This resulted in SEPA issuing a warning letter to DSRL.

In 2012, radioactive waste discharges from Dounreay were made by DSRL under authorisations granted by SEPA. The quantities of both gaseous and liquid discharges were generally similar to those in 2011 (Appendix 2). Sampling locations for the terrestrial and marine monitoring programme are shown in Figure 3.2 (north of Scotland) and Figure 3.3 (Dounreay).

The most recent habits survey was conducted in 2008 (Clyne *et al.*, 2011a). Figures for consumption rates, together with

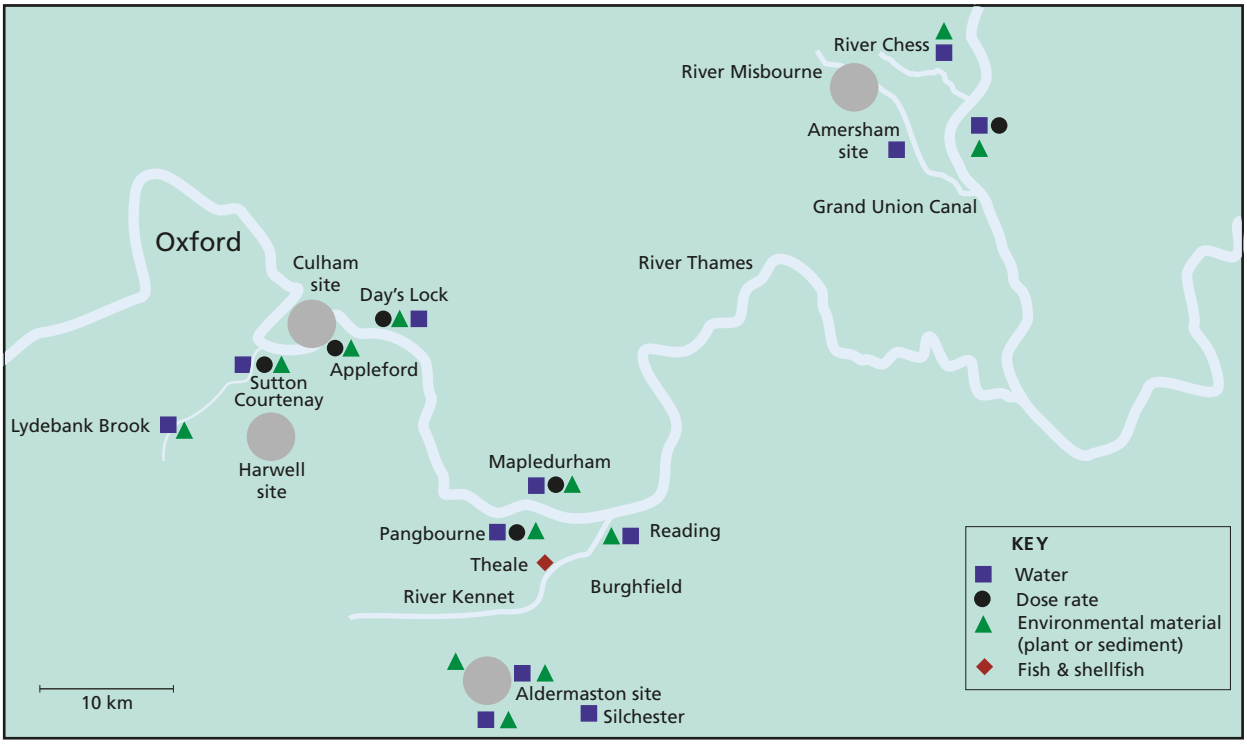


Figure 3.1. Monitoring locations at Thames sites, 2012 (not including farms)

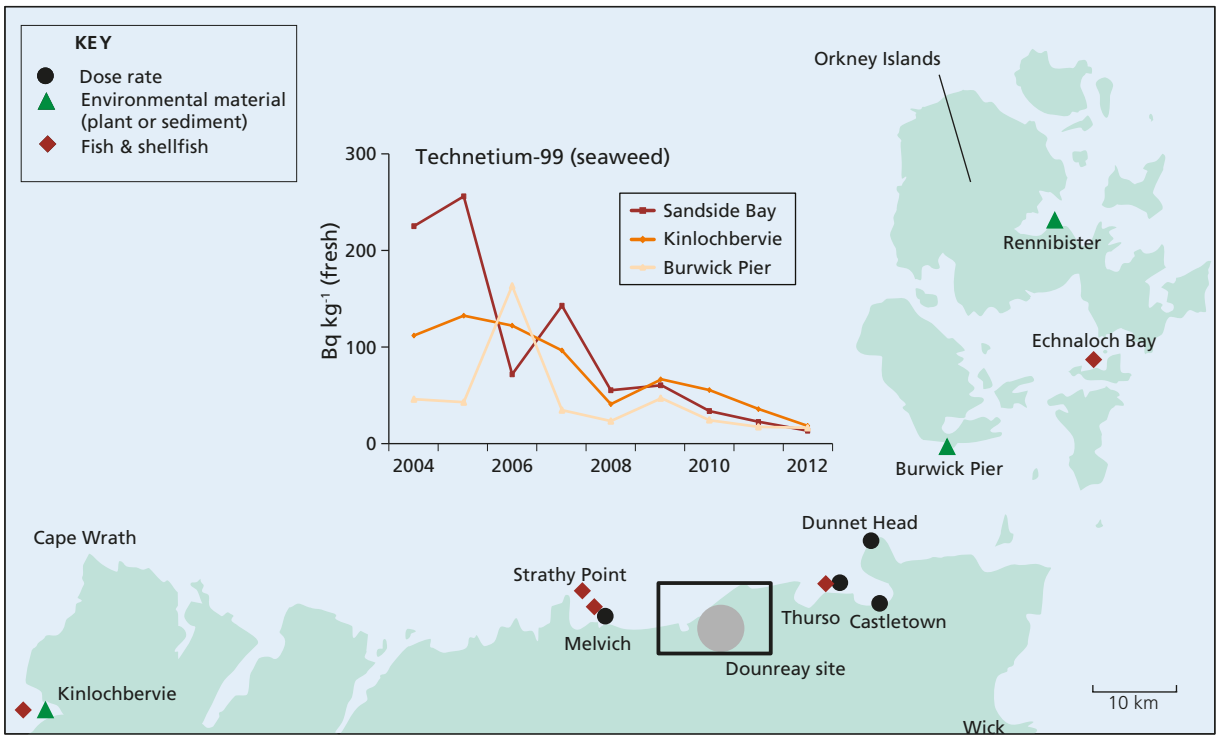


Figure 3.2. Monitoring locations and concentrations of technetium-99 in seaweed in the north of Scotland, 2012 (not including farms)

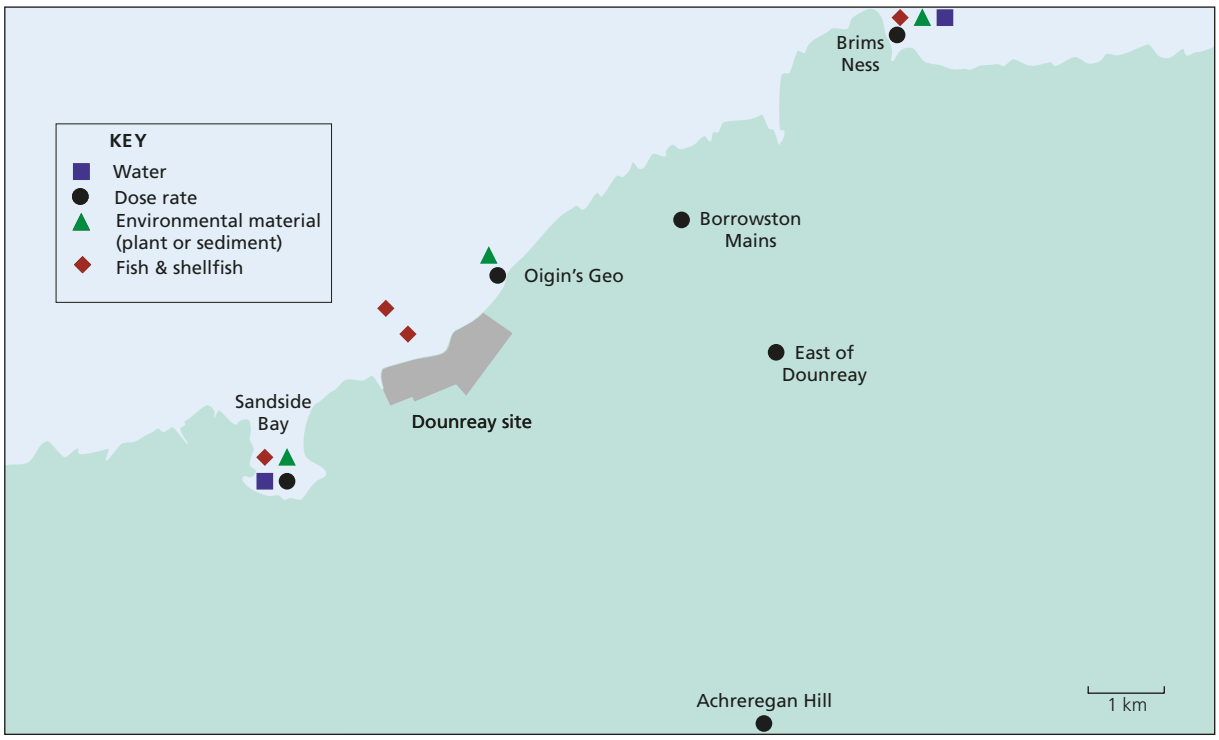


Figure 3.3. Monitoring locations at Dounreay, 2012 (not including farms)

handling and occupancy rates, are provided in Appendix 1 (Table X2.2). A habits survey to obtain data on activities undertaken on beaches relating to potential public exposure to radioactive particles at Dunnet Bay, Highland was undertaken in 2009 (Clyne *et al*., 2011b).

Doses to the public

In 2012, the *total dose* from all pathways and sources of radiation is assessed to have been 0.017 mSv (Table 3.1) or less than 2 per cent of the dose limit. The people most exposed were high-rate consumers (1-year-old infants) of milk, as in 2011. The overall small decrease in dose (from 0.018 mSv in 2011) was due to lower reported LoDs in milk for contributing radionuclides in 2012.

The trend in *total dose* over the period 2004 – 2012 is given in Figure 1.1. The variations in recent years were due to changes in caesium-137 concentrations in game meat and the type of game sampled, but *total doses* were low.

Source specific assessments for high-rate consumers of seafood, and for external pathways (both for Geo occupants, who live at or regularly visit Oigin's Geo, and fishermen), give exposures of less than the *total dose* in 2012 (Table 3.1). The dose to consumers of terrestrial foodstuffs was 0.027 mSv or less than 3 per cent of the dose limit for members of the public of 1 mSv. This dose in 2011 was 0.028 mSv and the reason for the small decrease in 2012 was the same as that contributing to the maximum *total dose*. The dose to consumers of fish and shellfish, including external exposure from occupancy over local beaches, was 0.006 mSv. The decrease in dose from 0.010 mSv (in 2011) was mostly due to lower dose rates over the winkle bed at Sandside Bay, and to a lesser extent, lower rates over sand at other locations in 2012.

Gaseous discharges and terrestrial monitoring

DSRL is authorised by SEPA to discharge gaseous wastes to the local environment via stacks to the atmosphere. Discharges of krypton-85 increased from the Fast Reactor and Prototype Fast Reactor in comparison to those in 2011, due to the increase in the number of reactor gas blanket blow-down operations undertaken in 2012 as part of the implementation of the reactor decommissioning work. Monitoring conducted in 2012 included the sampling of air, freshwater, grass, soil and locally grown terrestrial foods including meat, vegetables and cereals as well as wild foods. As there are no dairy cattle herds in the Dounreay area, no milk samples were collected from cattle. However, monitoring for radionuclides in goats' milk was included in 2012. The results for terrestrial samples and radioactivity in air are given in Tables 3.3(a) and (c) and generally show low concentrations of radioactivity. In 2012, low concentrations of caesium-137, strontium-90, cobalt-60, europium-155, uranium, plutonium and americium-241 were reported in samples. In rabbit, the caesium-137 concentration was 1.6 Bq kg^{-1} in 2012 (and just above the LoD, as in 2011). Activity concentrations in air samples at locations near to the site were below the LoD.

Additional monitoring for caesium-137 in grouse samples was carried out in 2012 to determine typical background concentration in the vicinity of the site. The maximum caesium-137 activity in grouse was 320 Bq kg^{-1} and more elevated than those enhanced concentrations measured

in other game in previous years (venison: 69 Bq kg^{-1} in 2009, and rabbit: 110 Bq kg^{-1} in 2008). The variation of caesium-137 concentrations in the terrestrial environment in the Dounreay area will have been affected by fallout from weapons testing in the 1960s and from the Chernobyl reactor accident in 1986.

Liquid waste discharges and aquatic monitoring

Low level liquid waste is routed via a Low Level Liquid Effluent Treatment Plant (LLLETP). The effluent is discharged to sea (Pentland Firth) via a pipeline terminating 600 metres offshore at a depth of about 24 metres. The discharges also include groundwater pumped from the Dounreay Shaft, surface water runoff, leachate from the low level solid waste disposal facility, and a minor contribution from the adjoining reactor site (Vulcan NRTE), which is operated by the Defence Procurement Agency.

Routine marine monitoring included sampling of seafood, around the Dounreay outfall in the North Atlantic, and other materials further afield from the outfall, as well as the measurement of beta and gamma dose rates. Seafood samples from within the zone covered by a FEPA* Order are collected under consent granted in 1997 by the Scottish Office.

Crabs, mussels and winkles from the outfall area were sampled. Additionally, seawater and seaweed were sampled as indicator materials. The results for marine samples and gamma dose rates are given in Tables 3.3(a) and (b). Activity concentrations were generally low in 2012 and similar to those in recent years. Gamma dose rates were generally lower in 2012 (in comparison to 2011), with decreased rates over the winkle bed at Sandside Bay and over sand at other locations. Technetium-99 concentrations in seaweed remained at the expected levels for this distance from Sellafield and were generally similar to those in 2011. Figure 3.2 also gives time trend information for technetium-99 concentrations (from Sellafield) in seaweed at Sandside Bay (location shown in Figure 3.3), Kinlochbervie and Burwick. They show an overall decline in concentrations over the period at all three locations. Beta dose measurements were less than the LoD (Table 3.3(b)).

During 2012, DSRL continued vehicle-based monitoring of local public beaches for radioactive fragments in compliance with the requirements of the authorisation granted by SEPA. In 2012, 13 fragments were recovered from Sandside Bay and 4 from the Dounreay foreshore. The caesium-137 activity measured in the fragments recovered from Sandside Bay ranged between 0.32 kBq and 380 kBq (similar to ranges observed in 2011).

* *The FEPA Order was made in 1997 following the discovery of fragments of irradiated nuclear fuel on the seabed near Dounreay, by UKAEA, and prohibits the harvesting of seafoods within a 2 km radius of the discharge pipeline.*

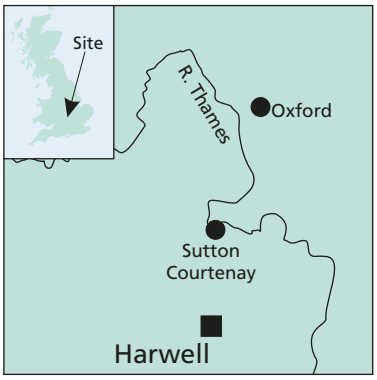
In February 2012, a particle was recovered from Sandside Bay which had a different composition compared to those previously detected at this location. Results from the analysis showed that the activity of the particle is dominated by strontium-90, with activity concentrations of approximately 0.7 MBq and 0.2 kBq for strontium-90 and caesium-137, respectively. Previously detected and recovered particles have had equal activity quantities of caesium-137 and strontium-90.

During 2012, operations were undertaken to recover fragments from the seabed using a remotely operated vehicle. The retrieval operations undertaken between May and August recovered 299 fragments from an area of 42 hectares of the offshore seabed. This compares with 352 fragments retrieved from an area of 23 hectares between May and July 2011.

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 (Dounreay Particles Advisory Group, 2008). Since the work of DPAG was concluded, the Particles Retrieval Advisory Group (Dounreay) (†PRAG (D)) has published reports in March 2010 and March 2011 and a further report planned for publication in 2013 (Particles Retrieval Advisory Group (Dounreay), 2010; 2011; *in press*).

In 2007, the Food Standards Agency reviewed the Dounreay FEPA Order. A risk assessment, that was peer-reviewed by PHE, indicated that the food chain risk was very small (Food Standards Agency, 2009). The FEPA Order was reviewed with regard to ongoing work to remove radioactive particles from the seabed and the food chain risk. In 2009, FSA in Scotland announced that the FEPA Order would remain in place, and be reviewed again when the seabed remediation work was complete.

3.3 Harwell, Oxfordshire



The site at Harwell was established in 1946 as Britain's first Atomic Energy Research Establishment. It accommodated five research reactors of various types. Decommissioning of redundant nuclear facilities is underway. The Harwell nuclear licensed site forms part of the Harwell Science and Innovation

† *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.*

Campus and is situated approximately 5 km southwest of the town of Didcot. Decommissioning of a building (occupied by GE Healthcare Limited) in one small area embedded within the licensed site was completed in 2011. GE Healthcare Limited surrendered their permit and nuclear site licence in April 2012. The most recent habits survey was conducted during 2007 (Garrod *et al*., 2008).

Doses to the public

In 2012, the *total dose* from all pathways and sources of radiation was 0.018 mSv (Table 3.1), which was less than 2 per cent of the dose limit. The dominant contribution to this dose was direct radiation from the site and the most exposed people were the prenatal children of local inhabitants. This dose was very similar to that in 2010 (0.017 mSv). The trend in *total dose* over the period 2004 – 2012 is given in Figure 1.1. The *total doses* remained broadly similar from year to year, and were very low.

Source specific assessments for high-rate consumers of terrestrial foods, and for anglers, give exposures that were less than the *total dose* (Table 3.1). The dose to anglers was 0.005 mSv in 2012 and the small decrease from 0.008 mSv (in 2011) was due to overall lower levels of gamma dose rates at Sutton Courtenay.

Gaseous discharges and terrestrial monitoring

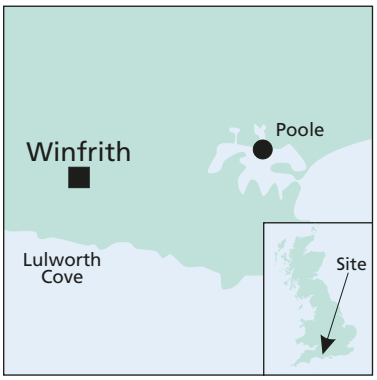
Gaseous wastes are discharged via stacks to the local environment. The monitoring programme sampled milk and other terrestrial foodstuffs. Sampling locations at Harwell and in other parts of the Thames catchment are shown in Figure 3.1. The results of the terrestrial programme are shown in Table 3.4(a). The results of tritium and caesium-137 analyses of terrestrial food samples were mostly below, or at, the LoD.

Liquid waste discharges and aquatic monitoring

Regulated discharges of radioactive wastes from Harwell continued in 2012 to the River Thames at Sutton Courtenay and to the Lydebank Brook north of the site. All permitted discharges to the River Thames and Lydebank Brook increased, in comparison to those in 2011, with the exception of tritium to the River Thames. Figure 3.4 shows trends of discharges over time (2000 – 2012) for cobalt-60 and caesium-137. There was an overall reduction in the discharges over the whole period, particularly for cobalt-60.

The aquatic monitoring programme is directed at consumers of freshwater fish and occupancy close to the liquid discharge point. Tritium and cobalt-60 concentrations in all aquatic samples, and caesium-137 concentrations in freshwater, were below the LoD. Caesium-137 concentrations in sediments continued to be enhanced above background levels (including those close to the outfall at Sutton Courtenay) in 2012, but were small in terms of any radiological effect. Concentrations of transuranic elements in sediments were either at or below the LoD. Overall, gamma dose rates were generally similar to those in recent years. A small decrease in the dose rates was measured at Sutton Courtenay in 2012 (in comparison to 2011). The concentrations of all radionuclides in flounder from the lower reaches of the Thames (from Beckton) were either very close to or below the LoD.

3.4 Winfrith, Dorset



The Winfrith site is located near Winfrith Newburgh. At various times there have been nine research and development reactors. The last operational reactor at Winfrith closed in 1995, since then, the focus for the site has been on decommissioning. The most recent habits survey undertaken for Winfrith was in 2003 (McTaggart *et al*., 2004b).

Doses to the public

In 2012, the *total dose* from all pathways and sources of radiation was less than 0.005 mSv (Table 3.1), or less than 0.5 per cent of the dose limit. Infants consuming milk at high-rates were the most exposed people and this represents a change from adults (spending time on local beaches) in 2011. Trends in *total doses* in the area of the south coast (and the Severn Estuary) over time are shown in Figure 6.2. At Winfrith, *total doses* remained broadly similar from year to year, and were very low.

Source specific assessments for high-rate consumers of locally grown food, and of fish and shellfish, give exposures that were also less than 0.005 mSv in 2012 (Table 3.1). Previous assessments have shown that other pathways are insignificant (Environment Agency, 2002a).

Gaseous discharges and terrestrial monitoring

Gaseous radioactive waste is discharged via various stacks to the local environment. Discharges of radioactive wastes from this site continued in 2012 at very low rates, although discharges of tritium increased from Winfrith (Inutec) in comparison to those in 2011. The main focus of the terrestrial sampling was for the content of tritium and carbon-14 in milk, crops and fruit. Local freshwater samples were also analysed. Sampling locations at Winfrith are shown in Figure 3.5. Data

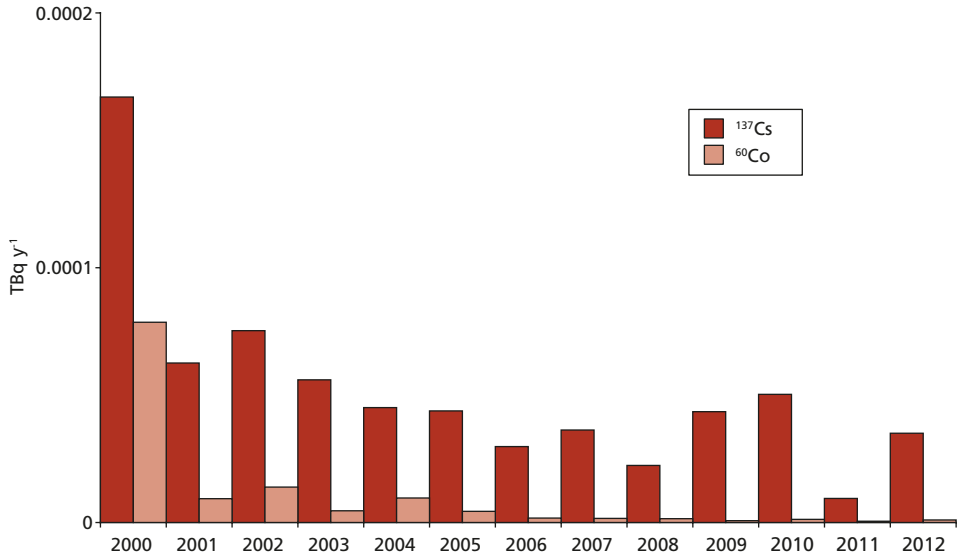


Figure 3.4. Trends in liquid discharges of caesium-137 and cobalt-60 from Harwell, Oxfordshire 2000-2012

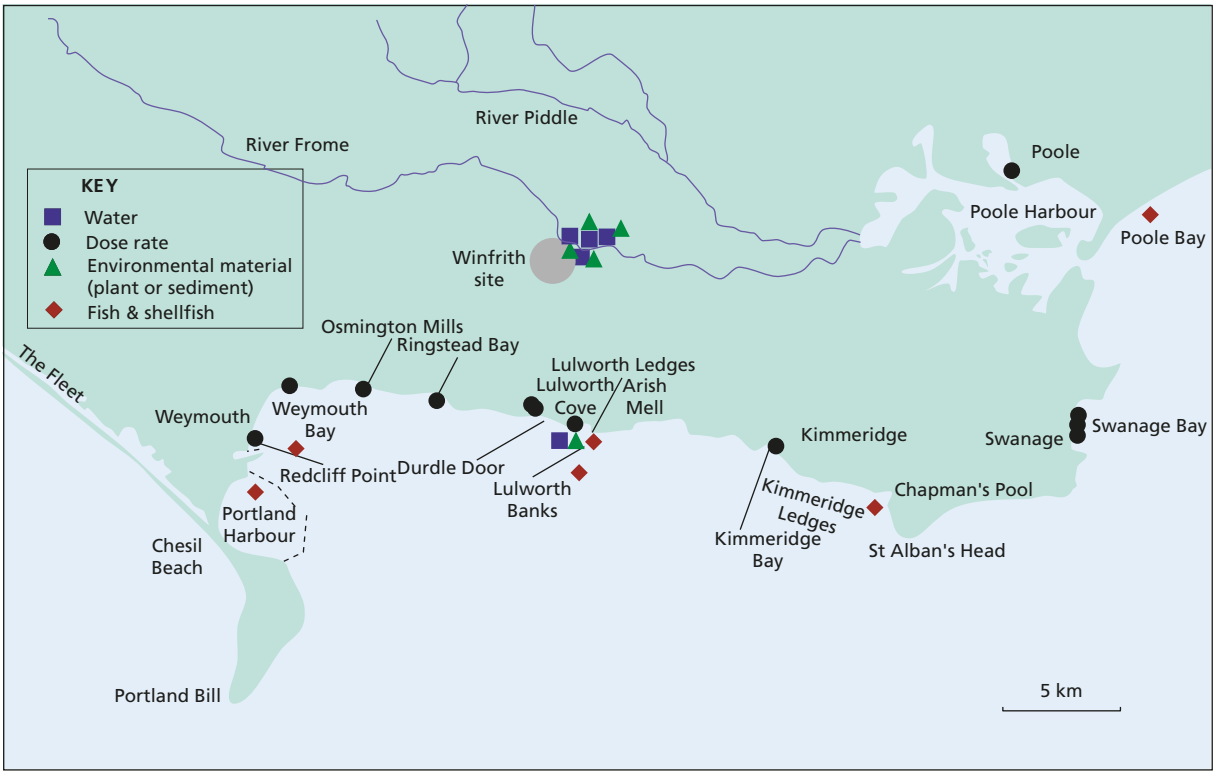


Figure 3.5. Monitoring locations at Winfrith, 2012 (not including farms)

for 2012 are given in Table 3.5(a). Results for terrestrial samples provide little indication of an effect due to gaseous discharges. Carbon-14 concentrations were detected in locally produced foods, above background concentrations, and these were generally higher in 2012 compared to those in 2011. The increase is most likely due to natural variation. Low concentrations of tritium were found in surface water to the north of the site, similar to previous years. In all cases the gross alpha and beta activities were below the WHO's screening levels for drinking water.

Liquid waste discharges and aquatic monitoring

Liquid wastes are disposed under permit to deep water in Weymouth Bay. Tritium discharges from Winfrith increased in comparison to those in most recent years. Figure 3.6 shows trends of liquid discharges over time (2000 – 2012) for tritium and alpha emitting radionuclides. Over the period, alpha radionuclide discharges have generally decreased since the peak in 2003, whilst tritium discharges have varied more

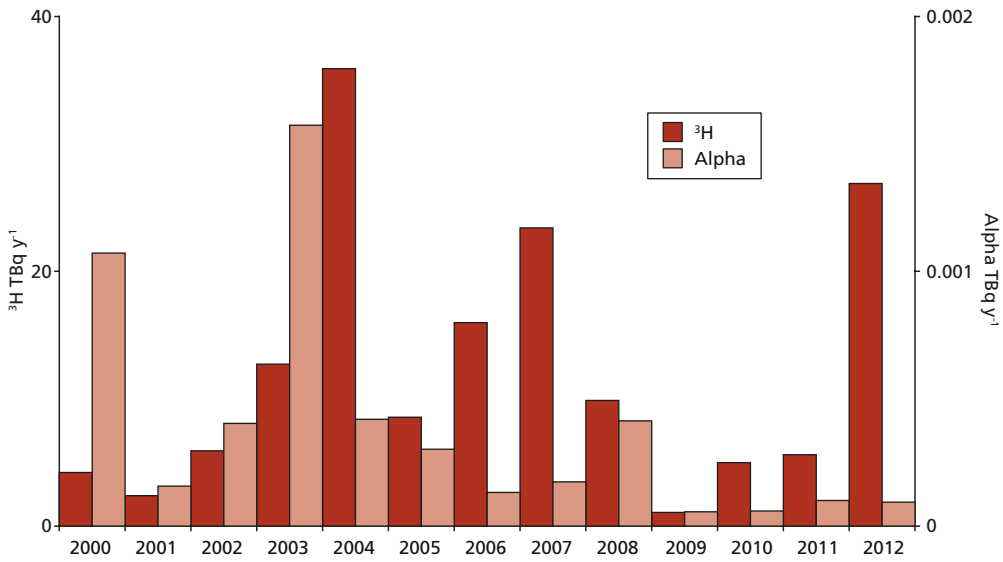


Figure 3.6. Trends in liquid discharges of tritium and alpha emitting radionuclides from Winfrith, Dorset 2000-2012

between years, with periodic peaks in releases (in 2004, 2007 and 2012).

Analyses of seafood and marine indicator materials and measurements of external radiation over muddy intertidal areas were conducted. Data for 2012 are given in Tables 3.5(a) and (b). Concentrations of radionuclides in the marine environment largely continued at the low levels found in recent years. Gamma dose rates were difficult to distinguish from natural background.

3.5 Imperial College Reactor Centre, Ascot, Berkshire

The licensed reactor at Imperial College is a minor site with very low radioactive discharges, and 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. Imperial College undertook a review of the future of the Reactor Centre at Silwood Park which concluded that the reactor should be closed and decommissioned for financial reasons. The reactor is now shut down and is being prepared for decommissioning.

In 2012, gaseous and aqueous discharges were very low (Appendix 2). Monitoring of the environmental effects involved the analysis of two grass samples by gamma-ray spectrometry. Activity concentrations in both samples were either close to or less than the limits of detection.

Table 3.1. Individual doses – research sites, 2012

Site	Exposed population[a]	Exposure, mSv per year						
		Total	Fish and Shellfish	Other local food	External radiation from intertidal areas, river banks or fishing gear	Intakes of sediment and water	Gaseous plume related pathways	Direct radiation from site
Culham								
Source specific dose	Drinkers of river water	<0.005	–	–	–	<0.005	–	–
Dounreay								
***Total dose* – all sources**	**Infant milk consumers**	**0.017**	**–**	**0.017**	**<0.005**	**–**	**–**	**–**
Source specific doses	Seafood consumers	0.006	<0.005	–	0.005	–	–	–
	Geo occupants[b]	<0.005	–	–	<0.005	–	–	–
	Infant consumers of locally grown food	0.027	–	0.027	–	–	<0.005	–
Harwell								
***Total dose* – all sources**	**Prenatal children of local inhabitants (0-0.25km)**	**0.018**	**–**	**<0.005**	**–**	**–**	**<0.005**	**0.018**
Source specific doses	Anglers	0.005	<0.005	–	0.005	–	–	–
	Infant consumers of locally grown food	<0.005	–	<0.005	–	–	<0.005	–
Winfrith								
***Total dose* – all sources**	**Infant milk consumers**	**<0.005**	**<0.005**	**<0.005**	**<0.005**	**–**	**<0.005**	**–**
Source specific doses	Seafood consumers	<0.005	<0.005	–	<0.005	–	–	–
	Infant consumers of locally grown food	<0.005	–	<0.005	–	–	<0.005	–

[a] *The* total dose *is the dose which accounts for all sources including gaseous and liquid discharges and direct radiation.*
The total dose *for the representative person with the highest dose is presented.*
Other dose values are presented for specific sources, either liquid discharges or gaseous discharges, 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.
Adults are the most exposed group unless otherwise stated

[b] *People who visit Oigin's Geo, a coastal feature to the east of Dounreay*

Table 3.2. Concentrations of radionuclides in the environment near Culham, 2012

Material	Location	No. of sampling observ-ations	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}						
			^{3}H	^{14}C	^{35}S	^{90}Sr	^{137}Cs	Gross alpha	Gross beta
Freshwater	River Thames (upstream)	2	<3.0				<0.21	<0.042	0.18
Freshwater	River Thames (downstream)	2	<3.2				<0.20	<0.058	0.18
Grass	1 km East of site perimeter	1	<11	<22	<2.4	<0.56	<0.79		200
Sediment	River Thames (upstream)	2					16		
Sediment	River Thames (downstream)	1					12		
Soil	1 km East of site perimeter	1	<3.0	<8.0	<20	<2.0	3.3		350

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

Table 3.3(a). Concentrations of radionuclides in food and the environment near Dounreay, 2012

Material	Location	No. of sampling observ-ations	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}						
			^{3}H	^{60}Co	^{65}Zn	^{90}Sr	^{99}Tc	^{137}Cs	^{154}Eu
Marine samples									
Cod	Scrabster	2		<0.10	<0.21			0.34	<0.13
Crabs	Pipeline inner zone	4		<0.10	<0.19	<0.10	2.0	<0.10	<0.10
Crabs	Pipeline outer zone	4		<0.10	<0.21	0.13	1.7	<0.10	<0.10
Crabs	Strathy	4		<0.10	<0.21			<0.10	<0.10
Crabs	Kinlochbervie	4		<0.10	<0.16		<0.099	<0.10	<0.10
Crabs	Melvich Bay	4		<0.10	<0.19		0.80	<0.10	<0.10
Winkles	Brims Ness	4		<0.11	<0.24	0.12		<0.10	<0.11
Winkles	Sandside Bay	4		<0.10	<0.21	<0.10	3.2	<0.10	<0.11
Mussels	Echnaloch Bay	4		<0.10	<0.19		5.1	<0.10	<0.10
Mussels	Thurso East Mains	4		<0.13	<0.24			<0.15	<0.10
Fucus vesiculosus	Kinlochbervie	4		<0.10	<0.17		19	<0.15	<0.10
Fucus vesiculosus	Brims Ness	4		<0.10	<0.15			<0.10	<0.10
Fucus vesiculosus	Sandside Bay	4		<0.10	<0.16		14	<0.10	<0.10
Fucus vesiculosus	Burwick Pier	4		<0.10	<0.16		17	<0.10	<0.10
Sediment	Oigin's Geo	2		<0.10	<0.42			2.3	<0.18
Sediment	Brims Ness	1		<0.10	<0.11			1.0	0.26
Sediment	Sandside Bay	1		<0.10	<0.11			2.3	0.22
Sediment	Rennibister	1		<0.10	<0.36			11	<0.17
Seawater	Brims Ness	4	<1.0	<0.10	<0.20			<0.10	<0.11
Seawater	Sandside Bay	4	<1.0	<0.10	<0.21			<0.10	<0.11
Spume	Oigin's Geo	3		<0.27	<0.85			11	<0.54

Material	Location	No. of sampling observ-ations	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}					
			^{155}Eu	^{238}Pu	^{239}Pu+ ^{240}Pu	^{241}Am	Gross alpha	Gross beta
Marine samples								
Cod	Scrabster	2	<0.19	0.00017	0.00062	0.00069		
Crabs	Pipeline inner zone	4	<0.13	0.0056	0.021	<0.10	<1.1	140
Crabs	Pipeline outer zone	4	<0.13	0.0015	0.011	<0.10	<0.98	140
Crabs	Strathy	4	<0.15	0.0057	0.030	0.16		
Crabs	Kinlochbervie	4	<0.14	0.00070	0.0036	<0.11		
Crabs	Melvich Bay	4	<0.13	0.00061	0.0040	0.0038		
Winkles	Brims Ness	4	<0.17	0.010	0.060	0.063		
Winkles	Sandside Bay	4	<0.16	0.012	0.057	0.059		
Mussels	Echnaloch Bay	4	<0.14	0.0092	0.056	0.027		
Mussels	Thurso East Mains	4	<0.14	0.011	0.068	0.057		
Fucus vesiculosus	Kinlochbervie	4	<0.15			<0.11		
Fucus vesiculosus	Brims Ness	4	<0.11			<0.13	<1.3	370
Fucus vesiculosus	Sandside Bay	4	<0.13			<0.12	<1.9	440
Fucus vesiculosus	Burwick Pier	4	<0.13			<0.12		
Sediment	Oigin's Geo	2	0.60	3.2	16	24		
Sediment	Brims Ness	1	<0.10	2.6	9.9	12		
Sediment	Sandside Bay	1	<0.12	2.5	10	11		
Sediment	Rennibister	1	0.64	<0.16	0.88	2.0		
Seawater	Brims Ness	4	<0.17			<0.11		
Seawater	Sandside Bay	4	<0.18			<0.11		
Spume	Oigin's Geo	3	<1.2	1.3	5.6	2.6		

Table 3.3(a). continued

Material	Location or selection[b]	No. of sampling observ-ations	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}								
			^{3}H	^{60}Co	^{90}Sr	^{106}Ru	^{129}I	^{134}Cs	^{137}Cs	^{144}Ce	^{155}Eu
Terrestrial samples											
Beef muscle		1	<5.0	<0.05	<0.10	<0.43	<0.05	<0.05	0.11	<0.30	
Beef offal		1	<5.0	<0.05	<0.10	<0.45	<0.05	<0.05	<0.05	<0.30	
Carrots		1	<5.0	<0.05	0.17	<0.31	<0.05	<0.05	<0.05	<0.17	
Goats' milk		1	<5.0	<0.05	<0.10	<0.30	<0.05	<0.05	0.06	<0.19	
Grouse[c]		3							290		
Grouse[c]	max								320		
Lamb muscle		1	<5.0	<0.05	<0.10	<0.35	<0.05	<0.05	0.05	<0.25	
Oats		1	<5.0	<0.05	0.37	<0.27	<0.05	<0.05	<0.05	<0.20	
Pheasants		1	<5.0	<0.05	0.17	<0.33		<0.05	0.26	<0.22	
Potatoes		1	<5.0	<0.05	<0.10	<0.39	<0.05	<0.05	0.05	<0.22	
Rabbit		1	<5.0	<0.07	<0.10	<0.70		<0.07	1.6	<0.49	
Rhubarb		1	<5.0	<0.05	0.12	<0.25	<0.05	<0.05	<0.05	<0.14	
Rosehips		2	<5.0	<0.06	1.2	<0.42	<0.05	<0.06	0.56	<0.26	
Rosehips	max				2.1	<0.53			1.0	<0.30	
Swede		1	<5.0	<0.05	0.33	<0.37	<0.05	<0.05	<0.05	<0.20	
Wild blackberries		1		<0.05	0.48	<0.45		<0.05	0.08	<0.30	
Wild mushrooms		1	<5.0	<0.05	0.17	<0.37	<0.07	<0.05	1.8	<0.24	
Grass		6	<5.0	<0.05	0.36	<0.25	<0.05	<0.05	<0.08	<0.18	
Grass	max				0.64	<0.33	<0.06		0.13	<0.22	
Soil		6	<5.0	<0.07	1.5	<0.61	<0.06	<0.08	15	<0.55	1.7
Soil	max			<0.10	2.7	<0.85	<0.08	<0.12	22	<0.79	1.9
Freshwater	Loch Calder	1	<1.0	<0.01		<0.08		<0.01	<0.01	<0.04	
Freshwater	Loch Shurrery	1	<1.0	<0.01		<0.06		<0.01	<0.01	<0.03	
Freshwater	Loch Baligill	1	<1.0	<0.01		<0.08		<0.01	<0.01	<0.04	
Freshwater	Heldale Water	1	<1.0	<0.01		<0.10		<0.01	<0.01	<0.05	

Material	Location or selection[b]	No. of sampling observ-ations	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}							
			^{234}U	^{235}U	^{238}U	^{238}Pu	^{239}Pu+ ^{240}Pu	^{241}Am	Gross alpha	Gross beta
Terrestrial samples										
Beef muscle		1	<0.050	<0.050	<0.050	<0.00080	<0.00080	0.0029		
Beef offal		1	<0.050	<0.050	<0.050	0.013	<0.0021	0.023		
Carrots		1				<0.050	<0.050	<0.050		
Goats' milk		1						<0.05		
Lamb muscle		1	0.063	<0.050	0.064	<0.050	<0.050	<0.050		
Oats		1				<0.050	<0.050	<0.050		
Pheasants		1						<0.08		
Potatoes		1				<0.050	<0.050	<0.050		
Rabbit		1						<0.10		
Rhubarb		1				<0.050	<0.050	<0.050		
Rosehips		2				<0.050	<0.050	<0.050		
Swede		1				<0.050	<0.050	<0.050		
Wild blackberries		1				<0.050	<0.050	<0.050		
Wild mushrooms		1				<0.050	<0.050	<0.050		
Grass		6	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050		
Soil		6	32	5.8	30	<0.050	0.35	0.22		
Soil	max		52	15	48		0.62	0.36		
Freshwater	Loch Calder	1						<0.01	0.011	0.050
Freshwater	Loch Shurrery	1						<0.01	<0.010	0.090
Freshwater	Loch Baligill	1						<0.01	0.012	0.070
Freshwater	Heldale Water	1						<0.01	<0.010	<0.044

[a] *Except for seawater and freshwater where units are Bq l^{-1}, and for soil and sediment where dry concentrations apply*
[b] *Data are arithmetic means unless stated as 'Max' in this column. 'Max' data are selected to be maxima. If no 'max' value is given the mean value is the most appropriate for dose assessments*
[c] *Ad hoc monitoring to determine typical background caesium-137 in the vicinity of the site*

Table 3.3(b). Monitoring of radiation dose rates near Dounreay, 2012

Location	Material or ground type	No. of sampling observ-ations	μGy h^{-1}
Mean gamma dose rates at 1m over substrate			
Sandside Bay	Sand	2	0.059
Sandside Bay	Winkle bed	2	0.090
Oigin's Geo	Spume/sludge	4	0.15
Brims Ness	Shingle and stones	2	0.077
Melvich	Salt Marsh	2	0.088
Melvich	Sand	2	0.058
Strathy	Sand	2	0.050
Thurso	Riverbank	2	0.081
Achreregan Hill	Soil	2	<0.047
Thurso Park	Soil	2	0.079
Borrowston Mains	Soil	2	0.084
East of Dounreay	Soil	2	0.074
Castletown Harbour	Sand	2	0.072
Dunnet	Sand	2	0.052
Mean beta dose rates			μSv h^{-1}
Sandside Bay	Sediment	4	<1.0
Oigin's Geo	Surface sediment	4	<1.0
Thurso	Riverbank	2	<1.0
Castletown Harbour	Surface sediment	2	<1.0

Table 3.3(c). Radioactivity in air near Dounreay, 2012

Location	No. of sampling observa-tions	Mean radioactivity concentration, mBq m^{-3}		
		^{137}Cs	Gross alpha	Gross beta
Shebster	10	<0.010	<0.0070	<0.20
Reay	12	<0.010	<0.010	<0.20
Balmore	12	<0.010	<0.0098	<0.20

Table 3.4(a). Concentrations of radionuclides in food and the environment near Harwell, 2012

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
Freshwater samples							
Flounder	Woolwich Reach	1	<25	<0.04	<0.10	0.08	
Sediment	Appleford	4[E]		<0.66		7.3	<0.45
Sediment	Outfall (Sutton Courtenay)	3[E]		<0.36		4.1	<0.46
Sediment	Day's Lock	3[E]		<0.57		6.6	<0.60
Sediment	Lydebank Brook	4[E]		<0.83		3.8	<0.58
Freshwater	Day's Lock	4[E]	<3.7	<0.25		<0.20	
Freshwater	Lydebank Brook	4[E]	<3.7	<0.27		<0.23	
Freshwater	R Thames (above discharge point)	4[E]	<3.3	<0.30		<0.24	
Freshwater	R Thames (below discharge point)	4[E]	<3.0	<0.26		<0.23	

Material	Location	No. of sampling observ-ations	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}			
			^{239}Pu + ^{240}Pu	^{241}Am	Gross alpha	Gross beta
Freshwater samples						
Flounder	Woolwich Reach	1		<0.05		
Sediment	Appleford	4[E]	<0.35	<0.49	<160	310
Sediment	Outfall (Sutton Courtenay)	3[E]	0.38	<0.99	<140	280
Sediment	Day's Lock	3[E]	<0.37	<0.65	<130	240
Sediment	Lydebank Brook	4[E]	<0.43	<0.96	<130	350
Freshwater	Day's Lock	4[E]			<0.044	0.21
Freshwater	Lydebank Brook	4[E]			<0.054	0.22
Freshwater	R Thames (above discharge point)	4[E]			<0.061	0.21
Freshwater	R Thames (below discharge point)	4[E]			<0.039	0.24

Material	Location or selection[b]	No. of sampling observ-ations[c]	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}		
			Organic ^{3}H	^{3}H	^{137}Cs
Terrestrial samples					
Milk		3	<4.2	<4.2	<0.20
Milk	max		<4.3	<4.3	
Apples		1	<6.0	6.0	<0.20
Blackberries		1	<4.0	<4.0	<0.20
Broad beans		1	<4.0	<4.0	<0.20
Honey		1		<7.0	<0.20
Potatoes		1	<9.0	9.0	<0.20
Strawberries		1	<8.0	8.0	<0.20

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

Table 3.4(b). Monitoring of radiation dose rates near Harwell, 2012

Location	Ground type	No. of sampling observations	µGy h^{-1}
Mean gamma dose rates at 1m over substrate			
Appleford	Sand and mud	1	0.068
Appleford	Sand	1	0.067
Sutton Courtenay	Mud	1	0.077
Sutton Courtenay	Grass	1	0.080
Day's Lock	Marsh	1	0.067
Day's Lock	Grass	1	0.059

Table 3.5(a). Concentrations of radionuclides in food and the environment near Winfrith, 2012

Material	Location	No. of sampling observ-ations	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}				
			^{14}C	^{60}Co	^{99}Tc	^{137}Cs	^{238}Pu
Marine samples							
Plaice	Weymouth Bay	2		<0.05		<0.05	
Bass	Weymouth Bay	2		<0.07		0.20	
Crabs	Chapman's Pool	1		<0.06		<0.05	0.000061
Crabs	Lulworth Banks	1	23	<0.05		0.06	0.000077
Pacific Oysters	Poole	1		<0.05		<0.05	
Cockles	Poole	1		0.09		<0.05	
Whelks	Poole Bay	1		<0.04		<0.03	0.00015
Whelks	Lyme Regis	1		<0.10		<0.08	0.00010
Scallops	Lulworth Ledges	1		<0.08		<0.07	0.00049
Scallops	Portland Harbour	1		<0.06		<0.06	
Seaweed	Lulworth Cove	1[E]		<0.72	<1.5	<0.49	
Seaweed	Bognor Rock	2[E]		<0.44	4.2	<0.33	
Seawater	Lulworth Cove	1[E]		<0.25		<0.21	

Material	Location	No. of sampling observ-ations	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}					
			^{239}Pu + ^{240}Pu	^{241}Am	^{242}Cm	^{243}Cm + ^{244}Cm	Gross alpha	Gross beta
Marine samples								
Plaice	Weymouth Bay	2		<0.11				
Bass	Weymouth Bay	2		<0.14				
Crabs	Chapman's Pool	1	0.00026	0.00061	0.000021	0.000016		
Crabs	Lulworth Banks	1	0.00050	0.00081	*	*		
Pacific Oysters	Poole	1		<0.16				
Cockles	Poole	1		<0.06				
Whelks	Poole Bay	1	0.00097	0.00093	*	*		
Whelks	Lyme Regis	1	0.00095	0.00053	*	*		
Scallops	Lulworth Ledges	1	0.0035	0.0011	*	0.000015		
Scallops	Portland Harbour	1		<0.18				
Seaweed	Lulworth Cove	1[E]		<0.70				
Seaweed	Bognor Rock	2[E]		<0.44				
Seawater	Lulworth Cove	1[E]		<0.29			<4.6	20

Material	Location or selection[b]	No. of sampling observ-ations[c]	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}						
			Organic ^{3}H	^{3}H	^{14}C	^{60}Co	^{137}Cs	Gross alpha	Gross beta
Terrestrial samples									
Milk		4	<4.7	<4.7	21	<0.18	<0.20		
Milk	max		<5.8	<5.8	24	<0.20			
Apples		1	<4.0	<4.0	19	<0.10	<0.20		
Blackberries		1	<4.0	<4.0	22	<0.20	<0.30		
Broad beans		1	<4.0	<4.0	19	<0.20	<0.20		
Cabbage		1	<4.0	<4.0	11	<0.20	<0.20		
Carrots		1	<4.0	<4.0	12	<0.20	<0.30		
Honey		1		<7.0	75	<0.20	0.20		
Grass		2	<5.0	<5.0	21	<0.15	<0.40		
Grass	max					<0.20	0.60		
Sediment	North of site (Stream A)	1[E]				<0.18	4.3	130	110
Sediment	R Frome (upstream)	1[E]				<0.16	<0.14	<83	100
Sediment	R Frome (downstream)	1[E]				<1.6	13	200	300
Sediment	R Win, East of site	1[E]				<0.19	<0.18	<100	<81
Freshwater	North of site (Stream A)	2[E]		12		<0.29	<0.24	<0.056	0.15
Freshwater	R Frome (upstream)	2[E]		<3.1		<0.24	<0.20	<0.037	<0.11
Freshwater	R Frome (downstream)	2[E]		<3.2		<0.23	<0.20	<0.037	<0.10
Freshwater	R Win, East of site	2[E]		<3.6		<0.23	<0.20	<0.083	0.19

* *Not detected by the method used*

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

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

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

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

Table 3.5(b). Monitoring of radiation dose rates near Winfrith, 2012

Location	Ground type	No. of sampling observ-ations	μGy h^{-1}
Mean gamma dose rates at 1m over substrate			
Weymouth Bay	Sand and shingle	1	0.054
Red Cliffe Point to Black Head	Shingle	1	0.053
Osmington Mills	Pebbles and rock	1	0.064
Ringstead Bay	Sand and shingle	1	0.056
Durdle Door	Shingle	1	0.057
St Oswald's Head	Sand and shingle	1	0.056
Lulworth Cove	Sand	1	0.060
Kimmeridge Bay	Pebbles and rock	1	0.091
Swanage Bay 1	Sand	1	0.056
Swanage Bay 2	Sand	1	0.056
Swanage Bay 3	Sand	1	0.060
Poole Harbour	Sand	1	0.053

4. Nuclear power stations

Key points

- Public radiation doses from all sources were less than 4 per cent of the dose limit for all sites assessed
- Electricity production continued at two Magnox stations (Oldbury and Wylfa) and all the EDF power stations in 2012
- Discharges, environmental concentrations and dose rates in 2012 were broadly similar to those in 2011
- Concentrations of radiocaesium and transuranic elements were enhanced around some sites. These were mainly due to discharges from Sellafield

Berkeley, Gloucestershire and Oldbury, South Gloucestershire

- Public radiation doses from all sources increased in 2012
- Oldbury ceased to be an electricity generator during 2012
- Gaseous and liquid discharges decreased from Oldbury due to the closure of Reactor 1

Bradwell, Essex

- Public radiation doses from all sources decreased in 2012

Chapelcross, Dumfries and Galloway

- Public radiation doses from all sources decreased in 2012
- As in recent years, tritium was detected in surface water around the site in 2012

Dungeness, Kent

- Public radiation doses from all sources decreased in 2012
- There were increases in public radiation doses from liquid discharges due to higher gamma dose rates in intertidal areas in 2012
- Gaseous tritium and argon-41 discharges, and liquid tritium discharges, increased from Dungeness B

Hartlepool, County Durham

- Public radiation doses from all sources decreased in 2012
- Gaseous discharges of sulphur-35 increased in 2012
- Environmental concentrations due to natural radionuclides were enhanced due to factors other than power station operation

Heysham, Lancashire

- Gaseous discharges of argon-41 and carbon-14 decreased from Heysham 2. Liquid discharges of tritium decreased from Heysham 1 and increased from Heysham 2

Hinkley Point, Somerset

- Public radiation doses from all sources decreased in 2012
- Hinkley Point B operating life to be extended until at least 2023 (from 2016)
- A permit was granted relating to discharges of waste water generated from site preparation and construction activities at the Hinkley Point C site in 2012
- Liquid discharges of tritium and other radionuclides increased from Hinkley A

Hunterston, North Ayrshire

- Public radiation doses from all sources decreased in 2012
- At Hunterston B the authorisation was varied to revise the list of authorised gaseous discharge outlets
- Gaseous discharges of sulphur-35 and particulate beta decreased from Hunterston B, and liquid discharges of beta radionuclides increased from Hunterston A, in 2012

Sizewell, Suffolk

- Liquid discharges of caesium-137 decreased from both Sizewell A and Sizewell B

Torness, East Lothian

- A variation to the site's discharge authorisation was granted to allow the disposal of gaseous waste through additional routes
- Gaseous discharges of tritium decreased and sulphur-35 increased, liquid discharges of sulphur-35 increased in 2012

Trawsfynydd, Gwynedd

- Public radiation doses from all sources increased in 2012
- There were small decreases in public radiation doses from liquid discharges
- A revised permit was issued, with lower limits for gaseous and liquid discharges (in late 2011)
- Gaseous discharges of tritium and carbon-14 decreased and liquid discharges of caesium-137 and other radionuclides increased in 2012

Wylfa, Isle of Anglesey

- Public radiation doses from all sources decreased in 2012
- Power generation is to continue beyond 2012
- Gaseous discharges, and liquid discharges of tritium, decreased in 2012

This section considers the results of monitoring by the Environment Agency, Food Standards Agency and SEPA from nuclear power stations. There is a total of 19 nuclear power stations at 14 locations, nine in England (Berkeley, Oldbury, Bradwell, Calder Hall, Dungeness, Hartlepool, Heysham, Hinkley Point and Sizewell), three in Scotland (Chapelcross, Hunterston and Torness) and two in Wales (Trawsfynydd and Wylfa). Some of these stations are being decommissioned.

Eleven of the 19 nuclear power stations are older Magnox power stations, owned by the NDA. The NDA (set up under the Energy Act 2004) is a non-departmental public body, with a remit to secure the decommissioning and clean-up of the UK's civil public sector nuclear licensed sites. In 2012, the NDA published their strategy for long-term development, and in March 2013 a business plan for 2013/16 was published (Nuclear Decommissioning Authority, 2012; 2013).

In 2010, Magnox power stations were managed by two Site Licence Companies: Magnox North Limited and Magnox South Limited; the former being the operator for Chapelcross, Hunterston A, Oldbury, Trawsfynydd and Wylfa; the latter being the operator for Berkeley, Bradwell, Dungeness A, Hinkley Point A and Sizewell A. In 2010, Magnox North Limited applied to transfer the EPR 10 permits from Magnox South Limited sites in order to facilitate restructuring of the management of the ten Magnox sites under one Site Licence Company. At the same time (under the Nuclear Installations Act 1965) it applied to transfer the nuclear site licences for the five Magnox South sites. Magnox North and Magnox South were recombined into one entity as Magnox Limited in 2011. In 2012, the NDA announced its competition for the Parent Body Organisation contracts for Magnox Limited. More information can be found at: https://www.nda.gov.uk/news/energysolutions-eu.cfm

Magnox Limited is owned and operated by Energy Solutions on behalf of the NDA. During 2012, only two of these Magnox stations (Oldbury and Wylfa) continued to generate electricity, others are in the process of de-fuelling or decommissioning. In July 2012, Energy Solutions Inc (the US business) has advised the NDA of its intention to sell its European business, Energy Solutions EU Limited. The UK limited company has a contract to be the Parent Body Organisation for the Magnox Site Licence Company until mid 2014. More information can be found at: https://www.nda.gov.uk/contracts/competition/magnox-rsrl.cfm

In 2012, Magnox Limited requested permission from the Office of Nuclear Regulation (ONR) to make changes to decommissioning programmes, incorporating a single Magnox Optimised Decommissioning Programme (MODP), by which Magnox Limited seeks to integrate delivery of hazard reduction and decommissioning across sites (Berkeley, Bradwell, Chapelcross, Dungeness A, Hinkley Point A, Oldbury, Sizewell A, Trawsfynydd and Wylfa). The changes requested included proposals for changes to milestones and variations in management strategies for solid and wet Intermediate Level Waste. A key aim is to deliver the Bradwell and Trawsfynydd sites into states of Care and Maintenance earlier (by 2015 and 2016, respectively) than previously planned.

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 Advanced Gas-cooled Reactor (AGR) power stations and one Pressurised Water Reactor (PWR) power station were owned and operated by EDF Energy Nuclear Generation Limited in 2012. The parent company British Energy Group plc (of the former owner British Energy Generation Limited) was acquired by Électricité de France (EDF) Energy in early 2009 and continued as a wholly owned subsidiary of EDF until June 2011. By July 2011, the renaming of the operating company from British Energy Generation Limited to EDF Energy Nuclear Generation Limited was concluded. EDF Energy Nuclear Generation Limited owns and operates Dungeness B, Hartlepool, Heysham 1 and 2, Hinkley Point B and Sizewell B Power Stations in England, and Hunterston B and Torness Power Stations in Scotland. All of these were generating electricity during 2012.

Gaseous and liquid discharges from each of the power stations are regulated by the Environment Agency in England and Wales, and by SEPA in Scotland. In 2012, gaseous and liquid discharges were below regulated limits for each of the power stations (see Appendix 2). Independent monitoring of the environment around each of the power stations is conducted by the Food Standards Agency and the Environment Agency in England and Wales, and by SEPA in Scotland.

The medium-term trends in dose, discharges and environmental concentrations at these sites were considered in a summary report (Environment Agency, Food Standards Agency, Northern Ireland Environment Agency and Scottish Environment Protection Agency, 2010b).

The sites are grouped in this Section according to whether they are in England, Scotland or Wales.

ENGLAND

4.1 Berkeley, Gloucestershire and Oldbury, South Gloucestershire

Berkeley and Oldbury are both Magnox power stations. Berkeley Power Station is situated on the eastern bank of the River Severn and was powered by two Magnox reactors. Berkeley was the first commercial power station in the UK to enter into decommissioning. It ceased electricity generation in 1989 and de-fuelling was completed in 1992. Decommissioning is still in progress and radioactive wastes are still generated by these operations.

The Oldbury Power Station is located on the south bank of the River Severn close to the village of Oldbury-on-Severn and has two Magnox reactors. Oldbury Power Station ceased to be an electricity generator on 29 February 2012, with the closure of Reactor 1. Reactor 2 was previously shut-down in June 2011. A post operation and de-fuelling safety case was submitted to ONR in March 2012.

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 undertaken for the Berkeley and Oldbury sites was in 2007 (Clyne *et al*., 2008b).

Doses to the public

The *total dose* from all pathways and sources of radiation is assessed to have been 0.014 mSv in 2012 (Table 4.1), which was less than 2 per cent of the dose limit, and up from 0.006 mSv in 2011. The higher value in 2012 was due to an increase in the dominant contributor, from external exposure over intertidal areas, mostly because gamma dose rates were measured on different types of substrate (near the Oldbury site) from one year to the next. Adults were identified as the most exposed age group, a change from that in 2011 (prenatal children). The trend in the *total dose* over the period 2004 – 2012 is given in Figure 4.1. Any longer-term variations in *total doses* with time are attributable to changes in the contribution from direct radiation from the site.

The source specific assessment for high-rate consumers of locally grown foods gives exposures less than the *total dose* in 2012. The dose to consumers of fish and shellfish was estimated to be 0.018 mSv, which was less than 2 per cent of the dose limit for members of the public of 1 mSv (Table 4.1). This includes external radiation, a component due to the tritium historically originating from GE Healthcare Limited at Cardiff, and a component of the dose resulting from an increased tritium dose coefficient (see Appendix 1). The dose in 2011 was 0.008 mSv, and the reason for the increase in 2012 was the same as that contributing to the maximum *total dose*.

Gaseous discharges and terrestrial monitoring

The Berkeley and Oldbury sites discharge gaseous radioactive wastes via separate stacks to the atmosphere. Discharges from Oldbury were generally lower in comparison to those in 2011, due to the closure of Reactor 1 in 2012. The main focus of the terrestrial sampling was for the content of tritium, carbon-14 and sulphur-35 in milk, crops and fruit. Local freshwater samples were also analysed. Data for 2012 are given in Table 4.2(a). As in previous years, sulphur-35 was detected at very low levels in some of the terrestrial food samples. Carbon-14 was detected in locally produced foods, at concentrations just above background values, although this may be due to natural variation. Gross alpha and beta activities in surface waters were less than the WHO screening levels for drinking water.

Liquid waste discharges and aquatic monitoring

Liquid radioactive wastes are discharged to the Severn Estuary. Discharges from Oldbury decreased in comparison to those in 2011, due to the closure of Reactor 1 in 2012. Analyses of seafood and marine indicator materials and measurements of external radiation over muddy intertidal areas were conducted. Measurements of tritium in seafood were made in order to monitor the additional local effects of historical discharges from the GE Healthcare Limited radiopharmaceutical plant in Cardiff (see Section 6). Data for 2012 are given in Tables 4.2(a) and (b). Where comparisons can be drawn concentrations in the aquatic environment were generally similar to those in recent years. Most of the artificial radioactivity detected was due to caesium-137. Concentrations of radiocaesium represent the combined effect of discharges from the sites, other nuclear establishments discharging into the Bristol Channel and weapons testing, and possibly a small Sellafield-derived component. Caesium-137 concentrations in sediment have been generally consistent over the last 5 years (Figure 4.2). In 2012, tritium concentrations in fish were measured below the LoD and detected in lower concentrations in shrimps compared to those in 2010 (not sampled in 2011). In previous years, these activities have been relatively high and were likely to be mainly due to historical discharges from GE Healthcare Limited, Cardiff. Very small concentrations of other radionuclides were detected but, taken together, were of low radiological significance.

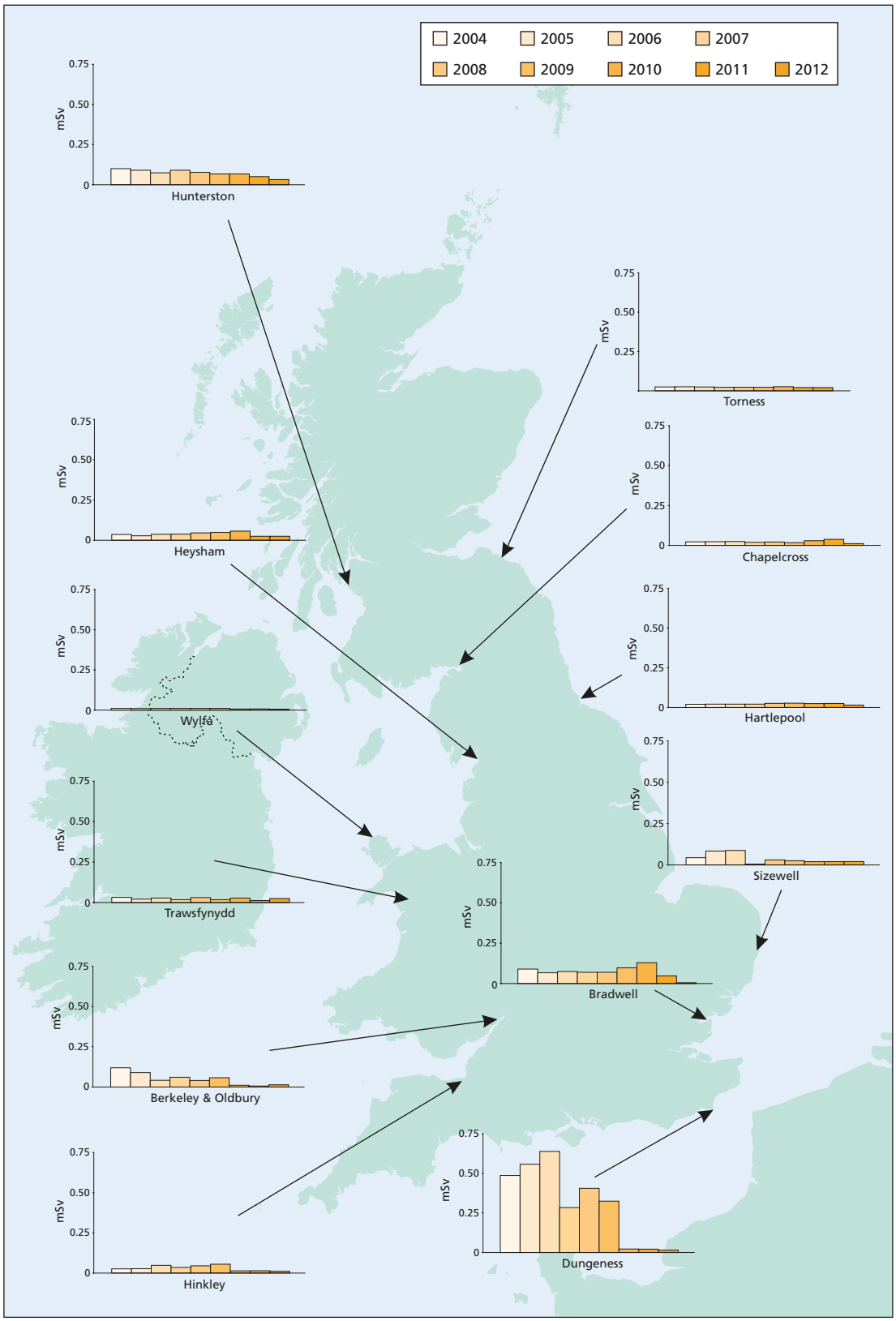


Figure 4.1. *Total dose* at nuclear power stations, 2004-2012
(Small doses less than or equal to 0.005 mSv are recorded as being 0.005 mSv)

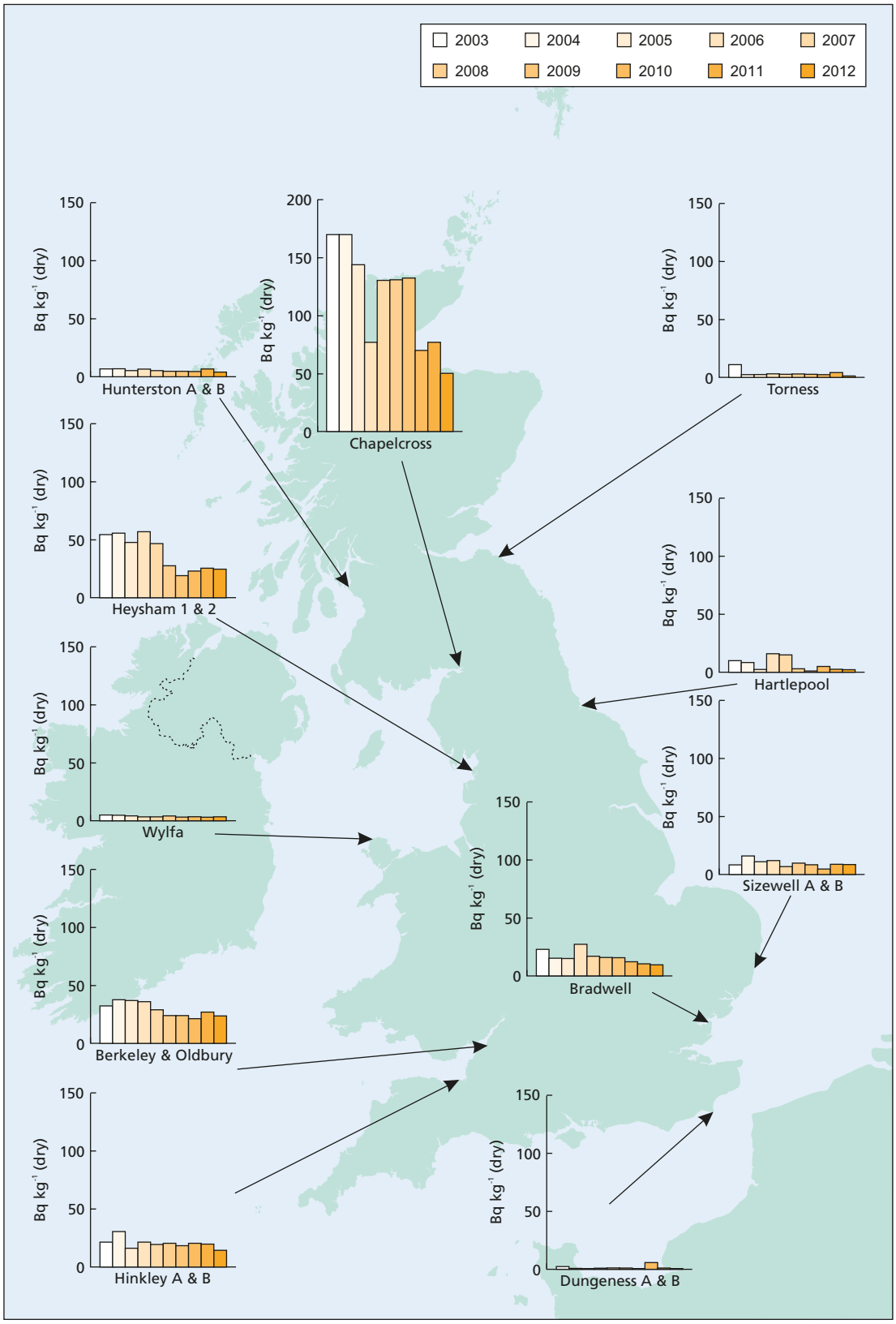
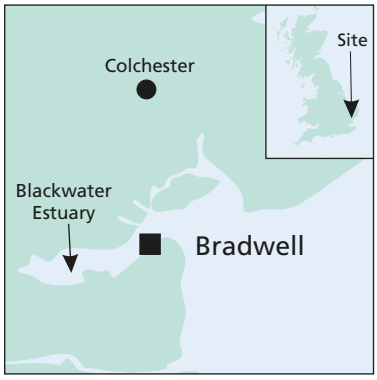


Figure 4.2. Caesium-137 concentration in marine sediments near nuclear power stations between 2003-2012

4.2 Bradwell, Essex



The Bradwell site is located on the south side of the Blackwater Estuary. This Magnox power station ceased electricity production in 2002 after 40 years of operation, and de-fuelling was completed in 2006. The focus for the site is now the completion of decommissioning projects. The aim is to deliver the Bradwell site into a state of Care and Maintenance by 2015, earlier than previously planned. The most recent habits survey was undertaken in 2007 (Tipple *et al.*, 2008).

Doses to the public

The *total dose* from all pathways and sources of radiation was less than 0.005 mSv in 2012 (Table 4.1), which was less than 0.5 per cent of the dose limit for members of the public of 1 mSv, and a decrease from 0.048 mSv in 2011. The lower value in 2012 was due to a decrease in the estimate of direct radiation from the site. The dose assessment identifies prenatal children of local inhabitants as the most exposed age group. The majority of the dose was received from the consumption of vegetables (in contrast to direct radiation in 2011). The trend in *total dose* over the period 2004 – 2012 is given in Figure 4.1. Any variations in *total dose* with time were attributed to changes in the estimate of direct radiation.

Source specific assessments for both high-rate consumers of locally grown foods and of fish and shellfish give exposures that were less than the *total dose* in 2012 (Table 4.1).

Gaseous discharges and terrestrial monitoring

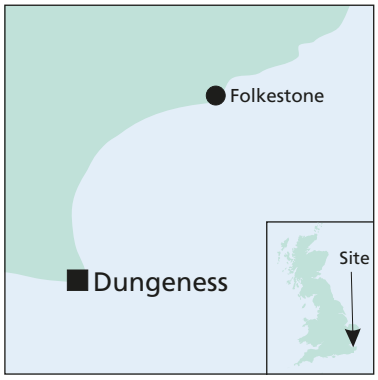
This power station is permitted to discharge gaseous wastes to the local environment via stacks to the atmosphere. In October 2012, the environmental permit was varied by the Environment Agency. The variation increased the allowance for tritium and carbon-14 contained in the gaseous discharges to atmosphere. The increase is needed so that Bradwell can carry out treatment of its Fuel Element Debris (FED), as part of preparations for the site's entry to Care and Maintenance. Under Article 37 of the Euratom Treaty, before making this change to the permit, the UK Government was required to make a submission of general data to the European Commission, detailing the potential impact to other Member States. The UK Government submission was made in March 2012 and the European Commission provided its opinion in June 2012. The Environment Agency then issued the permit in October 2012. Magnox expect to start the FED treatment programme in 2013 and for it to last up to eighteen months.

Terrestrial sampling is similar to that for other power stations including analyses of milk, fruit and crop samples for tritium, carbon-14 and sulphur-35. Samples of water are also taken from a coastal ditch and public supplies. Data for 2012 are given in Table 4.3(a). Activity concentrations were low in terrestrial food samples, though some enhancements of carbon-14 concentrations in some terrestrial samples (excluding milk) were apparent. The gross alpha and beta activities in freshwater (public supplies) were less than the WHO screening levels for drinking water. The gross beta activities in water from the coastal ditch continued to be enhanced above background levels, and these were in excess of the WHO screening level for drinking water (1 Bq l^{-1}). Tritium concentrations in coastal ditches were similar to those in 2011, and were substantially below the EU reference level for tritium of 100 Bq l^{-1}. The water in the ditches is not known to be used as a source of drinking water.

Liquid waste discharges and aquatic monitoring

Liquid wastes are discharged into the River Blackwater estuary. Aquatic sampling was directed at consumption of locally caught fish and shellfish and external exposure over intertidal sediments. Monitoring included the commercial oyster fishery of importance in the northern part of the estuary. Seaweeds were analysed as an environmental indicator material and leaf beet was collected because it is eaten locally and grows in areas that become tidally inundated. Data for 2012 are given in Tables 4.3(a) and (b). Low concentrations of artificial radionuclides were detected in aquatic materials as a result of discharges from the station, discharges from Sellafield and weapons testing. Due to the low concentrations detected, it is generally difficult to attribute the results to a particular source; however concentrations were generally similar to those for 2011. There is an overall decline in caesium-137 concentrations in sediments (Figure 4.2). The technetium-99 detected in seaweeds at Bradwell was likely to be due to the long distance transfer of Sellafield derived activity. Gamma dose rates on beaches were difficult to distinguish from natural background.

4.3 Dungeness, Kent



The Dungeness power stations are located on the south Kent coast between Folkestone and Rye. There are two separate A and B nuclear power stations on neighbouring sites; the A station was powered by two Magnox reactors and the B station has two AGRs. Discharges are made via separate and adjacent outfalls and stacks, but for the purposes of environmental monitoring these are considered together. Dungeness A ceased generating electricity in 2006. De-fuelling of both Magnox reactors was completed in 2012, with the spent fuel being dispatched to Sellafield (Cumbria) for reprocessing. It is estimated that Dungeness B will end power generation by 2018. The most recent habits survey was undertaken in 2010 (Clyne *et al*., 2011c).

Doses to the public

In 2012, the *total dose* from all pathways and sources of radiation was 0.015 mSv (Table 4.1), or less than 2 per cent of the dose limit of 1 mSv, and down from 0.021 mSv in 2011. As in recent years, this is almost entirely due to direct radiation from the site. Adults living near to the site were the most exposed people. The trend in *total dose* over the period 2004 – 2012 is given in Figure 4.1. *Total doses* ranged between 0.015 and 0.63 mSv over the time period and were dominated by direct radiation. Following the shut-down of the Magnox reactors in 2006, this dose has significantly declined.

Source specific assessments for high-rate consumers of locally grown foodstuffs, and for local bait diggers, give exposures that were less than the *total dose*. The dose to local bait diggers (who consume large quantities of fish and shellfish and spend long periods of time in the location being assessed) was 0.012 mSv, which was approximately 1 per cent of the annual dose limit for members of the public of 1 mSv (Table 4.1). The increase in dose (from 0.007 mSv in 2011) was due to an increase in gamma dose rate measurements taken at Dungeness East in 2012. With no gamma dose rates being measured at Rye Harbour since 2009, the estimated dose to houseboat occupants was 0.019 mSv, and the increase in dose (from 0.012 mSv in 2011) was due to higher gamma dose rate measurements (taken at Rye Bay) in 2012.

Gaseous discharges and terrestrial monitoring

Discharges of tritium and argon-41 increased from Dungeness B, in comparison to releases in 2011, due to an increase in power generation in 2012. Analyses of tritium, carbon-14 and sulphur-35 were made in terrestrial samples, including milk, crops and fruit. The results of monitoring for 2012 are given in Tables 4.4(a). Activity concentrations in many terrestrial foods were below or close to the LoD. Small enhancements of carbon-14 concentrations, above expected background, were observed in some foodstuffs (sea kale, blackberries and wheat) in 2012. Low concentrations of sulphur-35 were detected in some samples. Gross alpha and beta activities in freshwater were less than the WHO screening levels for drinking water.

Liquid waste discharges and aquatic monitoring

Discharges of tritium increased from Dungeness B, in comparison to releases in 2011, due to an increase in power generation in 2012. Marine monitoring included gamma dose rate measurements and analysis of seafood and sediments. The results of monitoring for 2012 are given in Tables 4.4(a) and (b). Caesium-137 concentrations in marine materials are attributable to discharges from the stations and to weapon test fallout with a long distance contribution from Sellafield and La Hague. Due to the low concentrations detected, it is generally difficult to attribute the results to a particular source. The low concentrations of transuranic nuclides in scallops and sediment were typical of levels expected at sites remote from Sellafield. No tritium was detected in seafood in 2012. Caesium-137 concentrations in sediment have remained low over the last decade (Figure 4.2); the apparent increase in 2010 was due to the inclusion of a value (<5.8 Bq kg^{-1}) which was reported as below the LoD. Gamma dose rates were generally difficult to distinguish from the natural background, but there were overall increases in rate measurements at Dungeness East and Rye Bay in 2012.

4.4 Hartlepool, County Durham

Hartlepool Power Station is situated on the mouth of the Tees estuary, on the north east coast of England, and is powered by twin AGRs. It is estimated that its power generation will continue until at least 2019. The most recent habits survey was conducted in 2008 (Garrod *et al*., 2009).

Doses to the public

The *total dose* from all pathways and sources of radiation was 0.015 mSv in 2012 (Table 4.1), which was less than less

than 2 per cent of the dose limit, and down from 0.025 mSv in 2011. The decrease in *total dose* (from 2011) was mostly due to lower direct radiation from the site in 2012. The most exposed people were adults living near to the site whose dose was from direct radiation (from the site) and, to a lesser extent, external exposure from activity in sand and sediment on local beaches. The trend in *total dose* over the period 2004 – 2012 is given in Figure 4.1. *Total doses* remained broadly similar from year to year, and were low.

Source specific assessments for both high-rate consumers of locally grown foodstuffs, and of fish and shellfish, give exposures that were less than the *total dose*. The dose to local fish and shellfish consumers, including external radiation but excluding naturally-occurring radionuclides, was 0.008 mSv, which was less than 1 per cent of the dose limit for members of the public of 1 mSv (Table 4.1). This dose was similar to that in 2011 (0.009 mSv), the small decrease was mostly due to lower gamma dose rates reported in 2012. Lower gamma dose rates in 2012 also decreased the dose received from people collecting sea coal at Carr House from 0.012 mSv in 2011 to 0.009 mSv in 2012.

An additional source specific assessment was undertaken in 2012 to determine the exposure from naturally-occurring radionuclides, as a consequence of the reported polonium-210 concentrations in mollusc samples. The area, inside the Tees Estuary entrance, in the proximity of Paddy's Hole was unlikely to sustain a high rate consumption of winkles, as it is an extremely localised area which contains oil and other wastes. In addition, the most recent habits survey undertaken in 2008 did not identify any consumption of molluscs from Paddy's Hole. However, in the unlikely event that some of these molluscs did enter the diet of the high-rate consumers of fish and shellfish, the dose from naturally-occurring radionuclides was assessed to be 0.070 mSv, in addition to that from artificial radionuclides. This estimate assumes that the median concentrations for naturally-occurring radionuclides at background (Appendix 1, Table X4.1) be subtracted from the total concentrations as measured in 2012.

Gaseous discharges and terrestrial monitoring

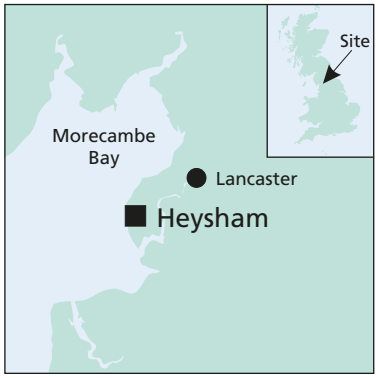
Gaseous radioactive waste is discharged via stacks to the local environment. Analyses of tritium, carbon-14 and sulphur-35 were made in terrestrial samples, including milk, crops and fruit. Samples of water are also taken from a borehole and public supplies. Data for 2012 are given in Table 4.5(a). The effects of gaseous disposals from the site were not easily detectable in foodstuffs, although small enhancements of sulphur-35 concentrations (just above the LoD) were measured in a few terrestrial samples. Carbon-14 concentrations generally increased in foodstuffs (in comparison to those in 2011) and most were above the default values used to represent background levels in 2012. The gross alpha and beta activities in freshwater were less than the WHO screening levels for drinking water.

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. Discharges of sulphur-35 increased, in comparison to releases in 2011. Results of the aquatic monitoring programme conducted in 2012 are shown in Tables 4.5(a) and (b). Small enhancements of carbon-14 concentrations, above expected background, were only observed in one seafood sample (mussels). Enhancements are most likely to be due to carbon-14 discharges from a nearby non-nuclear site since carbon-14 discharges from the power station are low. The reported carbon-14 concentration in mussels decreased again in 2012, in comparison to that in 2011, and was the lowest value in recent years. Technetium-99 analysis in seaweed is used as a specific indication of the far-field effects of disposals to sea from Sellafield. Concentrations in seaweed (*Fucus vesiculosus*) were low and much less than the peak observed in 1998 (see also Figure 2.8). They are less than 1 per cent of the equivalent concentrations near Sellafield. As in 2010 and 2009, iodine-131 was again positively detected in seaweed samples collected around the mouth of the River Tees Estuary in 2012. The detected values, as in previous years, are believed to originate from the therapeutic use of this radionuclide in a local hospital. Detectable concentrations of radiocaesium and transuranics were mainly due to disposals from Sellafield and to weapon test fallout. However, caesium-137 concentrations in sediment have remained low over the last 5 years (Figure 4.2). Overall, small decreases in gamma dose rates were measured in 2012, compared to those in 2011.

In 2012, the reported polonium-210 concentration in winkles from South Gare was 23 Bq kg^{-1} and enhanced above the value expected due to natural sources. Due to the scarcity of winkles at South Gare (inside the Tees Estuary entrance) in 2012, this sample consisted of a mixture including some winkles collected from the estuary entrance near Paddy's Hole. The polonium-210 concentration is consistent with previously reported values in winkles from Paddy's Hole, obtained from sampling and analysis undertaken between in 2004 and 2006. The enhanced levels at Paddy's Hole were believed to be due to a combination of waste slag from local iron and steel industries, used in sea defences, and/or the build up of naturally-occurring gamma-emitting radionuclides in sediments at this location as the result of degradation of the sea defence materials over time.

4.5 Heysham, Lancashire



Heysham Power Station is situated on the Lancashire coast to the south of Morecambe and near the port of Heysham. This establishment comprises two separate nuclear power stations, both powered by two AGRs. It is estimated that Heysham 1 and 2 will continue to generate electricity until at least 2019 and 2023, respectively. Disposals of radioactive waste from both stations are made under permit via separate outfalls to Morecambe Bay and via stacks, but for the purposes of environmental monitoring both stations are considered together. The most recent habits survey was undertaken in 2011 (Garrod *et al.*, 2012).

Doses to the public

The *total dose* from all pathways and sources of radiation was 0.025 mSv in 2012 (Table 4.1), and unchanged from 2011. This was less than 3 per cent of the dose limit for members of the public. In 2012, the most exposed people were adults who were high-rate consumers of molluscs. The trend in *total dose* over the period 2004 – 2012 is given in Figure 4.1. Any changes in *total doses* from 2004-2010 were attributable to environmental variability (in measurements of gamma dose rates), thereafter due to a lower occupancy rate over local beaches.

Source specific assessments for high-rate terrestrial food consumers, and from external exposure for turf cutters over salt marsh, give exposures that were less than the *total dose* (Table 4.1). The estimated dose to terrestrial food consumers in 2012 was 0.008 mSv, which was less than 1 per cent of the dose limit for members of the public of 1 mSv. The small increase in dose from 0.007 mSv (in 2011), was mostly due to enhanced carbon-14 concentrations in milk in 2012. The dose to local fishermen, who consume a large amount of seafood and are exposed to external radiation over intertidal areas, was 0.034 mSv in 2012, which was approximately 3 per cent of the dose limit for members of the public of 1 mSv (Table 4.1), and unchanged from 2011.

Gaseous discharges and terrestrial monitoring

Discharges of argon-41 and carbon-14 at Heysham 2 decreased in 2012, compared with 2011; discharges of other radionuclides were broadly comparable (including those from Heysham 1). The monitoring programme for the effects of gaseous disposals was similar to that for other power stations. Data for 2012 are given in Table 4.6(a). The effects of gaseous disposals were difficult to detect in 2012, although carbon-14 concentrations were generally increased in foodstuffs (in comparison to those in 2011) and most were above the default values used to represent background levels in 2012. Small enhancements of concentrations of sulphur-35 were measured in some samples and activities of cobalt-60 were mostly below, or at, the LoD.

Liquid waste discharges and aquatic monitoring

Discharges of tritium decreased from Heysham 1 and increased from Heysham 2 (compared with 2011); discharges of other radionuclides were broadly comparable. The monitoring programme for the effects of liquid disposals included sampling of fish, shellfish, sediment, seawater and measurements of gamma dose rates and for completeness the data considered in this section include all of those for Morecambe Bay. A substantial part of the programme is in place in order to monitor the effects of Sellafield disposals. The results for 2012 are given in Tables 4.6(a) and (b). In general, similar levels to those for 2011 were observed and the effect of liquid disposals from Heysham was difficult to detect above the Sellafield background. Concentrations of tritium in flounder and mussels were not sufficiently high to demonstrate that any originated as a result of discharges from Heysham. Concentrations of technetium-99 in marine samples remained at levels typical of recent years, caused by discharges from Sellafield. Concentrations of caesium-137 in sediments, largely due to Sellafield, are generally in decline (Figure 4.2). Gamma dose rates over intertidal sediment were generally similar to measurements in recent years.

4.6 Hinkley Point, Somerset

The Hinkley Point Power Station sites are situated on the Somerset coast, west of the River Parrett estuary. There are two separate A and B stations that include two Magnox reactors and two AGRs, respectively. Hinkley Point A started electricity generation in 1965 and ceased in 2000. This station completed de-fuelling in 2004 and is undergoing decommissioning. In 2012, EDF Energy announced that the operating life of Hinkley Point B is expected to be extended until at least 2023 (from 2016). Environmental monitoring covers the effects of the two power stations together.

In 2011, EDF Energy's and Centrica's joint venture company, NNB Generation Company Limited (NNB GenCo) applied

for an environmental permit relating to discharges (non-radioactive) of waste water generated from site preparation and construction activities at their Hinkley Point site. Following a public consultation, the Environment Agency granted a permit to NNB Generation Company Limited on 29 February 2012 (Environment Agency, 2012a). In addition, the Environment Agency issued three further environmental permits, on the 13 March 2013, for the new nuclear power station at Hinkley Point C covering (i) disposal and discharge of radioactive wastes, (ii) operation of standby power supply systems using diesel generators and (iii) discharge cooling water and liquid effluents into the Bristol Channel. More information can be found at: www.environment-agency.gov.uk/hinkleypoint.

The most recent habits survey was conducted in 2010 (Clyne *et al*, 2011d).

Doses to the public

The *total dose* from all pathways and sources of radiation was 0.011 mSv (Table 4.1), or approximately 1 per cent of the dose limit, and down from 0.014 mSv in 2011. The lower value in 2012 was due to a decrease from external exposure over intertidal areas. Direct radiation from the site was the dominant contributor to the dose in 2012. Prenatal children of local inhabitants were the most exposed people and a change from that in 2011 (adults who spend a large amount of time over sediments). The trend in *total dose* over the period 2004 – 2012 is given in Figure 4.1. In 2010, the decrease in *total dose* (and continued thereafter) was attributed to lower gamma dose rates over local beaches.

Source specific assessments for high-rate consumers of locally grown food gives exposures that were less than the *total dose* (Table 4.1). The dose to consumers of locally grown food was 0.007 mSv, and the increase in dose (from 0.005 mSv in 2011) was due to higher carbon-14 concentrations in milk in 2012. The dose to local fishermen, who consume a large amount of seafood and are exposed to external radiation over intertidal areas, was 0.013 mSv in 2012, which was approximately 1 per cent of the dose limit for members of the public of 1 mSv. This estimate also includes the effects of discharges of tritium and carbon-14 from Cardiff and uses an increased tritium dose coefficient (see Appendix 1). The decrease in dose from 0.020 mSv (in 2011) was due to the reduced gamma dose rates at Stolford.

Gaseous discharges and terrestrial monitoring

Gaseous radioactive waste is discharged via separate stacks to the local environment. Analyses of milk, crops and fruit were undertaken to measure activity concentrations of tritium, carbon-14, sulphur-35 and gamma emitters. Local reservoir water samples were also taken and analysed. Data for 2012 are given in Table 4.7(a). Activity concentrations of tritium and gamma emitters (including caesium-137) in terrestrial materials were mostly below, or at, the LoD. Sulphur-35 from Hinkley Point B was detected at low concentrations in some of the food samples. Most of the carbon-14 concentrations in foods were higher than the default values used to represent background levels (excluding carrots and potatoes) in 2012. Reservoir water contained alpha and beta activities less than WHO screening levels for drinking water.

Additional programme of dose rate monitoring

In 2011, allegations were made that soil at the Hinkley Point site was contaminated with enriched uranium from nuclear fuel. These allegations referred to measurements of dose rates taken near the site which were reported to show that the dose rates were higher than those reported officially. The Environment Agency considered that there is no route by which uranium from irradiated fuel could have been released and dispersed from the site without large amounts of other radionuclides (fission products) being released simultaneously. These releases would have been detected in the routine monitoring carried out by the operators and regulators.

However, public concerns were caused by these allegations. Therefore, in 2011, the Environment Agency undertook soil sampling and radioanalysis to provide scientific evidence of whether or not uranium contamination was present on the Hinkley Point site. These results were reported in the RIFE-17 report (Environment Agency, Food Standards Agency, Northern Ireland Environment Agency and Scottish Environment Protection Agency, 2011). In August 2012, the Environment Agency commissioned additional monitoring of dose rates at 18 locations around the Hinkley Point B site. The results of the dose rate monitoring are given in Table 4.7(c). Three dose rate instruments were used and set up using best practice (Her Majesty's Inspectorate of Pollution, 1995).

The mean dose rate from the three instruments at the 18 locations ranged from 0.087 μGy h^{-1} to 0.109 μGy h^{-1}. The inherent radioactivity of the instruments has been subtracted from the results. The results include the response by each instrument to cosmic radiation. The response by the instruments to cosmic radiation varies but was likely to be between 0.03 and 0.04 μGy h^{-1}. The results will vary depending on the levels of natural radioactivity which are also dependent on underlying geology and are broadly similar to those measured as part of our regular programme.

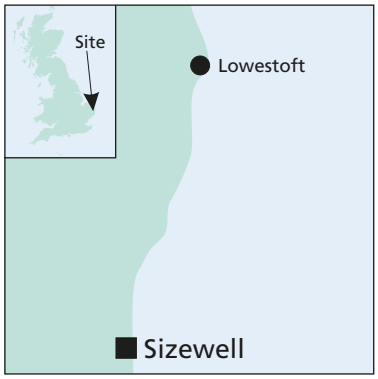
Liquid waste discharges and aquatic monitoring

Regulated discharges of radioactive liquid effluent from both power stations are made via separate outfalls into the Bristol Channel. Discharges of tritium and other radionuclides at Hinkley Point A increased in 2012, in comparison to those in 2011; discharges of other permitted radionuclides were broadly comparable (including those from Hinkley Point B). Analyses of seafood and marine indicator materials and

measurements of external radiation over intertidal areas were conducted. Measurements of tritium and carbon-14 are made primarily to establish the local effects of historical discharges from the GE Healthcare Limited plant at Cardiff.

The environmental results for 2012 are given in Tables 4.7 (a) and (b). Where results can be compared, the concentrations observed in seafood and other materials from the Bristol Channel were generally similar to those in recent years (see also Figure 4.2). Concentrations of tritium in shellfish in 2011 were similar in comparison to those in 2011. Further information on tritium concentrations in seawater from the Bristol Channel is given in Section 9. 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, GE Healthcare Limited at Cardiff, weapons tests and Chernobyl fallout. Due to the low concentrations detected, it is generally difficult to attribute the results to a particular source. The concentrations of transuranic nuclides in seafoods were of negligible radiological significance. The dose rates at Stolford decreased in comparison to those in 2011. Overall, gamma radiation dose rates over intertidal sediment were generally similar to measurements in recent years.

4.7 Sizewell, Suffolk



The two Sizewell Power Stations are located on the Suffolk coast, near Leiston. The A station has two Magnox reactors whilst the B station, powered by one PWR, is the UK's only commercial PWR power station. The B station began operation in 1995 and it is estimated that it will end power generation by 2035. Sizewell A power station ceased to be an electricity generator in 2006 and has begun de-fuelling (completion expected in 2014) as part of the site's decommissioning plan. The most recent habits survey was conducted in 2010 (Garrod *et al.*, 2011).

Doses to the public

As in recent years, the *total dose* from all pathways and sources was 0.021 mSv in 2012 (Table 4.1) or approximately 2 per cent of the dose limit. The dominant contribution to *total dose* at this site was from direct radiation. Dose from this pathway has reduced by a factor of three since Sizewell A ceased generation in 2006. The most exposed people were adults living in the vicinity of the site. The trend in *total dose* over the period 2004 – 2012 is given in Figure 4.1. The *total dose* declined at the end of 2006, following the closure of the Magnox reactors at Sizewell A, thereafter variations were due to the change in the contribution from direct radiation from the site.

Source specific assessments for both high-rate consumers of locally grown foodstuffs, and of fish and shellfish, and from external exposure for houseboat dwellers, give exposures that were less than the *total dose* in 2012 (Table 4.1). The dose to houseboat dwellers from external exposure was 0.010 mSv. The increase from less than 0.005 mSv in 2011 was due to higher dose rates at Southwold Harbour in 2012.

Gaseous discharges and terrestrial monitoring

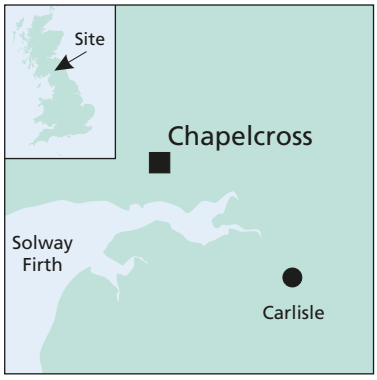
Gaseous wastes are discharged via separate stacks to the local environment. The results of the terrestrial monitoring in 2012 are shown in Table 4.8 (a). Gamma-ray spectrometry and analysis of tritium, carbon-14 and sulphur-35 in milk, crops and fruit generally showed very low concentrations of artificial radionuclides near the power stations in 2012. Tritium concentrations in local freshwater were all low, including those measured at the Leisure Park (positively detected in previous years). Carbon-14 concentrations were detected in locally produced foods, above background concentrations, and these were generally higher in 2012 compared to those in 2011. Gross alpha and beta activities in surface waters were less than the WHO screening levels for drinking water.

Liquid waste discharges and aquatic monitoring

Regulated discharges of radioactive liquid effluent are made via outfalls to the North Sea. Caesium-137 discharges decreased from both Sizewell A and Sizewell B in comparison to those in 2011. In the aquatic programme, analysis of seafood, sediment, and seawater, and measurements of gamma dose rates were conducted in intertidal areas. Data for 2012 are given in Tables 4.8(a) and (b). Concentrations of artificial radionuclides were low and mainly due to the distant effects of Sellafield discharges and to weapons testing. Tritium concentrations in seafood were all below the LoD. Caesium-137 concentrations in sediment have remained low over the last decade (Figure 4.2). Overall, gamma radiation dose rates over intertidal areas were difficult to distinguish from the natural background, although the dose rates at Southwold Harbour increased in comparison to those in recent years, most likely due to natural variation.

SCOTLAND

4.8 Chapelcross, Dumfries and Galloway



Chapelcross was Scotland's first commercial nuclear power station and has four Magnox reactors located near the town of Annan in Dumfries and Galloway. After 45 years of continuous operation, electricity generation ceased in 2004 and the station has been preparing for decommissioning. De-fuelling of the reactors began in 2008 and was completed during 2013. The major hazards on the site will now be decommissioned early, by 2017.

Habits surveys have been undertaken to investigate aquatic and terrestrial exposure pathways. The most recent habits survey for Chapelcross was conducted in 2010 (Clyne *et al.*, *in press/a*). Also during 2012, a habits survey was conducted to determine the consumption and occupancy rates by members of the public on the Dumfries and Galloway coast (Garrod *et al.*, *in press*). 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). Revised figures for consumption rates, together with occupancy rates, are provided in Appendix 1 (Table X2.2).

Doses to the public

The *total dose* from all pathways and sources of radiation is assessed to have been 0.011 mSv in 2012 (Table 4.1), which was approximately 1 per cent of the dose limit. As in recent years, infants who were high-rate consumers of milk were the most exposed people. The decrease in dose from 0.037 mSv (in 2011) was equally attributed to a decreased value for the maximum carbon-14 concentration in milk and the exclusion of the LoD for americium-241 activity in food in the 2012 assessment. In line with the rules on use of the results for dose calculations, americium-241 was excluded because detectable activity was not observed in other samples (soil) from the terrestrial environment in 2012. The trend in *total dose* over the period 2004 – 2012 is given in Figure 4.1. *Total doses* remained broadly similar from year to year, and were low.

Source specific assessments for high-rate consumers of seafood (crustaceans), and for wildfowlers, give exposures that were less than the *total dose* in 2012 (Table 4.1). The annual dose for high-rate terrestrial food consumers was estimated to be 0.010 mSv in 2012. The reasons for the decrease in dose (from 0.025 mSv in 2011) in 2012 are the same as those contributing to the maximum *total dose*.

A consideration of the discharges from Chapelcross indicates that they contribute a very small fraction of the dose to the local population from seafood consumption and occupancy over salt marsh; the greater proportion of the dose can be attributed to the discharges from Sellafield.

Gaseous discharges and terrestrial monitoring

Gaseous radioactive waste is discharged via stacks to the local environment. Terrestrial monitoring consisted of the analysis of a variety of foods, including milk, fruit, crops and game, as well as grass, soil and freshwater samples, for a range of radionuclides. Air samples at three locations were also monitored to investigate the inhalation pathway.

The results of terrestrial food and air monitoring in 2012 are given in Tables 4.9(a) and (c). The activity concentrations of radionuclides in milk and grass were generally similar to those observed in previous years. The maximum concentration of carbon-14 in milk was 20 Bq l^{-1} and lower than the value in 2011 (35 Bq l^{-1}). Americium-241 concentrations in all samples (including soil) were below the LoD in 2012. The results for terrestrial foods show the effects of discharges from Chapelcross in the concentrations of tritium in a range of foods, and these were mostly at or below the LoD. Activity concentrations in air samples at locations near to the site were below the LoD (Table 4.9(c)).

Weekly sampling and analysis for tritium of rainwater deposited close to the village of Creca was continued in 2012. As in 2011 and 2010, the levels of tritium were measured above the detection limit, but do not account for the current levels of tritium observed in local surface waters.

Liquid waste discharges and aquatic monitoring

Radioactive liquid effluents are discharged to the Solway Firth. Samples of seawater and *Fucus vesiculosus*, as environmental indicators, were collected in addition to seafood, sediments and dose rates. Data for 2012 are given in Tables 4.9(a) and (b). Concentrations of artificial radionuclides in marine materials in the Chapelcross vicinity are mostly due to the effects of Sellafield discharges and are consistent with values expected at this distance from Sellafield. Concentrations of most radionuclides and gamma dose rates remained at similar levels to those detected in recent years. Concentrations of technetium-99 in biota were generally similar to those observed in recent years. Concentrations of caesium-137 in sediments, largely due to Sellafield, are generally in decline (Figure 4.2). Measurements of the contact beta dose rate on stake nets were below the LoD.

Between 1992 and 2009, a number of particles was found at the end of the discharge outfall consisting of lime-scale originating from deposits within the pipeline. Magnox Limited continues to monitor this area frequently and no particles were found during 2012 (as for the interim years). The relining of the pipeline and grouting at strategic points, which was undertaken in 2009/2010, has reduced the potential for particles to be released.

4.9 Hunterston, North Ayrshire

Hunterston Power Station is located on the Ayrshire coast near West Kilbride. At this location there are two separate nuclear power stations - Hunterston A and Hunterston B. Hunterston A was powered by twin Magnox reactors until it ceased electricity production in 1990 and is now being decommissioned by Magnox Limited. Hunterston B is powered by a pair of AGRs. In 2012, EDF Energy announced that the operating life of Hunterston B is expected to be extended until at least 2023 (from 2016). Environmental monitoring in the area considers the effects of both sites together.

As reported in previous RIFE reports, during 2010, radioactively contaminated silt escaped from a contaminated area on the Hunterston A site onto the coastline. Since the 2010 event, Magnox Limited introduced temporary measures (routine emptying of sediment catch-pits in the land drainage system), to prevent any further release of contaminated sediment, and has undertaken regular environmental monitoring to demonstrate the effectiveness of these measures. During 2012, a grout curtain has been installed around the contaminated area at Hunterston A with the intention of permanently isolating the contaminated area and preventing any further release of contaminated sediment. Magnox Limited will continue the related environmental monitoring until the effectiveness of the remedial work has been demonstrated.

In June 2012, SEPA varied the authorisation for Hunterston B by inserting both Reactor 3 and Reactor 4 Pressure Vessel Relief Valves into the list of authorised gaseous discharge outlets. This variation allows the routine testing of valve functionality by deliberately releasing reactor gas through each of the valves on a rolling programme in order to demonstrate nuclear safety.

During June and July 2012, a habits survey was conducted to determine the consumption and occupancy rates by members of the public (Rumney *et al.*, *in press/c*). A decrease in the fish, crustacean and mollusc consumption rates has been observed, in comparison with those of the previous survey in 2007, whilst occupancy rates were unchanged in 2012. Revised figures for consumption rates, together with occupancy rates, are provided in Appendix 1 (Table X2.2).

Doses to the public

The *total dose* from all pathways and sources of radiation is assessed to have been 0.032 mSv in 2012 (Table 4.1), which was approximately 3 per cent of the dose limit, and down from 0.050 mSv in 2011. The dose was mainly from direct radiation from the site, and the most exposed people were the prenatal children of local inhabitants. The trend in *total dose* over the period 2004 – 2012 is given in Figure 4.1. The decrease in *total dose* in recent years reflected a downward trend in the reported direct radiation.

Source specific assessments for both high-rate consumers of locally grown food and of local seafood give exposures that were generally similar to those in 2011 and less than the *total dose* in 2012 (Table 4.1).

Gaseous discharges and terrestrial monitoring

Gaseous discharges are made via separate discharge points from the Hunterston A and Hunterston B stations. Discharges of sulphur-35 and particulate beta decreased from Hunterston B, in comparison to those releases in 2011. 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 2012 are given in Tables 4.10(a) and (c). The concentrations of radionuclides in air, milk, crops and fruit were generally low and, where comparisons can be drawn, similar to those in previous years. A few of the carbon-14 concentrations were higher than the default values used to represent background levels (kale and honey). Activity concentrations in air at locations near to the site were below the LoD (Table 4.10(c)).

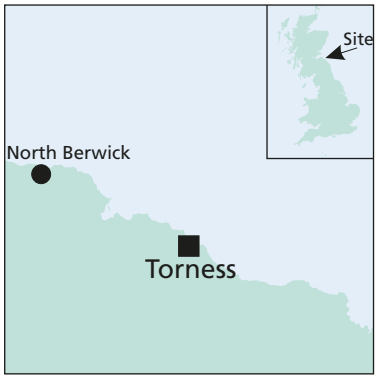
Liquid waste discharges and aquatic monitoring

Authorised liquid discharges are made to the Firth of Clyde by Hunterston B via the stations' cooling water outfall. Discharges from Hunterston B were generally similar to those in 2011. Authorised liquid discharges from Hunterston A are also made via the same outfall; discharges of beta radionuclides increased in 2012, compared to those in 2011, due to the decommissioning of the cartridge cooling pond. The main part of the aquatic monitoring programme consists of sampling of fish and shellfish and the measurement of gamma dose rates on the foreshore. Samples of sediment, seawater and seaweed are analysed as environmental indicator materials.

During 2012, Magnox Limited progressed the draining and decommissioning of the cartridge cooling pond; pond water is passed through an active effluent treatment plant prior to discharge via the authorised route. The discharge of treated pond water associated with the decommissioning of the cartridge cooling pond resulted in increased discharges from the Hunterston A.

The results of aquatic monitoring in 2012 are shown in Tables 4.10(a) and (b). The concentrations of artificial radionuclides in the marine environment are predominantly due to Sellafield discharges, the general values being consistent with those to be expected at this distance from Sellafield. The reported concentrations of technetium-99 from Sellafield in crabs around Hunterston were very low (just above the LoD) and concentrations in lobsters decreased in 2012, in comparison to those in 2011. Small concentrations (just above the LoD) of activation products (silver-110m and cobalt-60) were also detected (in foodstuffs and seaweed), that were likely to have originated from the site, but these were of negligible radiological significance. Caesium-137 concentrations in sediment have remained low over the last decade (Figure 4.2). Gamma dose rates were generally similar to those in 2011.

4.10 Torness, East Lothian



Torness Power Station is located near Dunbar on the east coast of Scotland. This station, which is powered by two AGRs, began operation at the end of 1987 and it is estimated that its power generation will end by 2023. Disposals and discharges of radioactive waste from the site are made in accordance with the Radioactive Substances Act authorisation issued to the site by SEPA in 2007. In 2011, British Energy Generation Limited changed its company name to EDF Energy Generation Limited. This did not require any change to the extant authorisations.

During 2012, a variation to the 2007 authorisation was granted by SEPA to allow the disposal of gaseous wastes through a previously unidentified outlet. This variation was to allow a new method for the routine testing of reactor pressure relief valves, as requested by ONR. There was no change to the limits for gaseous discharges. The gaseous and liquid discharges from the site are given in Appendix 2.

EDF has continued with a programme to inject carbonyl sulphide (COS) into both reactors to reduce the amount of carbon deposition within the reactors. As expected, this has resulted in increases in sulphur-35 levels for both liquid and gaseous discharges. The discharge levels remain within the authorised limits.

The most recent habits survey was undertaken in 2011 (Clyne *et al.*, *in press/b*).

Doses to the public

In 2012, the *total dose* from all pathways and sources of radiation was 0.020 mSv (Table 4.1) or 2 per cent of the dose limit, and unchanged from 2011. Direct radiation was the dominant contributor to the dose and the most exposed people were adults. The trend in *total dose* over the period 2004 – 2012 is given in Figure 4.1. *Total doses* remained broadly similar from year to year, and were low.

Source specific assessments for both high-rate consumers of locally grown foods and of local fish and shellfish give exposures that were less than the *total dose* in 2012 (Table 4.1). The estimated dose to terrestrial food consumers was 0.006 mSv, which was approximately 0.6 per cent of the dose limit for members of the public of 1 mSv, and unchanged from 2011. The dose to people consuming fish and shellfish was less than 0.005 mSv.

Gaseous discharges and terrestrial monitoring

In 2012, the discharges of tritium decreased, and sulphur-35 increased, in comparison to those in 2011. A variety of foods, including milk, crops and fruit as well as grass and soil samples, were measured for a range of radionuclides. Goats' milk (analysed in previous years) was not sampled in 2012. Air sampling at two locations was undertaken to investigate the inhalation pathway. The results of terrestrial food and air monitoring in 2012 are given in Tables 4.11(a) and (c). As in recent years, the effects of discharges from the power station were not observed for concentrations of sulphur-35, which were below the LoD in terrestrial foods and environmental indicator materials. In 2012, americium-241 concentrations, measured by gamma–ray spectrometry, were below the LoD. Measured concentrations of radioactivity in air at locations near to the site were also below the LoD (Table 4.11(c)).

Liquid waste discharges and aquatic monitoring

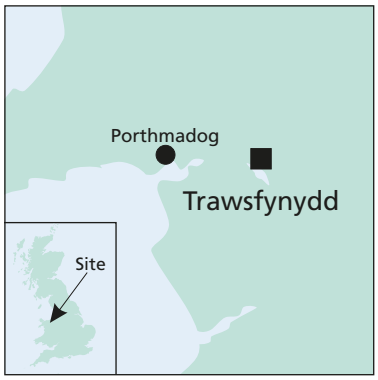
Discharges of sulphur-35 increased, in comparison to those releases in 2011. Samples of seawater and *Fucus vesiculosus*, as useful environmental indicators, were collected in addition to seafood. Measurements were also made of gamma dose rates over intertidal areas, supported by analyses of sediment, and beta dose rates on fishing gear.

The results of the aquatic monitoring in 2012 are shown in Tables 4.11(a) and (b). Concentrations of artificial radionuclides were mainly due to the distant effects of Sellafield discharges

and to weapon testing and Chernobyl fallout. As in recent years, a few very low concentrations of activation products were detected in seafood and environmental indicators. These were likely to have originated from the station. Technetium-99 concentrations in marine samples were similar to those in 2011. Caesium-137 concentrations in sediment have remained low over the last decade (Figure 4.2). Beta radiation from fishermen's nets and pots was below the LoD. Gamma dose rates over intertidal areas were generally indistinguishable from natural background and were similar to those measured in recent years.

WALES

4.11 Trawsfynydd, Gwynedd



Trawsfynydd Power Station is located on the northern bank of an inland lake in the heart of Snowdonia National Park, North Wales and was powered by twin Magnox reactors. Trawsfynydd ceased to generate electricity in 1991. De-fuelling of the reactors was completed in 1995 and the station is being decommissioned. The focus for the site is now the completion of decommissioning projects. The aim is to deliver the Trawsfynydd site into a state of Care and Maintenance by 2016, earlier than previously planned. Monitoring is conducted on behalf of the Welsh Government. The most recent habits survey was undertaken in 2005 (Tipple *et al.,* 2006). In November 2011, the Environment Agency revised the permit to reduce limits of gaseous discharges of of tritium and liquid discharges of tritium, caesium-137 and other radionuclides, with liquid discharges of strontium-90 no longer in the permit.

Doses to the public

The *total dose* from all pathways and sources of radiation was 0.025 mSv in 2012 (Table 4.1), which was less than 3 per cent of the dose limit, and up from 0.012 mSv in 2011. The higher value in 2012 was due to an increase in the direct radiation from the site. Infants living near to the site were the most exposed people, a change from the situation in 2011 (adults). In 2011, the majority of the dose was received from the consumption of fish combined with external exposure from activity in lakeside sediment. The trend in *total dose* over the period 2004 – 2012 is given in Figure 4.1. *Total doses* remained broadly similar from year to year, and were low.

Source specific assessments for high-rate consumers of both locally grown foods and for anglers, give exposures that were less than the *total dose* in 2012 (Table 4.1). The dose to anglers (who consume large quantities of fish and spend long periods of time in the location being assessed) was 0.010 mSv in 2012, which was 1 per cent of the dose limit for members of the public of 1 mSv. The observed activity concentrations in lake sediments are used as the basis for external radiation calculations in view of the difficulty in establishing the increase in measured dose rates above natural background levels. The decrease from the estimate of 0.011 mSv in 2011 resulted from lower caesium-137 concentrations in lake sediments in 2012.

Gaseous discharges and terrestrial monitoring

Discharges of tritium and carbon-14 decreased in 2012 in comparison to those in 2011. The results of the terrestrial programme, including those for local milk, crops and animal samples, are shown in Table 4.12(a). Concentrations of activity in all terrestrial foods were low. As in 2011, concentrations of carbon-14 in 2012 were generally higher than the default values used to represent background levels. In 2012, measured activities for caesium-137 in terrestrial foods were below the LoD. The most likely source of total radiocaesium (in sheep and milk samples) is fallout from Chernobyl and weapon tests, though it is conceivable that a small contribution may be made by re-suspension of lake activity. In recognition of this potential mechanism, monitoring of transuranic radionuclides was also conducted in crop and animal samples. Detected activities were low and generally similar to observations in other areas of England and Wales, where activity was attributable to weapon test fallout. There was no evidence of re-suspension of activity in sediment from the lake shore contributing to increased exposure from transuranic radionuclides in 2012.

Liquid waste discharges and aquatic monitoring

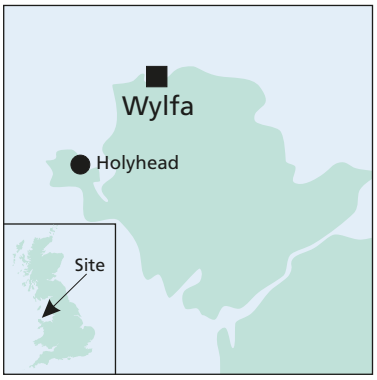
Discharges of liquid radioactive waste are made to a freshwater lake making the power station unique in UK terms. Discharges of caesium-137 and other radionuclides increased in comparison to those in 2011. The aquatic monitoring programme was directed at consumers of freshwater fish caught in the lake and external exposure over the lake shoreline; the important radionuclides are radiocaesium and, to a lesser extent, strontium-90. Freshwater and sediment samples are also analysed. Habits surveys have established that the species of fish regularly consumed are brown and rainbow trout. Perch and most brown trout are indigenous to the lake but rainbow trout are introduced from a hatchery. Because of the limited period that they spend in the lake, introduced fish generally exhibit lower radiocaesium concentrations than indigenous fish.

Data for 2012 are given in Tables 4.12(a) and (b). The majority of activity concentrations in fish and sediments result from historical discharges. Concentrations of radiocaesium in fish

in 2012 were similar to those in 2011. Concentrations in the water column are predominantly maintained by processes that release activity (such as remobilisation) from near surface sediments. Low concentrations of other radionuclides including transuranics were also detected, particularly in lake sediments; in previous years' monitoring, it has been demonstrated that these concentrations increase with depth beneath the sediment surface. Caesium-137 concentrations in the lake sediments generally decreased in comparison to those in 2011, but were similar to those in previous years. In 2012, sediment concentrations of strontium-90, americium-241 and plutonium radionuclide at two locations (Bailey Bridge and fish farm) were lower than those in 2011, but overall, sediment activity concentrations in 2012 were similar to those in recent years prior to 2011. Strontium-90 and transuranic concentrations in fish continued to be very low in 2012 and it is the effects of caesium-137 that dominate the fish consumption and external radiation pathways.

In the lake itself, there remains clear evidence for the effects of discharges from the power station. However, gamma dose rates found on the shoreline where anglers fish were difficult to distinguish from background levels, although there is limited evidence to suggest that rates were lower in comparison to those in 2011. The predominant radionuclide was caesium-137. The time trends of concentrations of caesium-137 in sediments and discharges are shown in Figure 4.3. A substantial decline in levels was observed in the late 1990s in line with reducing discharges. In the earlier part of the last decade, the observed concentrations were mainly affected by sample variability. In recent years, with sustained reductions in discharges of caesium-137, there is now a general progressive decrease in these concentrations in sediments, with the lowest concentrations reported in 2010.

4.12 Wylfa, Isle of Anglesey



Wylfa Power Station is located on the north coast of Anglesey and generates electricity from two Magnox reactors. It was the last and largest power station of its type to be built in the UK and commenced electricity generation in 1971. Magnox North Limited requested a short-term life extension to continue power generation at Wylfa beyond December 2010 (the date previously scheduled for the cessation of generating electricity). Wylfa Site's Reactor 2 ceased generating electricity in April 2012, in line with the station's agreed operating plan. The ONR has approved changes to the operating rules at Wylfa Power Station, allowing the transfer of partially used fuel from its shutdown reactor to the one remaining operational reactor (from Reactor 2 to Reactor 1), enabling electricity generation to continue until 2014, almost four years beyond its original closure date. Environmental monitoring of the effects of discharges on the Irish Sea and the local environment is conducted on behalf of the Welsh Government. The most recent habits survey was undertaken in 2009 (Garrod *et al*., 2010).

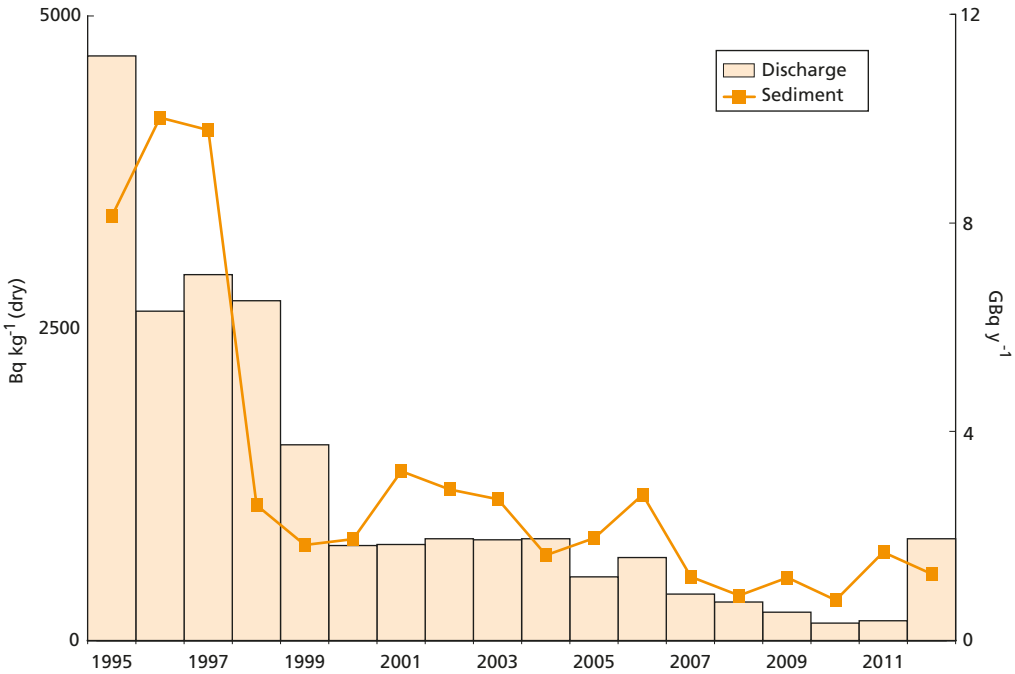


Figure 4.3. Caesium-137 liquid discharge from Trawsfynydd and concentration in sediment in Trawsfynydd lake, 1995-2012

Doses to the public

The *total dose* from all pathways and sources of radiation was 0.006 mSv in 2012 (Table 4.1), which was 0.6 per cent of the dose limit, and down from 0.008 mSv 2011. The most exposed people were local adults consuming marine plants and algae. The decrease in *total dose* (from 2011) was mostly due to lower external exposure over intertidal areas in 2012. The trend in *total dose* over the period 2004 – 2012 is given in Figure 4.1. *Total doses* remained broadly similar from year to year, and were low.

Source specific assessments for high-rate consumers of locally grown foods give exposures that were less than the *total dose* in 2012 (Table 4.1). The dose to high-rate consumers of fish and shellfish (including external radiation) was 0.009 mSv, which was less than 1 per cent of the dose limit for members of the public of 1 mSv. The reason for the small decrease in dose in 2012 (from 0.010 mSv in 2011) is the same as that contributing to maximum *total dose* from liquid discharges.

Gaseous discharges and terrestrial monitoring

All permitted discharges decreased (with the exception of beta radionuclides), in comparison to those in 2011, due to the cessation of power generation at Wylfa Site's Reactor 2. The main focus of the terrestrial sampling was for the content of tritium, carbon-14 and sulphur-35 in milk, crops and fruit. Data for 2012 are given in Table 4.13(a). Sulphur-35 was detected at very low concentrations in some of the food samples. Carbon-14 was detected in locally produced foods, with some elevated above those concentrations expected for background levels. Overall the effects of discharges are very low. Gross alpha and beta activities in surface water were less than the WHO screening levels for drinking water.

Liquid waste discharges and aquatic monitoring

Discharges of tritium decreased in comparison to releases in 2011 (due to power cessation). The monitoring programme for the effects of liquid disposals included sampling of fish, shellfish, sediment, seawater and measurements of gamma dose rates. The results of the programme in 2012 are given in Tables 4.13 (a) and (b). The data for artificial radionuclides related to the Irish Sea continue to reflect the distant effects of Sellafield discharges. The activity concentrations in 2012 were similar to those in 2011, including technetium-99 derived from Sellafield. Caesium-137 concentrations in sediment have remained low over the last decade (Figure 4.2). Where comparisons can be made (from similar ground types and locations), gamma dose rates were generally lower in comparison to those in 2011.

Table 4.1. Individual doses – nuclear power stations, 2012

Site	Exposed population[a]	Exposure, mSv per year					
		Total	Fish and shellfish	Other local food	External radiation from intertidal areas or the shoreline	Gaseous plume related pathways	Direct radiation from site
England							
Berkeley and Oldbury							
Total dose – all sources	**Adult occupants over sediment**	**0.014**	**<0.005**	**<0.005**	**0.014**	**–**	**–**
Source specific doses	Seafood consumers	0.018	<0.005	–	0.018	–	–
	Infant inhabitants and consumers of locally grown food	<0.005	–	<0.005	–	<0.005	–
Bradwell							
Total dose – all sources	**Prenatal children of green vegetable consumers**	**<0.005**	**–**	**<0.005**	**–**	**–**	**–**
Source specific doses	Seafood consumers	<0.005	<0.005	–	<0.005	–	–
	Prenatal children of inhabitants and consumers of locally grown food	<0.005	–	<0.005	–	<0.005	
Dungeness							
Total dose – all sources	**Local adult inhabitants (0.5-1km)**	**0.015**	**<0.005**	**<0.005**	**<0.005**	**<0.005**	**0.013**
Source specific doses	Seafood consumers	0.012	<0.005	–	0.010	–	–
	Houseboat occupants	0.019	–	–	0.019	–	–
	Infant inhabitants and consumers of locally grown food	0.005	–	<0.005	–	<0.005	–
Hartlepool							
Total dose – all sources	**Local adult inhabitants (0-0.25km)**	**0.015**	**–**	**–**	**<0.005**	**<0.005**	**<0.010**
Source specific doses	Seafood consumers[b]	0.008	<0.005	–	0.007	–	–
	Infant inhabitants and consumers of locally grown food	<0.005	–	<0.005	–	<0.005	–
	Sea coal collectors	0.009	–	–	0.009	–	–
Heysham							
Total dose – all sources	**Adult mollusc consumers**	**0.025**	**0.015**	**–**	**0.010**	**–**	**–**
Source specific doses	Seafood consumers	0.034	0.014	–	0.019	–	–
	Turf cutters	0.018	–	–	0.018	–	–
	Infant inhabitants and consumers of locally grown food	0.008	–	0.007	–	<0.005	–
Hinkley Point							
Total dose – all sources	**Prenatal children of occupants for direct radiation**	**0.011**	**<0.005**	**<0.005**	**<0.005**	**<0.005**	**0.010**
Source specific doses	Seafood consumers	0.013	<0.005	–	0.013	–	–
	Infant inhabitants and consumers of locally grown food	0.007	–	0.007	–	<0.005	–
Sizewell							
Total dose – all sources	**Local adult inhabitants (0-0.25km)**	**0.021**	**<0.005**	**<0.005**	**<0.005**	**<0.005**	**0.020**
Source specific doses	Seafood consumers	<0.005	<0.005	–	<0.005	–	–
	Houseboat occupants	0.010	–	–	0.010	–	–
	Infant inhabitants and consumers of locally grown food	<0.005	–	<0.005	–	<0.005	–
Scotland							
Chapelcross							
Total dose – all sources	**Infant milk consumers**	**0.011**	**<0.005**	**0.011**	**<0.005**	**–**	**–**
Source specific doses	Salmon and wildfowl consumers	<0.005	<0.005	<0.005	<0.005	–	–
	Crustacean consumers	<0.005	<0.005	–	–	–	–
	Infant inhabitants and consumers of locally grown food	0.010	–	0.010	–	<0.005	–
Hunterston							
Total dose – all sources	**Prenatal children of local inhabitants (0.25-0.5km)**	**0.032**	**–**	**<0.005**	**<0.005**	**<0.005**	**0.031**
Source specific doses	Seafood consumers	<0.005	<0.005	–	<0.005	–	–
	Infant inhabitants and consumers of locally grown food	0.007	–	0.006	–	<0.005	–

Table 4.1. continued

Site	Exposed population[a]	Exposure, mSv per year					
		Total	Fish and shellfish	Other local food	External radiation from intertidal areas or the shoreline	Gaseous plume related pathways	Direct radiation from site
Torness							
***Total dose* – all sources**	**Local adult inhabitants (0.5–1km)**	**0.020**	**<0.005**	**<0.005**	**<0.005**	**<0.005**	**0.020**
Source specific doses	Seafood consumers	<0.005	<0.005	–	<0.005	–	–
	Infant inhabitants and consumers of locally grown food	0.006	–	0.006	–	<0.005	–
Wales							
Trawsfynydd							
***Total dose* – all sources**	**Infant local inhabitants (0.25–0.5km)**	**0.025**	**–**	**<0.005**	**–**	**<0.005**	**0.023**
Source specific doses	Anglers	0.010	0.006	–	<0.005	–	–
	Infant inhabitants and consumers of locally grown food	<0.005	–	<0.005	–	<0.005	–
Wylfa							
***Total dose* – all sources**	**Adult consumers of marine plants and algae**	**0.006**	**<0.005**	**<0.005**	**<0.005**	**–**	**–**
Source specific doses	Seafood consumers	0.009	<0.005	–	0.006	–	–
	Infant inhabitants and consumers of locally grown food	<0.005	–	<0.005	–	<0.005	–

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

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

Table 4.2(a). Concentrations of radionuclides in food and the environment near Berkeley and Oldbury nuclear power stations, 2012

Material	Location	No. of sampling observ-ations	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}					
			^{3}H	^{14}C	^{99}Tc	^{134}Cs	^{137}Cs	^{238}Pu
Marine samples								
Salmon	Beachley	2	<25			<0.13	0.19	
Elvers	River Severn	1	<25			<0.08	<0.07	
Shrimps	Guscar	2	75	26		<0.05	0.37	0.00053
Seaweed	Pipeline	2[E]			3.3	<0.72	<0.64	
Sediment	Hills Flats	2[E]					17	
Sediment	1 km south of Oldbury	2[E]				<0.97	29	
Sediment	2 km south west of Berkeley	2[E]				<0.62	27	
Sediment	Sharpness	2[E]					15	
Seawater	Local beach	2[E]				<0.26	<0.20	

Material	Location	No. of sampling observ-ations	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}					
			^{239}Pu + ^{240}Pu	^{241}Am	^{242}Cm	^{243}Cm + ^{244}Cm	Gross alpha	Gross beta
Marine samples								
Salmon	Beachley	2		<0.23				
Elvers	River Severn	1		<0.06				
Shrimps	Guscar	2	0.0035	0.0047	0.000032	0.000054		
Seaweed	Pipeline	2[E]		<0.81				
Sediment	Hills Flats	2[E]		<0.76				
Sediment	1 km south of Oldbury	2[E]		<2.1				
Sediment	2 km south west of Berkeley	2[E]		<0.79				
Sediment	Sharpness	2[E]		<0.71				
Seawater	Local beach	2[E]		<0.30			<1.3	5.8

Material	Location or selection[b]	No. of sampling observ-ations[c]	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}					
			^{3}H	^{14}C	^{35}S	^{137}Cs	Gross alpha	Gros beta
Terrestrial samples								
Milk		8	<4.4	20	<0.28	<0.20		
Milk	max		<5.5	23	0.38			
Apples		2	<5.0	8.5	<0.10	<0.20		
Apples	max		5.0	10		<0.30		
Beans		1	<4.0	5.0	0.50	<0.20		
Beetroot/Potatoes			1	<5.0	16	0.40	<0.30	
Blackberries		1	5.0	20	0.20	<0.20		
Cabbage		1	<4.0	7.0	1.2	<0.20		
Potatoes		1	<5.0	26	0.40	<0.20		
Wheat		1	<7.0	110	0.40	<0.20		
Freshwater	Gloucester and Sharpness Canal	2[E]	<2.8		<1.6	<0.20	<0.034	0.17
Freshwater	Public supply	2[E]	<2.8		<1.4	<0.22	<0.046	0.16

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

Table 4.2(b). Monitoring of radiation dose rates near Berkeley and Oldbury nuclear power stations, 2012

Location	Ground type	No. of sampling observations	μGy h^{-1}
Mean gamma dose rates at 1m over substrate			
1 km south of Oldbury	Grass and salt marsh	2	0.083
2 km south west of Berkeley	Mud and salt marsh	2	0.078
Guscar Rocks	Mud and salt marsh	2	0.083
Lydney Rocks	Mud and rock	2	0.089
Sharpness	Mud and salt marsh	2	0.079
Hills Flats	Mud and salt marsh	1	0.080
Hills Flats	Grass and salt marsh	1	0.078

Table 4.3(a). Concentrations of radionuclides in food and the environment near Bradwell nuclear power station, 2012

Material	Location	No. of sampling observations	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}				
			^{90}Sr	^{99}Tc	^{137}Cs	^{238}Pu	^{239}Pu + ^{240}Pu
Marine samples							
Sole	Bradwell	2			<0.21		
Bass	Pipeline	1			0.39		
Thornback ray	Pipeline	1			0.39		
Lobsters	West Mersea	1			0.13		
Native oysters	Tollesbury N. Channel	1			<0.10	0.00012	0.00071
Pacific oysters	Goldhanger Creek	2			<0.10		
Winkles	Pipeline	2			<0.24		
Winkles	Heybridge Basin	2			<0.16		
Seaweed	Waterside	2^E		6.4	<0.45		
Leaf beet	Tollesbury	1			<0.05		
Samphire	Tollesbury	1			0.17		
Sediment	Pipeline	2^E	<2.0		6.6		
Sediment	Waterside	2^E	<2.0		10		
Sediment	West Mersea Beach Huts	2^E	<2.0		<0.82		
Sediment	West Mersea Boatyard	2^E	<2.0		6.8		
Sediment	Maldon	2^E	<2.0		23		
Sediment	N side Blackwater Estuary	2^E	<2.0		10		
Seawater	Bradwell	2^E			<0.20		

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							
Sole	Bradwell	2	<0.17				
Bass	Pipeline	1	<0.05				
Thornback ray	Pipeline	1	<0.06				
Lobsters	West Mersea	1	<0.05				
Native oysters	Tollesbury N. Channel	1	0.0029	*	0.000067		
Pacific oysters	Goldhanger Creek	2	<0.09				
Winkles	Pipeline	2	<0.09				
Winkles	Heybridge Basin	2	<0.12				
Seaweed	Waterside	2^E	<0.65				
Leaf beet	Tollesbury	1	<0.05				
Samphire	Tollesbury	1	<0.05				
Sediment	Pipeline	2^E	<1.8				
Sediment	Waterside	2^E	<1.9				
Sediment	West Mersea Beach Huts	2^E	<0.94				
Sediment	West Mersea Boatyard	2^E	<1.8				
Sediment	Maldon	2^E	<2.5				
Sediment	N side Blackwater Estuary	2^E	<2.4				
Seawater	Bradwell	2^E	<0.31			<3.5	17

Table 4.3(a). continued

Material	Location or selection[b]	No. of sampling observ-ations[c]	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}					
			^{3}H	^{14}C	^{35}S	^{137}Cs	Gross alpha	Gross beta
Terrestrial samples								
Milk		3	<4.9	18		<0.20		
Milk	max		<6.3					
Apples		1	9.0	17		<0.20		
Blackberries		1	6.0	18		<0.20		
Cabbage		1	<4.0	19		<0.20		
Carrots		1	<4.0	16		<0.20		
Lucerne		1	<4.0	19		<0.30		
Potatoes		1	<4.0	27		<0.30		
Rabbit		1	<5.0	33		<0.20		
Rape oil		1	<9.0	63		<0.20		
Freshwater	Public supply, N side Estuary	1[E]	<2.4		<0.54	<0.19	<0.040	0.28
Freshwater	Public supply, S side Estuary	1[E]	<2.9			<0.19	<0.093	0.40
Freshwater	Coastal ditch 1	1[E]	<2.2			<0.20	<0.60	2.6
Freshwater	Coastal ditch 2	2[E]	<3.9			<0.20	<0.56	3.4
Freshwater	Coastal ditch 3	2[E]	7.3			<0.20	<0.55	12
Freshwater	Coastal ditch 4	2[E]	8.8			<0.19	<0.40	6.9

* *Not detected by the method used*

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

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

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

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

Table 4.3(b). Monitoring of radiation dose rates near Bradwell, 2012

Location	Ground type	No. of sampling observations	µGy h^{-1}
Mean gamma dose rates at 1m over substrate			
Bradwell Beach	Mud and sand	1	0.086
Bradwell Beach	Sand and shale	1	0.079
Beach opposite power station, N side of estuary	Mud and salt marsh	2	0.072
Waterside	Mud and salt marsh	1	0.062
Waterside	Salt marsh	1	0.066
Maldon	Mud	2	0.067
West Mersea Beach Huts	Mud and sand	1	0.068
West Mersea Beach Huts	Sand	1	0.072
West Mersea	Mud	1	0.058
West Mersea	Mud and sand	1	0.061

Table 4.4(a). Concentrations of radionuclides in food and the environment near Dungeness nuclear power stations, 2012

Material	Location	No. of sampling observ-ations	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}						
			Organic ^{3}H	^{3}H	^{14}C	^{60}Co	^{90}Sr	^{99}Tc	^{137}Cs
Marine samples									
Whiting	Pipeline	2		<25		<0.05			0.15
Bass	Pipeline	1		<25		<0.05			0.29
Sole	Pipeline	2	<25	<25		<0.05			<0.06
Crabs	Eastbourne / Folkestone landed	1				<0.06			<0.05
Shrimps	Pipeline	2	<25	<25	32	<0.07			<0.06
Scallops	Pipeline	2				<0.05	<0.055		<0.05
Sea kale	Dungeness Beach	1				<0.05			0.06
Seaweed	Folkestone	2[E]				<0.57		2.0	<0.38
Sediment	Rye Harbour 1	2[E]				<0.99			<0.96
Sediment	Camber Sands	2[E]				<0.52			<0.43
Sediment	Pilot Sands	2[E]				<0.67			<0.47
Seawater	Dungeness South	2[E]		<2.9		<0.24			<0.21

Material	Location	No. of sampling observ-ations	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}						
			^{238}Pu	^{239}Pu + ^{240}Pu	^{241}Am	^{242}Cm	^{243}Cm + ^{244}Cm	Gross alpha	Gross beta
Marine samples									
Whiting	Pipeline	2			<0.11				
Bass	Pipeline	1			<0.05				
Sole	Pipeline	2			<0.09				
Crabs	Eastbourne / Folkestone landed	1			<0.06				
Shrimps	Pipeline	2			<0.13				
Scallops	Pipeline	2	0.00058	0.0024	0.00089	*	*		
Sea kale	Dungeness Beach	1			<0.04				
Seaweed	Folkestone	2[E]			<0.56				
Sediment	Rye Harbour 1	2[E]	<0.79	<0.58	<1.4				480
Sediment	Camber Sands	2[E]			<0.75				
Sediment	Pilot Sands	2[E]			<0.72				
Seawater	Dungeness South	2[E]			<0.31			<4.1	17

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	<5.1	18	<0.20	<0.19	<0.20		
Milk	max		<5.8			<0.20			
Blackberries		1	<4.0	24	<0.10	<0.10	<0.20		
Potatoes		1	<5.0	20	0.50	<0.30	<0.20		
Rape oil		1	<10	48	1.6	<0.20	<0.20		
Sea kale		1	<5.0	19	5.0	<0.20	0.20		
Spinach		1	<4.0	5.0	0.20	<0.20	<0.20		
Wheat		1	<7.0	120	1.3	<0.30	<0.20		
Grass		1				<0.20	<0.20		
Freshwater	Long Pits	2[E]	<3.3		<0.32	<0.23	<0.20	<0.032	0.14
Freshwater	Pumping station Well number 1	1[E]	<2.9		<1.9	<0.24	<0.19	<0.028	0.15
Freshwater	Pumping station Well number 2	1[E]	<3.3		<0.36	<0.23	<0.20	<0.030	0.15
Freshwater	Reservoir	1[E]	<3.2		<0.57	<0.23	<0.19	<0.030	0.16

* *Not detected by the method used*

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

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

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

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

Table 4.4(b). Monitoring of radiation dose rates near Dungeness nuclear power stations, 2012

Location	Ground type	No. of sampling observations	μGy h^{-1}
Mean gamma dose rates at 1m over substrate			
Littlestone-on-Sea	Pebbles and sand	1	0.056
Littlestone-on-Sea	Sand and shingle	1	0.055
Greatstone-on-Sea	Sand and mud	1	0.060
Greatstone-on-Sea	Sand	1	0.058
Dungeness East	Sand and shingle	2	0.063
Dungeness South	Shingle	2	0.053
Jury's Gap	Sand and shingle	2	0.063
Rye Bay	Sand and shingle	2	0.061

Table 4.5(a). Concentrations of radionuclides in food and the environment near Hartlepool nuclear power station, 2012

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	2	<25	<25	21	<0.11		<0.34	0.18	
Cod	Pipeline	2				<0.07		<0.77	0.35	
Crabs	Pipeline	2			28	<0.07		*	<0.09	
Winkles	South Gare	2	<25	<29		<0.10		<1.4	<0.10	0.85
Mussels	South Gare	2				<0.08		<0.16	<0.08	
Mussels	Seal Sands	1			33					
Seaweed	Pilot Station	2[E]				<0.42	8.7	14	<0.28	
Sediment	Old Town Basin	2[E]				<0.30			1.4	
Sediment	Seaton Carew	2[E]				<0.27			<0.20	
Sediment	Paddy's Hole	2[E]				<0.32			2.2	
Sediment	North Gare	2[E]				<0.22			<0.18	
Sediment	Greatham Creek	2[E]				<0.43			1.9	
Sea coal	Old Town Basin	2[E]				<0.72			<0.71	
Sea coal	Carr House Sands	2[E]				<0.41			1.9	
Seawater	North Gare	2[E]		<3.0		<0.24			<0.20	

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	2				<0.07				
Cod	Pipeline	2				<0.18				
Crabs	Pipeline	2		0.00026	0.0017	0.0011	*	*		
Winkles	South Gare	2	23	0.0032	0.022	0.012	*	0.000037		
Mussels	South Gare	2				<0.06				
Mussels	Seal Sands	1								
Seaweed	Pilot Station	2[E]				<0.34				
Sediment	Old Town Basin	2[E]				<0.49				
Sediment	Seaton Carew	2[E]				<0.35				
Sediment	Paddy's Hole	2[E]				<0.66				
Sediment	North Gare	2[E]				<0.34				
Sediment	Greatham Creek	2[E]				<0.79				
Sea coal	Old Town Basin	2[E]				<1.2				
Sea coal	Carr House Sands	2[E]				<0.62				
Seawater	North Gare	2[E]				<0.30			<3.8	16

Material	Location or selection[b]	No. of sampling observ-ations[c]	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}						
			^{3}H	^{14}C	^{35}S	^{60}Co	^{137}Cs	Gross alpha	Gross beta
Terrestrial samples									
Milk		5	<5.0	19	<0.24	<0.17	<0.20		
Milk	max		<6.0	20	<0.28	<0.20			
Apples		1	<4.0	17	<0.10	<0.20	<0.20		
Beetroot		1	<4.0	11	<0.10	<0.30	<0.20		
Blackberries		1	<4.0	18	0.20	<0.20	<0.20		
Cabbage		1	9.0	11	0.20	<0.30	<0.20		
Honey		1	<7.0	100	<0.10	<0.10	<0.10		
Potatoes		1	<5.0	22	<0.10	<0.20	<0.20		
Runner beans		1	<4.0	9.0	0.60	<0.20	<0.20		
Wheat		1	<6.0	120	0.50	<0.30	<0.20		
Freshwater	Public supply	2[E]	<3.0		<2.8	<0.28	<0.23	<0.061	0.17
Freshwater	Borehole, Dalton Piercy	2[E]	<3.0		<3.5	<0.24	<0.20	<0.077	0.20

* *Not detected by the method used*

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

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

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

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

Table 4.5(b). Monitoring of radiation dose rates near Hartlepool nuclear power station, 2012

Location	Ground type	No. of sampling observations	μGy h^{-1}
Mean gamma dose rates at 1m over substrate			
Fish Sands	Sand	1	0.066
Fish Sands	Sand and stones	1	0.070
Old Town Basin	Sand	1	0.072
Old Town Basin	Sand and coal	1	0.070
Carr House	Sand	1	0.067
Carr House	Sand and coal	1	0.069
Seaton Carew	Sand	2	0.061
Seaton Sands	Sand	2	0.063
North Gare	Sand	2	0.065
Paddy's Hole	Sand and pebbles	2	0.16
Greatham Creek Bird Hide	Mud	1	0.086
Greatham Creek Bird Hide	Mud and sand	1	0.085

Table 4.6(a). Concentrations of radionuclides in food and the environment near Heysham nuclear power stations, 2012

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	^{125}Sb	^{137}Cs
Marine samples										
Flounder	Flookburgh	4			72	<0.13			<0.32	9.1
Flounder	Morecambe	4	28	<25		<0.10	0.040	0.31	<0.23	5.1
Whiting	Morecambe	4				<0.07			<0.17	5.8
Bass	Morecambe	2				<0.08			<0.24	11
Whitebait	Sunderland Point	1				<0.10	0.050		<0.22	2.6
Shrimps	Flookburgh	4			79	<0.08		0.63	<0.22	4.5
Shrimps	Morecambe	2				<0.08			<0.21	4.5
Cockles	Middleton Sands	2				0.18			<0.17	2.1
Cockles[b]	Flookburgh	4			69	<0.17		3.3	<0.21	2.9
Winkles	Red Nab Point	4				<0.09			<0.17	4.3
Mussels	Morecambe	4	32	<31	70	<0.07		56	<0.22	2.2
Wildfowl	Morecambe	1				<0.06			<0.14	<0.48
Samphire	Cockerham Marsh	1				<0.09			<0.21	1.5
Seaweed	Half Moon Bay	2[E]				<0.67		400	<2.4	3.7
Sediment	Half Moon Bay	2[E]				<0.34				47
Sediment	Pott's Corner	2[E]				<0.62				18
Sediment	Morecambe Central Pier	2[E]				<0.61				8.9
Sediment	Red Nab Point	2[E]				<0.34				18
Sediment	Sunderland Point	4[E]				<0.88			<3.2	68
Sediment	Conder Green	4[E]				<0.92			<3.4	82
Sediment	Sand Gate Marsh	4[E]				<0.65			<2.3	83
Seawater	Half Moon Bay	1								0.09
Seawater	Heysham Harbour	2[E]		13		<0.25				<0.20

Material	Location	No. of sampling observ-ations	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}							
			^{238}Pu	^{239}Pu + ^{240}Pu	^{241}Pu	^{241}Am	^{242}Cm	^{243}Cm + ^{244}Cm	Gross alpha	Gross beta
Marine samples										
Flounder	Flookburgh	4	0.00039	0.0025		0.0049	*	*		
Flounder	Morecambe	4				<0.12				
Whiting	Morecambe	4				<0.13				
Bass	Morecambe	2				<0.22				
Whitebait	Sunderland Point	1	0.029	0.17	<1.1	0.31	*	0.00022		
Shrimps	Flookburgh	4	0.0046	0.026	<0.25	0.041	*	*		
Shrimps	Morecambe	2				<0.16				
Cockles	Middleton Sands	2	0.29	1.7		4.7	*	*		
Cockles[b]	Flookburgh	4	0.24	1.7	8.8	4.3	*	*		
Winkles	Red Nab Point	4	0.29	1.6		3.3	*	*		
Mussels	Morecambe	4	0.28	1.7		2.9	*	*		
Wildfowl	Morecambe	1				<0.07				
Samphire	Cockerham Marsh	1				1.0				56
Seaweed	Half Moon Bay	2[E]				<0.72				
Sediment	Half Moon Bay	2[E]	6.3	38		65				
Sediment	Pott's Corner	2[E]				16				
Sediment	Morecambe Central Pier	2[E]				<7.0				
Sediment	Red Nab Point	2[E]				23				
Sediment	Sunderland Point	4[E]				72			250	590
Sediment	Conder Green	4[E]				91			340	790
Sediment	Sand Gate Marsh	4[E]				60			<150	550
Seawater	Heysham Harbour	2[E]				<0.30			<3.3	9.7

Table 4.6(a). continued

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	^{137}Cs	Gross alpha	Gross beta
Terrestrial samples										
Milk			6	<4.4	19	<0.23	<0.19	<0.20		
Milk		max		<5.0	22	<0.35	<0.20	<0.23		
Apples			1	<4.0	13	<0.10	<0.20	<0.20		
Barley			1	<7.0	110	0.30	<0.20	0.20		
Blackberries			1	<4.0	18	0.20	<0.20	<0.20		
Honey			1	<7.0	120	<0.10	<0.10	<0.20		
Potatoes			2	<4.5	28	<0.25	<0.25	<0.20		
Potatoes		max		<5.0	31	0.30	<0.30			
Runner beans			1	<4.0	7.0	0.20	<0.20	<0.20		
Freshwater	Lancaster		2[E]	<2.8		<2.0	<0.24	<0.19	<0.024	<0.057

* *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 14 Bq kg^{-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 4.6(b). Monitoring of radiation dose rates near Heysham nuclear power stations, 2012

Location	Ground type	No. of sampling observations	µGy h^{-1}
Mean gamma dose rates at 1m over substrate			
Greenodd Salt Marsh	Grass	2	0.081
Sand Gate Marsh	Grass	4	0.084
High Foulshaw	Grass and mud	2	0.082
High Foulshaw	Grass	2	0.080
Arnside 1	Mud and salt marsh	1	0.085
Arnside 1	Mud and sand	3	0.082
Arnside 2	Salt marsh	1	0.094
Arnside 2	Grass	3	0.091
Morecambe Central Pier	Sand	1	0.067
Morecambe Central Pier	Pebbles and sand	1	0.077
Half Moon Bay	Sand	1	0.081
Half Moon Bay	Pebbles and stones	1	0.078
Red Nab Point	Sand	1	0.082
Red Nab Point	Pebbles and sand	1	0.094
Middleton Sands	Sand	2	0.080
Sunderland	Salt marsh	4	0.091
Sunderland Point	Mud and sand	4	0.093
Colloway Marsh	Grass and salt marsh	1	0.13
Colloway Marsh	Grass	3	0.12
Lancaster	Grass	4	0.080
Aldcliffe Marsh	Grass	4	0.095
Conder Green	Mud	2	0.091
Conder Green	Mud and sand	1	0.087
Conder Green	Grass and mud	1	0.087

Table 4.7(a). Concentrations of radionuclides in food and the environment near Hinkley Point nuclear power stations, 2012

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	^{134}Cs	^{137}Cs
Marine samples										
Cod	Stolford	2	<37	<39	21	<0.05			<0.05	0.36
Shrimps	Stolford	2	44	48	32	<0.05			<0.05	0.21
Limpets	Stolford	1		28	21	<0.11			<0.11	0.24
Porphyra	Stolford	2				<0.04			<0.04	0.37
Seaweed	Pipeline	2[E]				<0.69		4.9	<0.59	<0.52
Sediment	Watchet Harbour	2[E]				<0.53	<2.0			10
Sediment	Pipeline	2[E]				<0.36	<2.0			5.1
Sediment	Stolford	2[E]				<0.97	<2.0			19
Sediment	Steart Flats	2[E]				<0.56	<2.0			9.6
Sediment	River Parrett	2[E]				<0.56	<2.1			24
Sediment	Weston-Super-Mare	2[E]				<0.30	<2.0			1.5
Sediment	Burnham-On-Sea	2[E]				<0.37	<2.0			1.3
Sediment	Kilve	2[E]				<0.89	<2.0			12
Sediment	Blue Anchor Bay	2[E]				<0.30	<2.7			1.5
Seawater	Pipeline	2[E]				<0.25	<0.040		<0.24	<0.20

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	Stolford	2			<0.10				
Shrimps	Stolford	2	0.000089	0.00048	0.00068	*	*		
Limpets	Stolford	1			<0.23				
Porphyra	Stolford	2			<0.04				
Seaweed	Pipeline	2[E]			<0.67				
Sediment	Watchet Harbour	2[E]			<0.75				
Sediment	Pipeline	2[E]			<0.58				
Sediment	Stolford	2[E]			<1.4				
Sediment	Steart Flats	2[E]			<0.75				
Sediment	River Parrett	2[E]			<1.1				
Sediment	Weston-Super-Mare	2[E]			<0.47				
Sediment	Burnham-On-Sea	2[E]			<0.42				
Sediment	Kilve	2[E]			<1.2				
Sediment	Blue Anchor Bay	2[E]			<0.49				
Seawater	Pipeline	2[E]			<0.30			<2.9	12

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		6	<4.6	21	<0.29	<0.17	<0.20		
Milk	max		<5.0	24	<0.40	<0.20			
Apples		1	<4.0	14	<0.10	<0.30	<0.30		
Barley		1	<8.0	110	1.4	<0.20	<0.20		
Blackberries		1	<4.0	26	0.40	<0.20	<0.10		
Cabbage		1	<4.0	12	0.70	<0.20	<0.20		
Carrots		1	5.0	7.0	<0.10	<0.10	<0.20		
Honey		1	8.0	120	<0.10	<0.10	<0.10		
Lettuce		1	5.0	9.0	0.40	<0.20	<0.20		
Potatoes		1	<4.0	19	0.70	<0.30	<0.20		
Freshwater	Durleigh Reservoir	2[E]	<3.4		<0.47	<0.24	<0.20	<0.055	0.19
Freshwater	Ashford Reservoir	2[E]	<2.9		<2.1	<0.24	<0.19	<0.045	<0.13

* *Not detected by the method used*

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

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

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

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

Table 4.7(b). Monitoring of radiation dose rates near Hinkley Point nuclear power stations, 2012

Location	Ground type	No. of sampling observations	μGy h^{-1}
Mean gamma dose rates at 1m over substrate			
Weston-Super-Mare	Mud and sand	4	0.068
Burnham	Mud and sand	4	0.065
River Parrett	Grass and mud	3	0.075
River Parrett	Salt marsh	1	0.073
Steart Flats	Mud	4	0.078
Stolford	Mud	1	0.085
Stolford	Mud and sand	3	0.085
Hinkley Point	Mud and pebbles	3	0.092
Hinkley Point	Mud and shingle	1	0.091
Kilve	Mud and rock	4	0.087
Watchet Harbour	Mud and sand	1	0.098
Watchet Harbour	Mud and stones	1	0.10
Watchet Harbour	Sand and stones	1	0.10
Watchet Harbour	Sand and pebbles	1	0.10
Blue Anchor Bay	Mud and sand	3	0.073
Blue Anchor Bay	Sand and pebbles	1	0.071

Table 4.7(c). Additional programme of monitoring of radiation dose rates near Hinkley Point B nuclear power station, 2012*

Monitoring Location	Monitor 2	Monitor 7	Monitor 12	Mean μGy h^{-1}
Location 1	0.103	0.1039	0.1111	0.106
Location 2	0.112	0.1097	0.1054	0.109
Location 3	0.1079	0.1108	0.1041	0.108
Location 4	0.0926	0.1027	0.1026	0.099
Location 5	0.0986	0.1021	0.1027	0.101
Location 6	0.1001	0.1094	0.1056	0.105
Location 7	0.104	0.0994	0.1076	0.104
Location 8	0.0975	0.1029	0.108	0.103
Location 9	0.0993	0.0973	0.1113	0.103
Location 10	0.0988	0.1016	0.1031	0.101
Location 11	0.106	0.1047	0.1046	0.105
Location 12	0.098	0.0969	0.1008	0.099
Location 13	0.1068	0.1006	0.1083	0.105
Location 14	0.1039	0.1081	0.1041	0.105
Location 15	0.0931	0.0899	0.0956	0.093
Location 16	0.0882	0.0876	0.0893	0.088
Location 17	0.0808	0.0897	0.0918	0.087
Location 18	0.0917	0.0911	0.0856	0.089

** Dose rates include the instrument response to cosmic radiation*

Table 4.8(a). Concentrations of radionuclides in food and the environment near Sizewell nuclear power stations, 2012

Material	Location	No. of sampling observations	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}				
			^{3}H	^{14}C	^{137}Cs	^{238}Pu	^{239}Pu + ^{240}Pu
Marine samples							
Cod	Sizewell	2	<25		0.21		
Sole	Sizewell	2	<25		<0.08		
Crabs	Sizewell	2		38	0.09	0.000053	0.00063
Lobsters	Sizewell	1			0.14	0.000044	0.00037
Pacific oysters	Butley Creek	1			0.04		
Pacific oysters	Blyth Estuary	1			0.07		
Mussels	River Alde	2	<30		<0.09		
Sediment	Rifle range	2[E]			<0.44		
Sediment	Aldeburgh	2[E]			<0.44		
Sediment	Southwold	2[E]			8.6		
Seawater	Sizewell	2[E]	<3.7		<0.21		

Material	Location	No. of sampling observations	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}				
			^{241}Am	^{242}Cm	^{243}Cm + ^{244}Cm	Gross alpha	Gross beta
Marine samples							
Cod	Sizewell	2	<0.04				
Sole	Sizewell	2	<0.12				
Crabs	Sizewell	2	0.00091	*	*		
Lobsters	Sizewell	1	0.00083	*	0.000023		
Pacific oysters	Butley Creek	1	<0.04				
Pacific oysters	Blyth Estuary	1	<0.07				
Mussels	River Alde	2	<0.15				
Sediment	Rifle range	2[E]	<0.63				
Sediment	Aldeburgh	2[E]	<0.64				
Sediment	Southwold	2[E]	<1.4				920
Seawater	Sizewell	2[E]	<0.31			<3.4	15

Material	Location or selection[b]	No. of sampling observ-ations[c]	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}					
			^{3}H	^{14}C	^{35}S	^{137}Cs	Gross alpha	Gross beta
Terrestrial samples								
Milk		4	<4.3	17	<0.27	<0.19		
Milk	max		<4.5	20	<0.33	<0.20		
Apples		1	<4.0	10	<0.10	<0.30		
Barley		1	<7.0	88	1.1	<0.10		
Blackberries		1	<4.0	13	<0.10	<0.20		
Cabbage		1	<4.0	15	<0.20	<0.20		
Honey		1	<7.0	94	<0.10	<0.20		
Onions		1	<4.0	11	<0.10	<0.20		
Potatoes		1	<5.0	23	0.20	<0.20		
Runner beans		1	<4.0	6.0	0.40	<0.20		
Freshwater	Nature Reserve	2[E]	<3.0		<1.1	<0.20	<0.034	0.24
Freshwater	The Meare	2[E]	<3.0		<1.2	<0.19	<0.056	0.33
Freshwater	Leisure Park	2[E]	<4.2		<2.0	<0.20	<0.048	0.26

* *Not detected by the method used*

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

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

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

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

Table 4.8(b). Monitoring of radiation dose rates near Sizewell, 2012

Location	Ground type	No. of sampling observations	μGy h^{-1}
Mean gamma dose rates at 1m over substrate			
Sizewell Beach	Sand and shingle	2	0.055
Dunwich	Sand and shingle	2	0.057
Rifle Range	Sand and shingle	2	0.055
Aldeburgh	Sand and shingle	2	0.056
Southwold Harbour	Mud	2	0.074

Table 4.9(a). Concentrations of radionuclides in food and the environment near Chapelcross nuclear power station, 2012

Material	Location	No. of sampling observ-ations	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}							
			^{3}H	^{14}C	^{60}Co	^{90}Sr	^{99}Tc	^{106}Ru	^{125}Sb	^{137}Cs
Marine samples										
Flounder	Inner Solway	2		28	<0.13	<0.10	5.6	<1.2	<0.33	11
Salmon	Inner Solway	1	<5.0		<0.10			<0.97	<0.26	0.36
Sea trout	Inner Solway	1	<5.0		<0.10			<1.2	<0.28	0.13
Shrimps	Inner Solway	2	4.9		<0.11	<0.10	2.7	<1.1	<0.30	1.9
Cockles	North Solway	1			0.25			<0.31	<0.10	2.1
Mussels	North Solway	4	<4.8	48	<0.15	0.42	15	<0.68	<0.20	2.5
Winkles	Southerness	4	<5.0		<0.12	0.21	16	<0.70	<0.20	1.0
Fucus vesiculosus	Pipeline	4			<0.10		57	<0.39	<0.11	4.2
Fucus vesiculosus	Browhouses	4			<0.14			<0.43	<0.13	6.7
Sediment	Pipeline	4	<5.0		0.54			<1.0	0.73	130
Sediment	Powfoot	1			<0.10			<0.57	<0.18	1.7
Sediment	Redkirk	1			0.18			<0.86	<0.30	50
Sediment	Southerness	1			<0.10			<0.73	<0.24	19
Seawater	Pipeline	4	<3.0		<0.10			<0.65	<0.18	<0.11
Seawater	Southerness	4	3.0		<0.10			<0.56	<0.16	<0.12

Material	Location	No. of sampling observ-ations	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}							
			^{154}Eu	^{155}Eu	^{238}Pu	^{239}Pu + ^{240}Pu	^{241}Pu	^{241}Am	Gross alpha	Gross beta
Marine samples										
Flounder	Inner Solway	2	<0.15	<0.26	<0.0011	0.0027		0.0051		
Salmon	Inner Solway	1	<0.13	<0.22				<0.14		
Sea trout	Inner Solway	1	<0.14	<0.25				<0.15		
Shrimps	Inner Solway	2	<0.14	<0.24	0.0039	0.019		0.037		
Cockles	North Solway	1	<0.10	0.14	0.47	2.8		8.9		
Mussels	North Solway	4	<0.12	<0.17	0.38	2.1	11	4.2		
Winkles	Southerness	4	<0.11	<0.18	0.12	0.64	3.1	1.4		
Fucus vesiculosus	Pipeline	4	<0.10	<0.15	0.25	1.4		2.0	4.0	290
Fucus vesiculosus	Browhouses	4	<0.10	<0.25				5.6	8.0	310
Sediment	Pipeline	4	0.38	1.2	11	65		140		
Sediment	Powfoot	1	<0.16	<0.34	<0.11	0.39		0.65		
Sediment	Redkirk	1	<0.17	0.49	5.7	28		44		
Sediment	Southerness	1	<0.15	0.65	3.6	18		34		
Seawater	Pipeline	4	<0.10	<0.15				<0.11		
Seawater	Southerness	4	<0.10	<0.14	0.00046	0.0028		0.0020		

Table 4.9(a). continued

Material	Location or selection[b]		No. of sampling observ-ations[c]	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}					
				^{3}H	^{14}C	^{35}S	^{60}Co	^{90}Sr	^{125}Sb
Terrestrial samples									
Milk			12	<6.8	<15	<0.61	<0.05	<0.10	
Milk		max		21	20	<0.78			
Apples			3	<5.0	<27	<0.50	<0.08	<0.17	
Apples		max			49		<0.13	0.27	
Beef muscle			1	<5.0	34	<0.50	<0.05	<0.10	
Cabbage			2	<6.2	<15	<0.50	<0.05	<0.10	
Cabbage		max		7.4				0.11	
Carrots			1	<5.0	28	<0.50	<0.05	0.15	
Cereals			1	<5.0	61	<0.50	<0.05	0.20	
Duck			3	<5.5	33	<0.81	<0.07	<0.10	
Duck		max		6.4	36	<0.88	<0.09		
Goose			5	<6.8	27	<0.76	<0.06	<0.11	
Goose		max		13	31	<0.92	<0.07	0.17	
Mixed root vegetables			1	5.0	16		<0.05	0.14	
Nettles			1	5.3	16	<0.70	<0.05	2.5	
Rosehips			1	<5.0	40	<0.50	<0.05	1.1	
Wild blackberries			1	4.2	20	<0.50	<0.05	0.38	
Grass			4	<21	22	<0.57	<0.05	0.28	
Grass		max		36	28	0.77		0.50	
Soil			4	<11	<19	<2.8	<0.05	0.88	0.09
Soil		max		25	<24	<3.4		1.2	
Freshwater	Purdomstone		1	1.5			<0.01		
Freshwater	Winterhope		1	2.0			<0.01		
Freshwater	Black Esk		1	1.8			<0.01		
Freshwater	Gullielands Burn		1	47			<0.01		
Rainwater	Creca		48	<31					
Rainwater		max		200					

Material	Location or selection[b]		No. of sampling observ-ations[c]	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}					
				^{134}Cs	^{137}Cs	^{155}Eu	^{241}Am	Gross alpha	Gross beta
Terrestrial samples									
Milk			12	<0.05	<0.05		<0.06		
Milk		max					<0.17		
Apples			3	<0.08	<0.07		<0.09		
Apples		max		<0.13	<0.12		<0.14		
Beef muscle			1	<0.05	0.07		<0.05		
Cabbage			2	<0.05	<0.05		<0.05		
Cabbage		max					<0.06		
Carrots			1	<0.05	<0.05		<0.05		
Cereals			1	<0.05	<0.05		<0.14		
Duck			3	<0.07	1.5		<0.09		
Duck		max		<0.09	1.9		<0.11		
Goose			5	<0.06	0.58		<0.10		
Goose		max		<0.08	0.89		<0.11		
Mixed root vegetables			1	<0.05	<0.05		<0.06		
Nettles			1	<0.05	<0.05		<0.07		
Rosehips			1	<0.05	<0.05		<0.06		
Wild blackberries			1	<0.05	<0.05		<0.05		
Grass			4	<0.05	<0.17		<0.10	<1.6	420
Grass		max			0.51		<0.11	4.3	460
Soil			4	<0.05	9.0	1.3	<0.18	180	1500
Soil		max		<0.07	11		<0.21	210	1600
Freshwater	Purdomstone		1	<0.01	<0.01		<0.01	<0.010	0.050
Freshwater	Winterhope		1	<0.01	<0.01		<0.01	<0.010	0.040
Freshwater	Black Esk		1	<0.01	<0.01		<0.01	<0.010	<0.010
Freshwater	Gullielands Burn		1	<0.01	<0.01		<0.01	<0.017	0.24

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

Table 4.9(b). Monitoring of radiation dose rates near Chapelcross, 2012

Location	Material or ground type	No. of sampling observations	μGy h^{-1}
Mean gamma dose rates at 1m over substrate			
Southerness	Winkle bed	4	0.063
Glencaple Harbour	Mud and sand	4	0.073
Priestside Bank	Salt marsh	4	0.064
Powfoot Merse	Mud	4	0.068
Pipeline	Sand	4	0.076
Pipeline	Salt marsh	4	0.079
Dumbretton	NA	1	0.062
Battlehill	Sand	4	0.076
Dornoch Brow	Mud and sand	4	0.073
Dornoch Brow	Salt marsh	4	0.068
Browhouses	NA	4	0.072
Redkirk	NA	4	0.068
Mean beta dose rates			μSv h^{-1}
Pipeline 500m east	NA	4	<1.0
Pipeline 500m west	NA	4	<1.0
Pipeline	Stake nets	3	<1.0

NA Not available

Table 4.9(c). Radioactivity in air near Chapelcross, 2012

Location	No. of sampling observa-tions	Mean radioactivity concentration, mBq m^{-3}		
		^{137}Cs	Gross alpha	Gross beta
Eastriggs	10	<0.010	<0.011	<0.20
Kirtlebridge	12	<0.010	<0.010	<0.20
Brydekirk	9	<0.010	<0.014	<0.20

Table 4.10(a). Concentrations of radionuclides in food and the environment near Hunterston nuclear power station, 2012

Material	Location	No. of sampling observ-ations	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}						
			^{3}H	^{35}S	^{54}Mn	^{60}Co	^{65}Zn	^{99}Tc	^{110m}Ag
Marine samples									
Cod	Millport	2			<0.11	<0.10	<0.22		<0.13
Hake	Millport	1			<0.10	<0.10	<0.22		<0.12
Crabs	Millport	2			<0.10	<0.10	<0.19	0.94	<0.10
Nephrops	Millport	1			<0.10	<0.10	<0.22		<0.11
Lobsters	Largs	1			<0.10	<0.10	<0.19	14	<0.10
Squat lobsters	Largs	2			<0.11	<0.11	<0.26	10	<0.13
Mussels	Hunterston	1			<0.10	<0.10	<0.17		<0.10
Winkles	Pipeline	2			<0.12	<0.13	<0.27		<0.86
Scallops	Largs	3			<0.11	<0.10	<0.29		<0.12
Oysters	Hunterston	1			<0.10	<0.10	<0.10		0.43
Fucus vesiculosus	N of pipeline	2			<0.36	0.27	<0.11		<0.35
Fucus vesiculosus	S of pipeline	2			<0.13	<0.20	<0.14		<0.13
Sediment	Millport	1			<0.10	<0.10	<0.14		<0.10
Sediment	Gull's Walk	1			<0.10	<0.10	<0.10		<0.10
Sediment	Ardneil Bay	1			<0.10	<0.10	<0.12		<0.10
Sediment	Fairlie	1			<0.10	<0.10	<0.17		<0.10
Sediment	Pipeline	1			<0.10	<0.10	<0.16		<0.10
Seawater	Pipeline	2	4.8	<0.63	<0.10	<0.10	<0.15		<0.10
Seawater	S of pipeline	2	1.2	<0.55	<0.10	<0.10	<0.15		<0.10

Material	Location	No. of sampling observ-ations	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}					
			^{125}Sb	^{137}Cs	^{155}Eu	^{239}Pu+ ^{238}Pu	^{240}Pu	^{241}Am
Marine samples								
Cod	Millport	2	<0.19	1.0	<0.18			<0.12
Hake	Millport	1	<0.21	1.1	<0.18			<0.12
Crabs	Millport	2	<0.19	0.20	<0.16	0.0013	0.0083	0.015
Nephrops	Millport	1	<0.22	0.82	<0.18			<0.11
Lobsters	Largs	1	<0.21	0.21	<0.20			<0.12
Squat lobsters	Largs	2	<0.24	0.43	<0.20	0.0028	0.022	0.019
Mussels	Hunterston	1	<0.18	0.21	<0.15			<0.10
Winkles	Pipeline	2	<0.23	<0.20	<0.17	0.012	0.060	0.029
Scallops	Largs	3	<0.26	0.24	<0.22	0.0067	0.048	0.014
Oysters	Hunterston	1	<0.11	0.17	<0.10			<0.10
Fucus vesiculosus	N of pipeline	2	<0.11	0.42	<0.11			<0.10
Fucus vesiculosus	S of pipeline	2	<0.14	0.36	<0.13			<0.10
Sediment	Millport	1	<0.13	3.9	<0.18			<0.17
Sediment	Gull's Walk	1	0.14	7.3	0.47			0.78
Sediment	Ardneil Bay	1	<0.12	2.2	<0.20			<0.21
Sediment	Fairlie	1	<0.14	3.4	<0.25			<0.19
Sediment	Pipeline	1	<0.14	3.3	<0.19			<0.18
Seawater	Pipeline	2	<0.14	<0.10	<0.13			<0.10
Seawater	S of pipeline	2	<0.13	<0.10	<0.12			<0.10

Table 4.10(a). continued

Material	Selection[b]	No. of sampling observ-ations[c]	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}					
			^{3}H	^{14}C	^{35}S	^{60}Co	^{90}Sr	^{110m}Ag
Terrestrial Samples								
Milk		5	<5.0	<15	<0.55	<0.05	<0.10	<0.05
Milk	max			<17	<0.59			
Apples		1	<5.0	<15	<0.50	<0.05	0.11	<0.05
Beef muscle		1	<5.0	44	<0.83	<0.05	<0.10	<0.05
Broad beans		1	<5.0	<15		<0.05	0.23	<0.05
Eggs		1	<5.0	33		<0.05	<0.10	<0.05
Honey		1	<5.0	94		<0.14	<0.10	<0.15
Kale		1	<5.0	17	<0.50	<0.05	0.24	<0.05
Pheasant		3	<5.0	23	<0.50	<0.05	<0.10	<0.05
Pheasant	max			29				<0.06
Potatoes		2	<5.0	<18	<0.50	<0.05	<0.10	<0.05
Potatoes	max			21				
Rabbit		1	<5.0	24	<0.62	<0.07	<0.10	<0.07
Rosehips		2	<5.0	25	<0.50	<0.05	0.73	<0.05
Rosehips	max			29			1.1	
Rowan berries		1	<5.0	25	<0.50	<0.05		<0.05
Wild blackberries		1	<5.0	41	<0.50	<0.08	0.72	<0.07
Grass		3	<5.0	<17	<0.77	<0.05	0.34	<0.05
Grass	max			18	1.3		0.47	
Soil		3	<5.0	<15	<0.50	<0.05	1.2	<0.05
Soil	max						1.8	
Freshwater	Knockenden	1	<1.0			<0.01		<0.01
Freshwater	Loch Ascog	1	<1.0			<0.01		<0.01
Freshwater	Munnoch Reservoir	1	<1.0			<0.01		<0.01
Freshwater	Camphill	1	<1.0			<0.01		<0.01
Freshwater	Outerwards	1	<1.0			<0.01		<0.01

Material	Selection[b]	No. of sampling observ-ations[c]	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}				
			^{137}Cs	^{155}Eu	^{241}Am	Gross alpha	Gross beta
Terrestrial Samples							
Milk		5	<0.05		<0.06		
Milk	max		<0.06				
Apples		1	<0.05		<0.05		
Beef muscle		1	0.24		<0.09		
Broad beans		1	<0.05		<0.06		
Eggs		1	<0.05		<0.05		
Honey		1	0.72		<0.20		
Kale		1	0.10		<0.05		
Pheasant		3	0.30		<0.08		
Pheasant	max		0.38		<0.13		
Potatoes		2	0.09		<0.06		
Potatoes	max		0.12				
Rabbit		1	0.16		<0.092		
Rosehips		2	<0.09		<0.10		
Rosehips	max		0.13		<0.13		
Rowan berries		1	<0.05		<0.05		
Wild blackberries		1	0.11		<0.11		
Grass		3	0.09		<0.10	0.55	260
Grass	max		0.11		<0.13	0.75	330
Soil		3	9.7	0.52	<0.15	91	940
Soil	max		10	0.57	<0.17	110	1300
Freshwater	Knockenden	1	<0.01		<0.01	<0.0093	0.046
Freshwater	Loch Ascog	1	<0.01		<0.01	<0.010	0.086
Freshwater	Munnoch Reservoir	1	<0.01		<0.01	<0.010	0.050
Freshwater	Camphill	1	<0.01		<0.01	<0.010	0.020
Freshwater	Outerwards	1	<0.01		<0.01	<0.010	0.040

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

Table 4.10(b). Monitoring of radiation dose rates near Hunterston nuclear power station, 2012

Location	Ground type	No. of sampling observa-tions	μGy h^{-1}
Mean gamma dose rates at 1m over intertidal areas			
Largs Bay	Stones	2	0.056
Kilchatten Bay	Sand	2	<0.047
Millport	Sand	2	<0.047
Gull's Walk	Mud	2	0.059
0.5 km north of pipeline	Sand	2	<0.052
0.5 km south of pipeline	Sand and stones	2	<0.049
Ardneil Bay	NA	2	<0.045
Ardrossan Bay	NA	2	<0.047
Milstonford	NA	2	0.050
Biglies	NA	2	0.057
Beta dose rates			μSv h^{-1}
Millport	Sand	1	<1.0
0.5 km north of pipeline	Sand	1	<1.0
0.5 km south of pipeline	Sand and stones	1	<1.0

NA Not available

Table 4.10(c). Radioactivity in air near Hunterston, 2012

Location	No. of sampling observa-tions	Mean radioactivity concentration, mBq m^{-3}		
		^{137}Cs	Gross alpha	Gross beta
Fencebay	11	<0.011	<0.010	<0.20
West Kilbride	12	<0.010	<0.0089	<0.20
Low Ballees	11	<0.010	<0.0094	<0.20

Table 4.11(a). Concentrations of radionuclides in food and the environment near Torness nuclear power station, 2012

Material	Location	No. of sampling observ-ations	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}					
			^{54}Mn	^{60}Co	^{65}Zn	^{99}Tc	^{110m}Ag	^{137}Cs
Marine samples								
Bass	Pipeline	1	<0.10	<0.10	0.16		<0.10	0.35
Crabs[d]	Torness	1	<0.11	<0.12	<0.30	0.53	<0.11	<0.10
Lobsters	Torness	1	<0.11	<0.11	<0.29	5.5	<0.11	<0.10
Nephrops	Dunbar	2	<0.10	<0.10	<0.21		<0.11	<0.10
Winkles	Pipeline	2	<0.19	0.31	<0.21		7.4	<0.17
Fucus vesiculosus	Pipeline	2	0.74	0.84	<0.15		<0.90	0.12
Fucus vesiculosus	Thornton Loch	2	0.74	<0.67	<0.12	22	<0.47	<0.10
Fucus vesiculosus	White Sands	2	<0.10	<0.10	<0.15		<0.10	0.15
Fucus vesiculosus	Pease Bay	2	<0.10	<0.10	<0.18		<0.10	<0.10
Fucus vesiculosus	Coldingham Bay	2	<0.10	<0.10	<0.12		<0.10	<0.10
Sediment	Dunbar	1	<0.10	<0.10	<0.21		<0.10	1.4
Sediment	Barns Ness	1	<0.10	<0.10	<0.15		<0.10	1.5
Sediment	Thornton Loch	1	<0.10	<0.10	<0.10		<0.10	1.1
Sediment	Heckies Hole	1	<0.10	<0.10	<0.14		<0.10	1.3
Sediment	Belhaven Bay	1	<0.10	<0.10	<0.19		<0.10	1.2
Salt marsh	Coldingham Bay	1	<0.10	<0.10	<0.22		<0.10	0.89
Seawater[e]	Pipeline	2	<0.10	<0.10	<0.16		<0.10	<0.10

Material	Location	No. of sampling observ-ations	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}					
			^{155}Eu	^{238}Pu	^{239}Pu+ ^{240}Pu	^{241}Am	Gross alpha	Gross beta
Marine samples								
Bass	Pipeline	1	<0.14			<0.10		
Crabs[d]	Torness	1	<0.20			<0.12		
Lobsters	Torness	1	<0.21			<0.17		
Nephrops	Dunbar	2	<0.15	0.00073	0.0056	0.0087		
Winkles	Pipeline	2	<0.15			<0.11	1.3	130
Fucus vesiculosus	Pipeline	2	<0.13			<0.10		
Fucus vesiculosus	Thornton Loch	2	<0.10			<0.10		
Fucus vesiculosus	White Sands	2	<0.14			<0.11		
Fucus vesiculosus	Pease Bay	2	<0.14			<0.10		
Fucus vesiculosus	Coldingham Bay	2	<0.10			<0.10		
Sediment	Dunbar	1	0.55			<0.23		
Sediment	Barns Ness	1	<0.22			<0.25		
Sediment	Thornton Loch	1	0.35			<0.12		
Sediment	Heckies Hole	1	0.61			<0.17		
Sediment	Belhaven Bay	1	<0.27			<0.33		
Salt marsh	Coldingham Bay	1	0.47			<0.23		
Seawater[e]	Pipeline	2	<0.13			<0.10		

Table 4.11(a). continued

Material	Location or Selection[b]	No. of sampling observ-ations[c]	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}					
			^{3}H	^{14}C	^{35}S	^{60}Co	^{90}Sr	^{95}Nb
Terrestrial Samples								
Milk		1	<5.0	<15	<0.71	<0.05	<0.10	<0.25
Apples		1	<5.0	17	<0.50	<0.05	<0.10	<0.06
Barley		1	<5.0	92	<0.70	<0.05	0.28	<0.12
Brussel sprouts		1	<5.0	18	<2.9	<0.05	0.16	<0.07
Cabbage		1	<5.0	17	<0.50	<0.05	<0.10	<0.07
Carrots		1	<5.0	<15	<0.50	<0.05	<0.10	<0.05
Hawthorn berries		1	<5.0	68	<0.50	<0.07	0.41	<0.13
Parsnips		1	<5.0	25	<0.50	<0.05	0.17	<0.12
Pheasant		2	<5.0	26	<0.86	<0.05	<0.10	<0.09
Pheasant	max			30	<0.89			<0.11
Potatoes		1	<5.0	20		<0.05	<0.10	<0.11
Rhubarb		1	<5.0	<15	<0.50	<0.05	<0.10	<0.09
Rosehips		1	<5.0	53	<0.50	<0.05	0.37	<0.05
Swede		1	<5.0	<15	<0.50	<0.05	<0.10	<0.09
Wild Blackberries		1	<5.0	16	<0.50	<0.05	<0.10	<0.05
Grass		3	<5.0	24	<0.50	<0.05	<0.31	<0.16
Grass	max			33	<0.51		0.54	
Soil[f]		3	<5.0	<15	<2.7	<0.05	<0.66	<0.19
Soil[f]	max				<3.9	<0.06	0.81	<0.28
Freshwater	Hopes Reservoir	1	<1.0			<0.01		<0.04
Freshwater	Thorter's Reservoir	1	<1.0			<0.01		<0.02
Freshwater	Whiteadder	1	1.0			<0.01		<0.02
Freshwater	Thornton Loch Burn	1	<1.0			<0.01		<0.05

Material	Location or Selection[b]	No. of sampling observ-ations[c]	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}				
			^{110m}Ag	^{137}Cs	^{241}Am	Gross alpha	Gross beta
Terrestrial Samples							
Milk		1	<0.05	<0.05	<0.06		
Apples		1	<0.05	<0.05	<0.05		
Barley		1	<0.05	<0.05	<0.10		
Brussel sprouts		1	<0.05	<0.05	<0.14		
Cabbage		1	<0.05	<0.05	<0.07		
Carrots		1	<0.05	<0.05	<0.05		
Hawthorn berries		1	<0.06	<0.06	<0.09		
Parsnips		1	<0.05	<0.05	<0.09		
Pheasant		2	<0.05	0.12	<0.06		
Pheasant	max			0.18			
Potatoes		1	<0.05	<0.05	<0.08		
Rhubarb		1	<0.05	<0.05	<0.05		
Rosehips		1	<0.05	<0.05	<0.09		
Swede		1	<0.05	<0.05	<0.05		
Wild Blackberries		1	<0.05	<0.05	<0.05		
Grass		3	<0.05	<0.05	<0.09	<0.84	520
Grass	max				<0.10	1.1	600
Soil[f]		3	<0.07	6.8	<0.20	180	1500
Soil[f]	max		<0.08	8.4	<0.24	200	1600
Freshwater	Hopes Reservoir	1	<0.01	<0.01	<0.01	<0.010	0.040
Freshwater	Thorter's Reservoir	1	<0.01	<0.01	<0.01	<0.013	0.020
Freshwater	Whiteadder	1	<0.01	<0.01	<0.01	<0.014	0.030
Freshwater	Thornton Loch Burn	1	<0.01	<0.01	<0.01	<0.011	0.041

[a] *Except for milk and seawater where units are Bq l^{-1} and for sediment and soil where dry concentrations apply*
[b] *Data are arithmetic means unless stated as 'max' in this column. 'Max' data are selected to be maxima. If no 'max' value is given the mean value is the most appropriate for dose assessments*
[c] *The number of farms from which milk is sampled. The number of analyses is greater than this and depends on the bulking regime*
[d] *The concentration of ^{14}C was 23 Bq kg^{-1}*
[e] *The concentrations of ^{3}H and ^{35}S were <1.0 and <0.77 Bq l^{-1} respectively*
[f] *The concentration of ^{155}Eu was 1.2 (max 1.4) Bq kg^{-1}*

Table 4.11(b). Monitoring of radiation dose rates near Torness nuclear power station, 2012

Location	Ground type	No. of sampling observa-tions	μGy h^{-1}
Mean gamma dose rates at 1m over intertidal areas			
Heckies Hole	Sediment	2	<0.048
Dunbar Inner Harbour	Sand	2	0.082
Belhaven Bay	Salt marsh	2	0.063
Barns Ness	Mud, sand and stones	2	0.061
Skateraw	Sand	2	0.054
Thornton Loch	Sand	2	0.047
Pease Bay	Sand	2	0.061
St Abbs Head	Mud	2	0.085
Coldingham Bay	Sand	2	0.053
West Meikle Pinkerton	Sediment	2	0.063
Mean beta dose rates on fishing gear			μSv h^{-1}
Torness	Lobster Pots	2	<1.0
Dunbar Harbour	Nets	2	<1.0

Table 4.11(c). Radioactivity in air near Torness, 2012

Location	No. of sampling observa-tions	Mean radioactivity concentration, mBq m^{-3}		
		^{137}Cs	Gross alpha	Gross beta
Innerwick	12	<0.010	<0.011	<0.20
Cockburnspath	11	<0.010	<0.0094	<0.20

Table 4.12(a). Concentrations of radionuclides in food and the environment near Trawsfynydd nuclear power station, 2012

Material	Location	No. of sampling observ-ations	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}						
			^{3}H	^{35}S	^{60}Co	^{90}Sr	^{134}Cs	^{137}Cs	^{154}Eu
Freshwater samples									
Brown trout[b]	Trawsfynydd Lake	6			<0.17	0.46	<0.24	42	<0.53
Rainbow trout	Trawsfynydd Lake	6			<0.27		<0.27	2.1	<0.80
Pike	Trawsfynydd Lake	1			<0.07		0.27	60	<0.24
Sediment	Lake shore	2[E]			<0.55	<2.0	<0.61	530	
Sediment	Bailey Bridge	2[E]			<2.3	9.7	<2.1	820	
Sediment	Fish farm	2[E]			1.8	<2.0	<0.69	960	
Sediment	Footbridge	2[E]			<0.54	<2.0	<0.51	280	
Sediment	Cae Adda	2[E]			<0.35	<2.0	<0.32	78	
Freshwater	Public supply	2[E]	<2.9	<3.0	<0.23		<0.24	<0.20	
Freshwater	Gwylan Stream	2[E]	<2.8	<2.2	<0.24		<0.25	<0.20	
Freshwater	Hot Lagoon	2[E]	<3.0	<1.6	<0.24		<0.25	<0.19	
Freshwater	Afon Prysor	2[E]	<2.8	<1.9	<0.24		<0.25	<0.20	
Freshwater	Trawsfynydd Lake	2[E]	<2.8	<0.78	<0.22		<0.21	<0.17	
Freshwater	Afon Tafarn-helyg	2[E]	<3.2	<1.4	<0.25		<0.27	<0.20	

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									
Brown trout[b]	Trawsfynydd Lake	6	0.000020	0.000089	0.00018	*	*		
Rainbow trout	Trawsfynydd Lake	6			<0.30				
Pike	Trawsfynydd Lake	1			<0.28				
Sediment	Lake shore	2[E]	<0.75	<1.3	2.2				
Sediment	Bailey Bridge	2[E]	2.0	7.7	15				
Sediment	Fish farm	2[E]	3.0	9.5	17				
Sediment	Footbridge	2[E]	<0.60	0.91	1.9				
Sediment	Cae Adda	2[E]	<0.70	<0.61	<1.2				
Freshwater	Public supply	2[E]						<0.028	<0.073
Freshwater	Gwylan Stream	2[E]						<0.033	<0.076
Freshwater	Hot Lagoon	2[E]						<0.025	0.081
Freshwater	Afon Prysor	2[E]						<0.028	<0.077
Freshwater	Trawsfynydd Lake	2[E]						<0.027	<0.076
Freshwater	Afon Tafarn-helyg	2[E]						<0.028	<0.099

Table 4.12(a). continued

Material	Selection[c]	No. of sampling observations[d]	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}				
			^{3}H	^{14}C	^{60}Co	^{90}Sr	^{134}Cs
Terrestrial Samples							
Milk		2	<4.0	21	<0.14	0.030	
Milk	max				<0.15	0.035	
Apples		1	<4.0	14	<0.20		<0.20
Blackberries		1	<4.0	13	<0.20		<0.20
Courgettes		1	5.0	<3.0	<0.20		<0.20
Eggs		1	<6.0	52	<0.20		<0.20
Potatoes		1	<5.0	25	<0.10		<0.10
Sheep muscle		2	<5.5	28	<0.15	0.0095	
Sheep muscle	max		6.0		<0.20	0.012	
Sheep offal		2	<8.0	31	<0.15	0.29	
Sheep offal	max			36	<0.20	0.50	

Material	Selection[c]	No. of sampling observations[d]	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}				
			^{137}Cs	Total Cs	^{238}Pu	^{239}Pu + ^{240}Pu	^{241}Am
Terrestrial Samples							
Milk		2		0.12			
Milk	max			0.13			
Apples		1	<0.20		0.00010	0.00010	<0.00020
Blackberries		1	<0.20		0.00010	<0.00010	0.00030
Courgettes		1	<0.20				
Eggs		1	<0.20		<0.00010	0.00010	0.00030
Potatoes		1	<0.20		0.00010	0.00020	0.00020
Sheep muscle		2		2.1	<0.00010	0.00020	<0.00025
Sheep muscle	max			2.6			0.00030
Sheep offal		2		0.73	<0.00010	0.00020	<0.00020
Sheep offal	max			0.81	0.00010		0.00020

* *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 ^{14}C was 24 Bq kg^{-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 4.12(b). Monitoring of radiation dose rates near Trawsfynydd nuclear power station, 2012

Location	Ground type	No. of sampling observations	μGy h^{-1}
Mean gamma dose rates at 1m over substrate			
Footbridge	Pebbles and stones	2	0.098
Lake shore	Pebbles and stones	2	0.096
Bailey Bridge	Grass	1	0.074
Bailey Bridge	Grass and leaves	1	0.076
Fish Farm	Pebbles and stones	2	0.10
Cae Adda	Pebbles and stones	2	0.085

Table 4.13(a). Concentrations of radionuclides in food and the environment near Wylfa nuclear power station, 2012

Material	Location	No. of sampling observ-ations	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}						
			Organic ^{3}H	^{3}H	^{14}C	^{99}Tc	^{137}Cs	^{238}Pu	^{239}Pu + ^{240}Pu
Marine samples									
Plaice	Pipeline	2	<25	<25	45		1.0		
Bass	Outfall	1					1.7		
Crabs	Pipeline	2				1.2	0.52	0.0036	0.021
Lobsters	Pipeline	2				20	0.42		
Winkles	Cemaes Bay	2	<25	<25	29		0.65	0.036	0.25
Seaweed	Cemaes Bay	2[E]				51	1.2		
Sediment	Cemaes Bay	2[E]					3.4		
Sediment	Cemlyn Bay West	2[E]					3.5		
Seawater	Cemaes Bay	2[E]		<3.6			<0.20		
Seawater	Cemlyn Bay West	2[E]					<0.20		

Material	Location	No. of sampling observ-ations	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}					
			^{241}Pu	^{241}Am	^{242}Cm	^{243}Cm + ^{244}Cm	Gross alpha	Gross beta
Marine samples								
Plaice	Pipeline	2		<0.06				
Bass	Outfall	1		<0.11				
Crabs	Pipeline	2		0.096	*	0.00017		
Lobsters	Pipeline	2		0.06				120
Winkles	Cemaes Bay	2	<1.7	0.37	*	*		
Seaweed	Cemaes Bay	2[E]		<0.66				
Sediment	Cemaes Bay	2[E]		1.5				
Sediment	Cemlyn Bay West	2[E]		1.8				
Seawater	Cemaes Bay	2[E]		<0.31			<2.7	9.0
Seawater	Cemlyn Bay West	2[E]		<0.31			<4.2	21

Material	Location or selection[b]	No. of sampling observ-ations[c]	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}					
			^{3}H	^{14}C	^{35}S	^{137}Cs	Gross alpha	Gross beta
Terrestrial samples								
Milk		5	<4.3	19	<0.36	<0.20		
Milk	max		<4.5	21	<0.43			
Apples		1	4.0	9.0	<0.10	<0.20		
Barley		1	<7.0	96	1.8	<0.20		
Blackberries		1	<4.0	20	0.70	<0.20		
Broad beans		1	<5.0	26	0.90	<0.20		
Honey		1	10	93	<0.10	0.10		
Potatoes		1	6.0	8.0	0.20	<0.20		
Squash		1	6.0	8.0	0.10	<0.20		
Freshwater	Public supply	1[E]	<2.6		<1.1	<0.21	<0.025	0.19

* *Not detected by the method used*

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

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

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

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

Table 4.13(b). Monitoring of radiation dose rates near Wylfa nuclear power station, 2012

Location	Ground type	No. of sampling observations	µGy h^{-1}
Mean gamma dose rates at 1m over substrate			
Cemaes Bay	Sand	2	0.062
Cemlyn Bay West	Pebbles	2	0.071

5. Defence establishments

This section considers the results of monitoring by the Environment Agency, Food Standards Agency and SEPA undertaken routinely near nine defence-related establishments in the UK. In addition, the Ministry of Defence (MoD) makes arrangements for monitoring at other defence sites where contamination may occur. The operator at the Atomic Weapons Establishment in Berkshire carries out environmental monitoring to determine the effects from low level gaseous discharges at its sites. Monitoring at nuclear submarine berths is also conducted by the MoD (DSTL Radiological Protection Services, 2013).

The medium-term trends in doses, discharges and environmental concentrations at Aldermaston, Devonport, Faslane and Coulport, and Rosyth were considered in a summary report (Environment Agency, Food Standards Agency, Northern Ireland Environment Agency and Scottish Environment Protection Agency, 2010b).

Key points

- Public radiation doses from all sources were less than 0.5 per cent of the dose limit at all those sites assessed except at Barrow where the effects of historical discharges from Sellafield were apparent
- Discharges, environmental concentrations and dose rates in 2012 were broadly similar to those in 2011 at all establishments

Aldermaston, Berkshire

- Discharges, concentrations and public dose rates in 2012 were broadly similar to those in 2011

Barrow, Cumbria

- New habits survey used for dose assessment
- Dose at Barrow was 6 per cent of the dose limit but dominated by effects from Sellafield
- Environmental concentrations and dose rates were similar to 2011

Devonport, Devon

- Liquid discharges of tritium increased in 2012
- Environmental concentrations of radionuclides were generally below the limits of detection

5.1 Aldermaston, Berkshire

The Atomic Weapons Establishment (AWE) at Aldermaston provides and maintains the fundamental components of the UK's nuclear deterrent (Trident). The site and facilities at Aldermaston remain in Government ownership under a Government Owned Contractor Operator (GOCO) arrangement. The day-to-day operations and the maintenance of Britain's nuclear stockpile are managed, on behalf of the MoD, by AWE plc. The site is regulated by the Environment Agency to discharge low concentrations of radioactive waste to the environment. With effect from 1 November 2012, the Environment Agency issued a new discharge permit for AWE Aldermaston following a change in regulations in 2010. A few minor changes were made to the permit, required by a combination of a change in regulatory requirements and improvements to better reflect operations taking place at the site.

During September 2011, a habits survey was conducted to determine the consumption and occupancy rates by members of the public (Ly *et al.*, 2012). An increase in occupancy rates was observed compared with the previous study in 2002 and no consumption of freshwater fish or crustaceans affected by liquid discharges was recorded. With the closure of the Pangbourne pipeline in 2005, fish and shellfish consumption and riverside occupancy along the River Thames (between Pangbourne and Reading) is no longer considered as part of habits survey area. Revised figures for consumption rates, together with handling and occupancy rates, are provided in Appendix 1 (Table X2.2).

Doses to the public

In 2012, the *total dose* from all pathways and sources of radiation was less than 0.005 mSv (Table 5.1), or less than 0.5 per cent of the dose limit. Infants consuming local cows' milk at high-rates were the most exposed group.

Source specific assessments for high-rate consumers of locally grown foods, for sewage workers and for anglers, give exposures that were also less than 0.005 mSv in 2012 (Table 5.1). Estimates of activity concentrations in fish have been based on shellfish samples from the aquatic monitoring programme for dose determination, and for anglers the assessment has conservatively included consumption of fish at a low rate of 1 kg per year.

Gaseous discharges and terrestrial monitoring

Gaseous radioactive waste is discharged via stacks on the site. In November 2012, a new discharge permit was issued by the Environment Agency. The limit on krypton-85 discharges was removed, as releases of krypton-85 are now exempt from regulation (up to a limit of 1 x 10^{11} Bq per year). Additionally, the description of argon-41 discharges was changed to "Activation Products" to better reflect site operations, but the limit was unchanged.

Gaseous discharges in 2012 were generally similar to those reported in 2011. Samples of milk, terrestrial foodstuffs, grass and soil were taken from locations close to the site (Figure 3.1). Activity concentrations in milk and foodstuffs (Table 5.2(a)) were generally below the limits of detection, as in 2011. The tritium concentrations in all milk and foodstuffs were below the LoD in 2012. The tritium levels in grass and soil, at different locations to 2011, were elevated above the LoD, but are comparable to previous years. Tritium is considered in the dose assessment and is of very low significance. In soil samples, where comparisons can be drawn at the same location, concentrations of caesium-137 were similar to values in 2011. Levels of uranium isotopes also remained similar to 2011. Natural background or weapon test fallout would have made a significant contribution to the levels detected.

Liquid waste discharges and aquatic monitoring

Discharges of radioactive liquid effluent are made under permit to the sewage works at Silchester (Figure 3.1), and to the Aldermaston stream. Discharges of alpha and other beta radionuclides to Silchester in 2012 were similar to those reported in 2011; discharges of tritium to Aldermaston Stream were very low and similar to those in previous years. There are two factors behind the longer-term decline in discharges of tritium from Aldermaston (Figure 5.1): the closure and decommissioning of the original tritium facility (the replacement facility uses sophisticated abatement technology that results in the discharge of significantly less tritium into the environment), and the historical contamination of groundwater. The historical contamination has been reduced in recent years by radioactive decay and dilution by natural processes. Environmental monitoring of the River Thames (Pangbourne and Mapledurham) has continued to assess the effect of historical discharges.

Activity concentrations for freshwater, fish and sediment samples, and measurements of dose rates, are given in Tables 5.2(a) and (b). The concentrations of artificial radioactivity detected in the Thames catchment were very low and similar to those for 2011. Concentrations of tritium in freshwater samples were generally below the LoD though higher levels were found in some gullypot sediments. Activity concentrations of artificial radionuclides in River Kennet shellfish were at very low levels and similar to those reported in 2011. Analyses of radiocaesium and uranium activity levels in River Kennet sediments were broadly consistent with previous years. Gross alpha and beta activities in freshwater samples were below the WHO screening levels for drinking water, and this pathway of exposure has been shown to be insignificant (Environment Agency, 2002a).

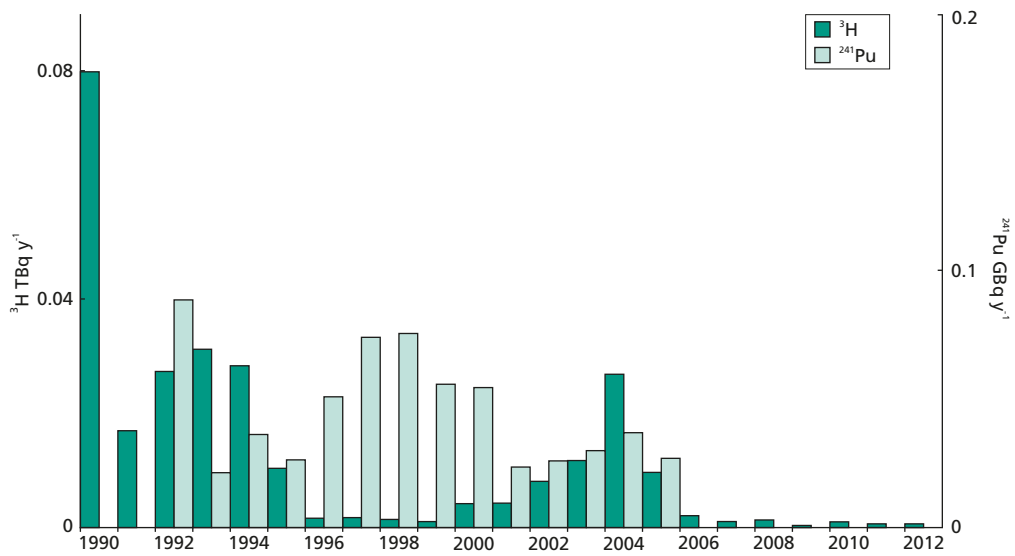


Figure 5.1. Trends in liquid discharges of tritium and plutonium-241 from Aldermaston, Berkshire 1990-2012 (including discharges to River Thames at Pangbourne, Silchester sewer and Aldermaston Stream)

5.2 Barrow, Cumbria

At Barrow, BAE Systems Marine Limited (BAESM) builds, tests and commissions new nuclear powered submarines. Discharges are made under permit and in 2012 continued to be very low. The Food Standards Agency's terrestrial monitoring is limited to grass sampling, but a larger programme operates in the marine environment in and around Barrow directed primarily at the far-field effects of Sellafield discharges. A habits survey was undertaken in 2012 (Garrod *et al*., 2013). This has allowed a full dose assessment to be introduced, making use of the marine data. The *total dose* from all pathways and sources of radiation was 0.057 mSv (Table 5.1), which was less than 6 per cent of the dose limit. The most exposed people were living on local houseboats. Virtually this entire dose was due to the effects of Sellafield discharges. No assessment of dose was made in 2011. Source specific assessments for high rate fish and shellfish consumers and for people living on local houseboats were also carried out. The doses in 2012 for both groups were less than 6 per cent of the dose limit. As for *total dose* the Sellafield source dominated.

Dose rates in intertidal areas near Barrow were slightly enhanced above those expected due to natural background (Table 5.3(b)). This enhancement was due to the far-field effects of historical discharges from Sellafield. Concentrations of radionuclides in local shellfish and sediment are included for the first time in Table 5.3(a) to support the dose assessment. These samples are taken primarily to show the effects of discharges from Sellafield. In 2012 the concentrations observed are typical of those expected at this distance from Sellafield. No effects of discharges from Barrow were apparent. Tritium activity in grass samples was below the LoD (Table 5.3(a)).

5.3 Derby, Derbyshire

Rolls-Royce Marine Power Operations Limited (RRMPOL), a subsidiary of Rolls-Royce plc, carries out design, development, testing and manufacture of nuclear-powered submarine fuel at its two adjacent sites in Derby. Small discharges of liquid effluent are made via the Megaloughton Lane Sewage Treatment Works to the River Derwent and very low concentrations of alpha activity are present in releases to atmosphere. Other wastes are disposed of by transfer to other sites, including the LLWR near Drigg. Only one habits survey has been undertaken at Derby, in 2009 (Elliott *et al*., 2010).

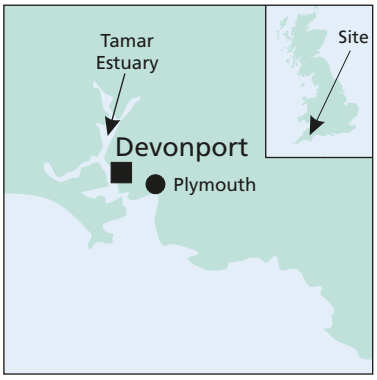
Doses to the public

In 2012, the *total dose* from all pathways and sources of radiation (based on a limited amount of monitoring data with which to perform the assessment) was less than 0.005 mSv (Table 5.1), which is less than 0.5 per cent of the dose limit. Source specific assessments for consumption of vegetables, fish and drinking river water at high-rates, and for local residents exposed to external and inhalation pathways from gaseous discharges, give exposures that were also less than 0.005 mSv in 2011 (Table 5.1).

Results of the routine monitoring programme at Derby are given in Table 5.3(a). Analysis of uranium activity in grass and soil samples taken around the site in 2011 found levels broadly consistent with previous years. More detailed analysis in previous years has shown the activity as being consistent with natural sources. Radionuclide concentrations in cabbage and sludge pellets were very low or below the limit of detection. Gross alpha and beta activities in water from the River Derwent were less than the WHO screening levels for drinking water, and the dose from using the river as a source of drinking water was much less than 0.005 mSv per year (Table 5.1).

Table 5.3(a) also includes analysis results from a water sample taken from Fritchley Brook, downstream of Hilts Quarry. RRMPOL formerly used the quarry for the controlled burial of solid low level radioactive waste. Uranium isotopes detected in the sample were similar to those levels observed elsewhere in Derbyshire (Table 9.11).

5.4 Devonport, Devon



Devonport consists of two parts: the Naval Base and Devonport Royal Dockyard, which are owned and operated by the MoD and by Babcock International Group plc, respectively. Devonport Royal Dockyard refits, refuels, repairs and maintains the Royal Navy's nuclear powered submarines 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. During June 2011, a habits survey was conducted to determine the consumption and occupancy rates by members of the public (Clyne *et al.*, 2012). A slight increase in the houseboat occupancy rate has been observed, together with a decrease in the consumption of fish, crustaceans, and molluscs, and occupancy over riverside sediment rates, in comparison with those of the previous survey in 2004. Revised figures for consumption rates, together with handling and occupancy rates, are provided in Appendix 1 (Table X2.2). The routine monitoring programme in 2012 consisted of measurements of gamma dose rate and analysis of fruit, vegetables, fish, shellfish and other marine indicator materials (Tables 5.3(a) and (b)).

Doses to the public

In 2012, the *total dose* from all pathways and sources of radiation was less than 0.005 mSv (Table 5.1), which was less than 0.5 per cent of the dose limit. Adults spending a long time over riverside sediments during houseboat occupancy received the highest exposures. Trends in *total doses* in the area of the south coast (and the Severn Estuary) are shown in Figure 6.2.

Source specific assessments for high-rate consumers of locally grown food and for fish and shellfish, and for occupants of houseboats, give exposures that were also less than 0.005 mSv (Table 5.1) which was less than 0.5 per cent of the dose limit for members of the public of 1 mSv.

Gaseous discharges and terrestrial monitoring

Gaseous discharges of carbon-14 and argon-41, which are very small from this site, increased in 2012 in comparison to those in 2011, due to the periodic nature of routine submarine refit operations. Samples of fruit and vegetables were analysed for a number of radionuclides, and concentrations were below the limits of detection in all terrestrial foods.

Liquid waste discharges and marine monitoring

Discharges of carbon-14 and "other radionuclides" to the Hamoaze were at levels similar to those reported in 2011. Discharges of cobalt-60 were somewhat lower than in 2011 while those of tritium were considerably higher, and similar to those in 2009. Figure 5.2 shows the discharge history of tritium and cobalt-60 since 1990. The main contributor to the variations in tritium discharges over time has been the re-fitting of Vanguard class submarines. These submarines have a high tritium inventory as they do not routinely discharge primary circuit coolant until they undergo refuelling at Devonport. The underlying reason for the overall decrease in cobalt-60 discharges over this period was the improvement in submarine reactor design so that less cobalt-60 was produced during operation, and therefore less was released during submarine maintenance operations. In marine samples, concentrations of tritium and cobalt-60 were below limits of detection. The effects of increased tritium discharges were not observed. Trace amounts of caesium-137, likely to originate from Chernobyl and global weapons test fallout, were measured in fish samples. The seaweed samples contained very low concentrations of

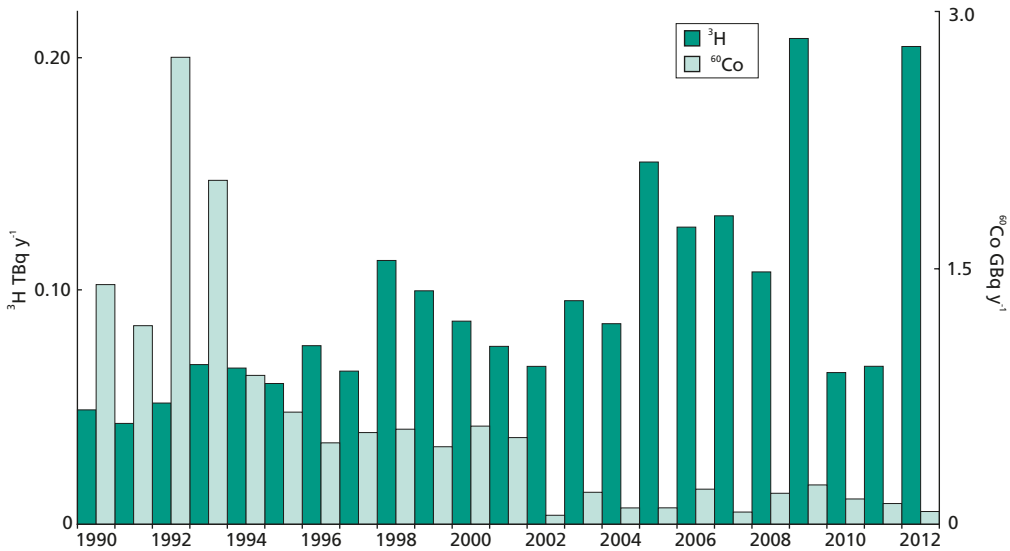
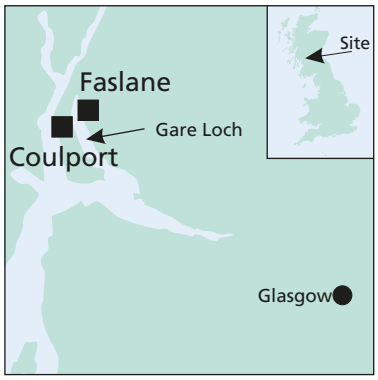


Figure 5.2. Trends in liquid discharges of tritium and cobalt-60 from Devonport, Devon 1990-2012

iodine-131 in 2012, which were most likely to have originated from the therapeutic use of this radionuclide in a local hospital. Gamma dose rates in the vicinity of Devonport were similar to 2011, although some small changes (at the same locations) were noted because rates were measured on different types of substrate from one year to the next.

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. Following a review by MoD of future delivery options many of the activities undertaken at Coulport have been outsourced. A contract was awarded to an industrial alliance made up of AWE plc, Babcock and Lockheed Martin UK (known as ABL). ABL will be managed by a resident director but MoD will continue to remain in control of the undertaking through NBC (Clyde). These arrangements formally began in January 2013.

Discharges of liquid radioactive waste into Gare Loch from Faslane and the discharge of gaseous radioactive waste in the form of tritium to the atmosphere from Coulport are made under letters of agreement between SEPA and the MoD. SEPA reviewed these letters in 2012 and the process of updating the letters will begin in 2013. The discharges released during 2012 are shown in Appendix 2. The disposal of solid radioactive waste from each site is also made under letters of agreement between SEPA and the MoD. Disposals of solid waste from the sites continued during 2012.

During August 2011, a habits survey was conducted to determine the consumption and occupancy rates by members of the public (Rumney *et al.*, *in press/a).* A slight increase in the mollusc consumption rate has been observed, together with a decrease in the occupancy rates. No crustacean consumption was reported in comparison with that of the previous survey in 2006. Revised figures for consumption rates, together with handling and occupancy rates, are provided in Appendix 1 (Table X2.2).

The *total dose* from all pathways and sources of radiation was less than 0.005 mSv in 2012 (Table 5.1). The most exposed people were adults consuming local food, but as in 2011 the dose was less than 0.5 per cent of the dose limit for members of the public. Source specific assessments for high-rate consumers of fish and shellfish (using seafood concentrations based on earlier data), and consumers of locally grown food (based on limited data), give exposures that were also less than 0.005 mSv.

The routine marine monitoring programme consisted of the analysis of seawater, seaweed and sediment samples, and gamma dose rate measurements. Samples of non-migratory fish species were not available in 2012. Mollusc samples collected included the separate radioanalysis of mussel flesh and mussel shell (to assess the impact of utilising the latter as a fertiliser). Terrestrial monitoring included beef, honey, grass and soil sampling. The results are given in Tables 5.3(a) and (b) and were similar to those in 2011. Radionuclide concentrations were generally below the limits of detection, with caesium-137 concentrations in sediment consistent with the distant effects of discharges from Sellafield, and with weapons testing and Chernobyl fallout. Gamma dose rates measured in the surrounding area were difficult to distinguish from natural background.

5.6 Holy Loch, Argyll and Bute

A small programme of monitoring at Holy Loch continued during 2012 in order to determine the effects of past discharges from the US submarine support facilities which closed in 1992. Radionuclide concentrations were low (Table 5.3(a)). Gamma dose rate measurements from intertidal areas (Table 5.3(b)) were less than those observed in 2011. The external radiation dose to people spending time on the loch shore was less than 0.005 mSv in 2012, which was less than 0.5 per cent of the dose limit for members of the public of 1 mSv (Table 5.1).

5.7 Rosyth, Fife

The site is operated by Babcock Marine, a division of Babcock International Group plc, who are responsible for the management of radioactive waste that was generated when the site supported the nuclear submarine

fleet. Site decommissioning started in April 2006 and has mainly been completed, with the exception of some small areas of the site where facilities continue to be required to manage radioactive wastes. To date, more than 99 per cent of the waste arising as a result of site decommissioning is being recycled.

Radioactive waste produced during decommissioning has been disposed of under an authorisation granted to Rosyth Royal Dockyard Limited (RRDL) in October 2008. Radioactive aqueous and gaseous wastes continue to be discharged in accordance with conditions in the same authorisation.

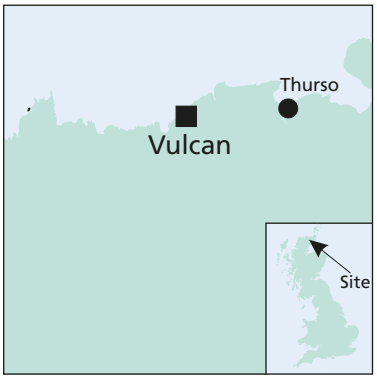
SEPA, and other stakeholders, are currently engaging with the MoD Nuclear Legacy Works Team based at Rosyth to identify the Best Practicable Environmental Option (BPEO) for managing radiologically contaminated ion-exchange resins stored securely in the Active Waste Accumulation Facility on the Rosyth site. SEPA is working closely with the Office for Nuclear Regulation and the Environment Agency on resin management as the issue is common to the Rosyth and Devonport naval sites.

The *total dose* from all pathways and sources was less than 0.005 mSv in 2012 (Table 5.1), which was less than 0.5 per cent of the dose limit. The people most exposed were adults who consume fish at high rates. The assessment of *total dose* is conservative, by estimating activity concentrations in seafood using reported environmental data in 2012. The source specific assessment for local fishermen (also by conservatively estimating seafood concentrations) and beach users gives an exposure that was also less than 0.005 mSv in 2012.

In 2012, authorised gaseous discharges from Rosyth were below the LoD. Liquid wastes are discharged via pipeline to the Firth of Forth. Tritium releases during 2012 were typical of the low levels discharged since 2000, and cobalt-60 discharges continued to decline. In all cases the activities in the liquid discharged were below authorised limits. Discharges of tritium from Rosyth increased slightly in 2012, due to an increase in the numbers of samples of nuclear submarine primary coolant that were disposed of following analysis in the Rosyth Radiochemistry Laboratory.

SEPA's routine monitoring programme included analysis of environmental indicator materials and measurements of gamma dose rates in intertidal areas. Results are shown in Tables 5.3(a) and (b). The radioactivity levels detected were at similar low levels to 2011 and in most part due to the combined effects of Sellafield, weapons testing and Chernobyl. Gamma dose rates were difficult to distinguish from natural background. The most recent habits survey was undertaken in 2010 (Rumney *et al.*, *in press/b).*

5.8 Vulcan NRTE, Highland



The Vulcan Naval Reactor Test Establishment is operated by the Defence Equipment and Support (Submarines) and acts as the test bed for prototype submarine nuclear reactors. It is located adjacent to the DSRL Dounreay site and the impact of its discharges is considered along with those from Dounreay (in Section 3). The site continued operations in 2012, with increased discharges of noble gases (in comparison to those in 2011) resulting from ongoing operations. In Written Parliamentary Statements made on 2nd of November 2011, it was stated that "the Vulcan NRTE site will not be required to support reactor core prototyping activity when the current series of PWR2 reactor core prototype tests are complete in 2015. Options for the future of the site are currently being assessed; these range from placing the prototype facilities into care and maintenance while retaining the site's strategic capabilities, to decommissioning the site and returning it to Nuclear Decommissioning Authority ownership".

Table 5.1. Individual doses – defence sites, 2012

Site	Exposed population[a,b]	Exposure mSv, per year					
		Total	Fish and shellfish	Other local food	External radiation from intertidal areas or river banks	Intakes of sediment or water	Gaseous plume related pathways
Aldermaston and Burghfield							
Total dose – all sources	**Infant milk consumers**	**<0.005**	**–**	**<0.005**	**–**	**–**	**–**
Source specific doses	Anglers[c]	<0.005	<0.005	–	<0.005	–	–
	Infant consumers of locally grown food[c]	<0.005	–	<0.005	–	–	<0.005
	Workers at Silchester STW	<0.005	–	–	<0.005[d]	<0.005[e]	–
Barrow							
***Total dose* – all sources**	**Adult houseboat occupants**	**0.057**	**–**	**–**	**0.057**	**–**	**–**
Source specific doses	Houseboat occupants	0.055	–	–	0.055	–	–
	Seafood consumers	0.033	0.017	–	0.017	–	–
Derby							
***Total dose* – all sources**	**Infant consumers of cattle meat**	**<0.005**	**–**	**<0.005**	**–**	**–**	**–**
Source specific doses	Anglers consuming fish and drinking water[f]	<0.005	<0.005	–	<0.005	<0.005	–
	Infant consumers of locally grown food	<0.005	–	<0.005	–	–	<0.005
Devonport							
***Total dose* – all sources**	**Adult houseboat occupants**	**<0.005**	**–**	**–**	**<0.005**	**–**	**–**
Source specific doses	Seafood consumers	<0.005	<0.005	–	<0.005	–	–
	Houseboat occupants	<0.005	–	–	<0.005	–	–
	Prenatal children of consumers of locally grown food	<0.005	–	<0.005	–	–	<0.005
Faslane							
***Total dose* – all sources**	**Adult cattle meat consumers**	**<0.005**	**–**	**<0.005**	**–**	**–**	**–**
Source specific doses	Seafood consumers	<0.005	<0.005	–	<0.005	–	–
	Consumers of locally grown food	<0.005	–	<0.005	–	–	–
Holy Loch							
Source specific dose	Anglers	<0.005	–	–	<0.005	–	–
Rosyth							
***Total dose* – all sources**	**Adult sea fish consumers**	**<0.005**	**<0.005**	**–**	**–**	**–**	**–**
Source specific doses	Fishermen and beach users	<0.005	<0.005	–	<0.005	–	–

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

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

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

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

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

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

Table 5.2(a). Concentrations of radionuclides in food and the environment near Aldermaston, 2012

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	<0.10	0.08			
Signal crayfish	Ufton Bridge – Theale	1	<25	<25	<0.31	<0.04	0.034	0.0010	0.025
Sediment	Pangbourne	4[E]				4.1	12	<1.7	13
Sediment	Mapledurham	4[E]				11	10	<1.2	11
Sediment	Aldermaston	4[E]				2.4	12	<1.3	11
Sediment	Spring Lane	4[E]				<2.2	10	<1.2	11
Sediment	Stream draining south	4[E]				<0.64	30	<2.1	29
Sediment	Reading (Kennet)	4[E]				3.9	12	<1.7	12
Gullypot sediment	Falcon Gate	1[E]		31		3.4	16	<1.3	16
Gullypot sediment	Main Gate	1[E]		23		<0.91	12	<1.1	14
Gullypot sediment	Tadley Entrance	1[E]		<8.1		8.6	14	<1.6	16
Gullypot sediment	Burghfield Gate	1[E]		<5.2		2.7	18	<1.3	20
Freshwater	Pangbourne	4[E]		<3.1		<0.22	0.011	<0.0046	0.0087
Freshwater	Mapledurham	4[E]		<3.0		<0.21	0.013	<0.0060	0.010
Freshwater	Aldermaston	4[E]		<5.2		<0.19	0.0090	<0.0041	0.0067
Freshwater	Spring Lane	4[E]		<3.3		<0.21	<0.0056	<0.0038	<0.0045
Freshwater	Reading (Kennet)	4[E]		<3.2		<0.19	<0.0064	<0.0041	<0.0056
Crude liquid effluent	Silchester treatment works	4[E]		<9.1		<0.21	<0.012	<0.011	<0.0082
Final Liquid effluent	Silchester treatment works	4[E]		<11		<0.23	<0.011	<0.0088	<0.0074
Sewage sludge	Silchester treatment works	4[E]		<10		<0.22	0.16	<0.030	0.14

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			<0.05				
Signal crayfish	Ufton Bridge – Theale	1	<0.00020	0.000047	0.000042	*	*		
Sediment	Pangbourne	4[E]	<0.76	<0.54	<0.98			<210	320
Sediment	Mapledurham	4[E]	<0.57	<0.55	<0.90			<140	240
Sediment	Aldermaston	4[E]	<0.55	1.7	<1.1			210	310
Sediment	Spring Lane	4[E]	<0.57	<0.48	<1.2			<130	320
Sediment	Stream draining south	4[E]	<0.45	<0.46	<1.1			440	990
Sediment	Reading (Kennet)	4[E]	<0.54	<0.48	<1.3			<130	340
Gullypot sediment	Falcon Gate	1[E]	<0.40	<0.70	<1.9			350	710
Gullypot sediment	Main Gate	1[E]	<0.50	<0.60	<1.3			190	250
Gullypot sediment	Tadley Entrance	1[E]	<0.40	0.57	<1.8			200	420
Gullypot sediment	Burghfield Gate	1[E]	<0.60	<0.60	<1.5			210	410
Freshwater	Pangbourne	4[E]	<0.0045	<0.0043	<0.0080			<0.046	0.24
Freshwater	Mapledurham	4[E]	<0.0045	<0.0043	<0.0075			<0.046	0.23
Freshwater	Aldermaston	4[E]	<0.0045	<0.0043	<0.0068			<0.044	0.22
Freshwater	Spring Lane	4[E]	<0.0050	<0.0043	<0.0063			<0.032	0.16
Freshwater	Reading (Kennet)	4[E]	<0.0050	<0.0043	<0.0065			<0.035	0.12
Crude liquid effluent	Silchester treatment works	4[E]	<0.0090	<0.0058	<0.30			<0.052	0.64
Final Liquid effluent	Silchester treatment works	4[E]	<0.017	<0.011	<0.31			<0.052	0.51
Sewage sludge	Silchester treatment works	4[E]	<0.013	<0.079	<0.34			<5.9	7.9

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		4	<4.8	<0.20	<0.0022	<0.00058	<0.00093
Milk	max		<5.0		0.0037	<0.00070	0.0010
Barley		1	<7.0	<0.20	0.0012	<0.00080	0.0016
Beetroot		1	<4.0	<0.20	0.0050	0.0010	0.0045
Blackberries		1	6.0	<0.20	0.0023	0.00040	<0.00070
Courgettes		1	7.0	<0.20	0.00070	<0.00040	<0.00060
Honey		1	<6.0	<0.10	0.00060	<0.00030	<0.00050
Potatoes		1	<5.0	<0.20	0.0085	0.00060	0.0084
Rabbit		1	<5.0	<0.20	0.0025	<0.00030	0.0019
Runner beans		1	8.0	<0.20	0.0038	0.00030	0.0028
Grass	Kestrel Meads	1[E]	<32	<0.90	1.9	<0.25	1.8
Grass	Industrial Estate	1[E]	<30	<0.67	<0.61	<0.25	<0.57
Grass	Location 3	1[E]	<27	<1.1	<0.42	<0.43	<0.39
Grass	Tatley	1[E]	<13	<1.4	<0.96	<1.4	<1.2
Grass	Location 8	1[E]	40	<0.81	2.0	<0.39	2.5
Grass	Opposite Gate 36	1[E]	52	<0.98	<0.45	<0.30	<0.22
Soil		1[#]			3.6	0.12	3.6
Soil	Kestrel Meads	1[E]	16	5.3	16	<1.3	16
Soil	Industrial Estate	1[E]	11	2.6	15	<1.4	14
Soil	Location 3	1[E]	<6.2	14	14	<1.4	13
Soil	Tatley	1[E]	<9.2	5.9	12	<1.3	13
Soil	Location 8	1[E]	<17	13	13	<1.6	16
Soil	Opposite Gate 36	1[E]	<19	18	13	<1.4	15

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		4	<0.00010	<0.00011	<0.00011		
Milk	max			<0.00013	<0.00013		
Barley		1	<0.00010	0.00010	0.00020		
Beetroot		1	<0.00010	<0.00010	0.00020		
Blackberries		1	<0.00010	<0.00010	<0.00010		
Courgettes		1	<0.00010	<0.00010	0.00020		
Honey		1	<0.00020	0.00020	0.00010		
Potatoes		1	<0.00010	0.00020	0.00030		
Rabbit		1	<0.00020	<0.00010	0.00020		
Runner beans		1	<0.00010	<0.00010	0.00020		
Grass	Kestrel Meads	1[E]	<0.40	<0.30		<4.3	240
Grass	Industrial Estate	1[E]	<0.20	<0.090		<2.1	180
Grass	Location 3	1[E]	<0.30	<0.20		<4.6	260
Grass	Tatley	1[E]	<0.40	<0.30		<4.6	290
Grass	Location 8	1[E]	<0.40	0.62		15	120
Grass	Opposite Gate 36	1[E]	<0.10	<0.10		<2.5	150
Soil		1[#]					
Soil	Kestrel Meads	1[E]	<0.70	<0.40		130	450
Soil	Industrial Estate	1[E]	<0.60	<0.50		160	580
Soil	Location 3	1[E]	<0.50	<0.70		180	320
Soil	Tatley	1[E]	<0.70	0.63		170	380
Soil	Location 8	1[E]	<0.60	0.82		180	420
Soil	Opposite Gate 36	1[E]	<0.70	0.71		<110	260

* *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, 2012

Location	Ground type type	No. of sampling observations	μGy h^{-1}
Mean gamma dose rates at 1m over substrate			
Pangbourne, riverbank	Grass	4	0.061
Mapledurham, riverbank	Mud	1	0.058
Mapledurham, riverbank	Grass and mud	1	0.061
Mapledurham, riverbank	Grass and stones	1	0.062
Mapledurham, riverbank	Grass	1	0.063

Table 5.3(a). Concentrations of radionuclides in food and the environment near defence establishments, 2012

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	^{58}Co	^{60}Co	^{110m}Ag	^{125}Sb	^{131}I	^{134}Cs
Barrow											
Crabs[c]	Barrow	4[F]				<0.15	<0.08	<0.14	<0.17	*	<0.07
Lobsters[d]	Barrow	4[F]				<0.11	<0.06	<0.11	<0.14	*	<0.06
Grass	Barrow	2[F]		<5.0							
Sediment	Walney Channel – N of discharge point	2					0.87		<1.6		<0.39
Sediment	Walney Channel – S of discharge point	2					0.76		<1.4		<0.36
Derby											
Cabbage	Derby	1[F]				<0.09	<0.09	<0.11	<0.18	<0.70	<0.08
Sediment	River Derwent, upstream	1					<0.41				
Sediment	Fritchley Brook	1					<0.31				
Sediment	River Derwent, downstream	4					<1.3				
Water	River Derwent, upstream	1					<0.22				
Water[e]	Fritchley Brook	1		<3.2			<0.21				
Water	River Derwent, downstream	4					<0.27				
Sewage pellets	Derby	1[F]				<0.26	<0.17	<0.32	<0.47	*	<0.25
Devonport											
Grey mullet	Plymouth Sound	2[F]			27	<0.06	<0.05	<0.08	<0.10	*	<0.04
Crabs	Plymouth Sound	2[F]			26	<0.10	<0.08	<0.15	<0.18	<0.65	<0.09
Shrimp/prawn	Lynher Estuary	1[F]			25	<0.31	<0.12	<0.24	<0.26	*	<0.13
Cockles	Southdown	1[F]				<0.14	<0.13	<0.20	<0.25	<1.1	<0.12
Pacific oysters	Southdown	1[F]				<0.03	<0.03	<0.05	<0.06	<0.11	<0.03
Mussels	River Lynher	2[F]	<25	<25		<0.23	<0.12	<0.21	<0.24	*	<0.11
Seaweed[f]	Kinterbury	2					<0.55			4.5	
Sediment[g]	Kinterbury	2		<16			<1.3				
Sediment	Torpoint South	2		<8.0			<1.0				
Sediment	Lopwell	2		<13			<1.8				
Seawater	Torpoint South	2		<3.2	<5.0		<0.24				
Seawater	Millbrook Lake	2		<3.3	<7.3		<0.25				
Beetroot		1[F]		<4.0			<0.10	<0.20			<0.20
Blackberries		1[F]		<4.0			<0.30	<0.20			<0.20
Courgettes		1[F]		<4.0			<0.20	<0.20			<0.10
Lettuce		1[F]		<4.0			<0.20	<0.20			<0.20
Faslane											
Mussel shells	Rhu	1				<0.22	<0.10	<0.12	<0.26		<0.11
Mussels	Rhu	1				<0.10	<0.10	<0.10	<0.18		<0.10
Winkles	Garelochhead	1				<0.18	0.12	<0.10	<0.20		<0.10
Winkles	Helensburgh	1				<0.12	<0.10	<0.10	<0.17		<0.10
Fucus vesiculosus	Rhu	1				<0.77	<0.10	<0.14	<0.20		<0.10
Sediment	Carnban boatyard	1				<0.10	<0.10	<0.10	<0.16		<0.10
Seawater	Carnban boatyard	2		<1.0		<0.30	<0.10	<0.10	<0.13		<0.10
Beef muscle	Faslane	1					<0.05	<0.05			<0.05
Honey	Faslane	1					<0.14	<0.13			<0.13
Grass	Auchengaich	1		<5.0			<0.05	<0.05			<0.05
Grass	Lochan Ghlas Laoigh	1		<5.0			<0.05	<0.05			<0.05
Soil	Auchengaich	1					<0.05	<0.06			<0.06
Soil	Lochan Ghlas Laoigh	1					<0.05	<0.07			<0.05
Freshwater	Helensburgh Reservoir	1		<1.0			<0.01	<0.01			<0.01
Freshwater	Loch Finlas	1		<1.1			<0.01	<0.01			<0.01
Freshwater	Auchengaich	1		<1.1			<0.01	<0.01			<0.01
Freshwater	Lochan Ghlas Laoigh	1		<1.0			<0.01	<0.01			<0.01
Freshwater	Loch Eck	1		<1.0			<0.01	<0.01			<0.01
Freshwater	Loch Lomond	1		<1.1			<0.01	<0.01			<0.01
Holy Loch											
Sediment	Mid-Loch	1				<0.10	<0.10	<0.10	<0.16		<0.10
Rosyth											
Fucus vesiculosus	East of dockyard	1				<0.10	<0.10	<0.10	<0.10		<0.10
Sediment	East of dockyard	1				<0.10	<0.10	<0.10	<0.18		<0.10
Sediment	Port Edgar	1				<0.12	<0.10	<0.12	<0.26		<0.11
Sediment	West of dockyard	1				<0.10	<0.10	<0.10	<0.14		<0.10
Sediment	East Ness Pier	1				<0.10	<0.10	<0.10	<0.18		<0.10
Sediment	Blackness Castle	1				<0.16	<0.10	<0.14	<0.29		<0.13
Sediment	Charlestown Pier	1				<0.10	<0.10	<0.10	<0.21		<0.10
Seawater	East of dockyard	2		<1.0		<0.11	<0.10	<0.10	<0.21		<0.10
Freshwater	Castlehill	1		<1.1			<0.01	<0.01			<0.01
Freshwater	Holl Reservoir	1		<1.1			<0.01	<0.01			<0.01
Freshwater	Gartmorn	1		<1.1			<0.01	<0.01			<0.01
Freshwater	Morton No. 2	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}							
			^{137}Cs	^{155}Eu	^{234}U	^{235}U	^{238}U	^{241}Am	Gross alpha	Gross beta
Barrow										
Crabs[c]	Barrow	4[F]	0.76	<0.12				0.72		
Lobsters[d]	Barrow	4[F]	1.2	<0.12				1.0		180
Sediment	Walney Channel – N of discharge point	2	100	<0.81				240	510	740
Sediment	Walney Channel – S of discharge point	2	88	<1.8				210	320	640
Derby										
Cabbage	Derby	1[F]	<0.07	<0.12				<0.06		
Sediment	River Derwent, upstream	1	3.6		26	<2.1	24		250	460
Sediment	Fritchley Brook	1	0.55		20	<1.5	21		<110	310
Sediment	River Derwent, downstream	4	4.6		31	<1.2	30		370	690
Grass		4[F]			0.044	<0.0016	0.040			
Grass	max				0.12	0.0045	0.10			
Soil		4[F]			15	0.54	14			
Soil	max				20	0.74	20			
Water	River Derwent, upstream	1							<0.043	0.15
Water[e]	Fritchley Brook	1	<0.20		0.020	<0.0031	0.018		<0.070	0.25
Water	River Derwent, downstream	4							<0.080	0.17
Sewage pellets	Derby	1[F]	1.0	<0.50				<0.29		
Devonport										
Grey mullet	Plymouth Sound	2[F]	0.13	<0.08				<0.05		
Crabs	Plymouth Sound	2[F]	<0.08	<0.13				<0.07		
Shrimp/prawn	Lynher Estuary	1[F]	<0.11	<0.18				<0.09		
Cockles	Southdown	1[F]	<0.11	<0.17				<0.09		
Pacific oysters	Southdown	1[F]	<0.03	<0.04				<0.02		
Mussels	River Lynher	2[F]	<0.10	<0.16				<0.08		
Sediment[g]	Kinterbury	2						<1.3		
Sediment	Lopwell	2	8.0							
Beetroot		1[F]	<0.20							
Blackberries		1[F]	<0.30							
Courgettes		1[F]	<0.20							
Lettuce		1[F]	<0.20							
Faslane										
Mussel shells	Rhu	1	<0.10	<0.23				<0.23		
Mussels	Rhu	1	0.28	<0.17				0.15		
Winkles	Garelochhead	1	0.23	<0.16				<0.10		
Winkles	Helensburgh	1	0.65	<0.13				<0.10		
Fucus vesiculosus	Rhu	1	0.42	<0.19				<0.12		
Sediment	Carnban boatyard	1	4.7	0.59				<0.27		
Seawater	Carnban boatyard	2	<0.10	<0.11				<0.10		
Beef muscle	Faslane	1	0.24					<0.09		
Honey	Faslane	1	<0.14					<0.19		
Grass	Auchengaich	1	0.23					<0.07		
Grass	Lochan Ghlas Laoigh	1	0.65					<0.10		
Soil	Auchengaich	1	57	1.5				0.90		
Soil	Lochan Ghlas Laoigh	1	9.8	1.2				<0.16		
Freshwater	Helensburgh Reservoir	1	<0.01					<0.01	<0.010	<0.010
Freshwater	Loch Finlas	1	<0.01					<0.01	<0.010	<0.010
Freshwater	Auchengaich	1	<0.01					<0.01	<0.010	<0.010
Freshwater	Lochan Ghlas Laoigh	1	<0.01					<0.01	<0.010	0.020
Freshwater	Loch Eck	1	<0.01					<0.01	<0.013	0.020
Freshwater	Loch Lomond	1	<0.01					<0.01	<0.010	0.020
Holy Loch										
Sediment	Mid-Loch	1	4.2	0.47				<0.21		
Rosyth										
Fucus vesiculosus	East of dockyard	1	<0.10	<0.10				<0.10		
Sediment	East of dockyard	1	2.9	<0.25				0.32		
Sediment	Port Edgar	1	11	1.3				<0.43		
Sediment	West of dockyard	1	1.1	<0.21				<0.20		
Sediment	East Ness Pier	1	7.1	<0.18				<0.22		
Sediment	Blackness Castle	1	13	1.6				1.2		
Sediment	Charlestown Pier	1	1.8	<0.29				<0.28		
Seawater	East of dockyard	2	<0.10	<0.19				<0.12		
Freshwater	Castlehill	1	<0.01					<0.01	<0.010	<0.010
Freshwater	Holl Reservoir	1	<0.01					<0.01	<0.010	0.030
Freshwater	Gartmorn	1	<0.01					<0.01	<0.010	0.13
Freshwater	Morton No. 2	1	<0.01					<0.01	<0.013	0.020

* *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 ^{238}Pu and $^{239+240}$Pu were 0.019 and 0.10 Bq kg^{-1} respectively*

[d] *The concentration of ^{99}Tc was 93 Bq kg^{-1}*

[e] *The concentrations of ^{228}Th, ^{230}Th and ^{232}Th were <0.0050, <0.0050 and <0.0050 Bq l^{-1} respectively*

[f] *The concentration of ^{99}Tc was 2.3 Bq kg^{-1}*

[g] *The concentrations of ^{238}Pu and $^{239+240}$Pu were <0.40 and <0.60 Bq kg^{-1} respectively*

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

Table 5.3(b). Monitoring of radiation dose rates near defence establishments, 2012

Establishment	Location	Ground type	No. of sampling observations	μGy h^{-1}
Mean gamma dose rates at 1m over substrate				
Barrow	Walney Channel, N of discharge point	Mud and sand	2	0.084
Barrow	Walney Channel, S of discharge point	Mud and salt marsh	1	0.093
Barrow	Walney Channel, S of discharge point	Mud and sand	1	0.092
Devonport	Torpoint South	Mud and stones	2	0.10
Devonport	Kinterbury Access Gate	Mud and stones	2	0.086
Devonport	Lopwell	Mud	1	0.093
Devonport	Lopwell	Mud and salt marsh	1	0.11
Faslane	Garelochhead	Mud, sand and stones	2	<0.053
Faslane	Gulley Bridge Pier	Sand and stones	2	0.059
Faslane	Rhu	Gravel	2	<0.050
Faslane	Helensburgh	Sand	2	0.052
Faslane	Carnban boatyard	Gravel	2	0.061
Holy Loch	North Sandbank	Mud and sand	1	0.050
Holy Loch	Kilmun Pier	Sand and stones	1	0.051
Holy Loch	Mid-Loch	Sand	1	0.050
Rosyth	Blackness Castle	Mud and sand	2	0.059
Rosyth	Charlestown Pier	Sand	2	0.054
Rosyth	East Ness Pier	Sand	2	<0.053
Rosyth	East of Dockyard	Sand	2	0.054
Rosyth	Port Edgar	Mud	2	0.062
Rosyth	West of Dockyard	Mud and rock	2	<0.048

6. Radiochemical production

This section considers the results of monitoring by the Environment Agency and Food Standards Agency at two sites associated with the radiopharmaceutical industry. The sites, at Amersham and Cardiff, are operated by GE Healthcare Limited. This is a health science company functioning in world-wide commercial healthcare and life science markets.

Permits have been issued by the Environment Agency to each of the sites allowing the discharge of gaseous and liquid radioactive wastes (Appendix 2). Independent monitoring of the environment around the Amersham and Cardiff sites is conducted by the Food Standards Agency and the Environment Agency. The medium-term trends in discharges, environmental concentrations and dose at Amersham and Cardiff were considered in a summary report (Environment Agency, Food Standards Agency, Northern Ireland Environment Agency and Scottish Environment Protection Agency, 2010b).

Key points

GE Healthcare Limited, Grove Centre, Amersham, Buckinghamshire

- Public radiation doses from all sources were less than 22 per cent of the dose limit. The highest dose was due to direct radiation from the site
- Gaseous discharges of radon-222 decreased in 2012
- Concentrations of radioactivity in terrestrial and aquatic samples, and gamma dose rates, were low and generally similar to those in 2011

GE Healthcare Limited, Maynard Centre, Cardiff, South Glamorgan

- Public radiation doses from all sources were less than 1 per cent of the dose limit
- The highest *total dose* relating to liquid discharges was the lowest reported value in 2012 and the exposure was due to external radiation emitted from radionuclides in intertidal sediment
- Gaseous and liquid discharges of tritium and carbon-14 remained low in 2012
- Tritium concentrations in most fish species continued their long-term decline

6.1 Grove Centre, Amersham, Buckinghamshire

GE Healthcare Limited's principal establishment is located in Amersham, Buckinghamshire. It consists of a wide range of plants for manufacturing diagnostic imaging products, using short half-life radionuclides such as technetium-99m, for use in medicine and research. The routine monitoring programme consists of analysis of fish, crops, water, sediments and environmental materials, and measurements of gamma dose rates. The monitoring locations are shown in Figure 3.1. The most recent habits survey was undertaken in 2009 (Clyne *et al*., 2010b).

Doses to the public

The *total dose* from all pathways and sources of radiation was 0.22 mSv, or 22 per cent of the dose limit (Table 6.1), and unchanged from 2011. This dose was primarily due to direct radiation to local inhabitants. Exposure from direct radiation varies around the boundary of the Grove Centre and therefore the *total dose* is determined as a cautious upper value. The trend in *total dose* over the period 2004 – 2012 is given in Figure 1.1. *Total doses* remained broadly similar with time and were dominated by direct radiation.

Source specific assessments for high-rate consumers of locally grown foods, for anglers, and for workers at Maple Lodge sewage treatment works, which serves the sewers to which permitted discharges are made, give exposures that were less than the *total dose* in 2012 (Table 6.1). The dose for high-rate consumers of locally grown foods (which included a contribution from the gaseous plume related pathways) was 0.009 mSv, or less than 1 per cent of the dose limit to members of the public of 1 mSv. The decrease in dose, from 0.022 mSv in 2011, was primarily due to lower atmospheric discharges of radon-222 in 2012; this radionuclide remains the dominant contributor. It should be noted that the current assessment methodology uses a conservative dose factor based on this nuclide being in equilibrium with its daughter products. The dose to local anglers was less than 0.005 mSv in 2012, which was less than 0.5 per cent of the dose limit for members of the public of 1 mSv (Table 6.1). The dose was 0.007 mSv in 2011, and the decrease was due to lower

gamma dose rates above the banks of the canal near the Maple Lodge outfall in 2012.

The 2009 habits survey at Amersham did not directly identify any consumers of fish, shellfish or freshwater plants. As in previous surveys, however, there was anecdotal evidence of fish consumption, albeit occasional and at low rates. To allow for this, a consumption rate of 1 kg per year for fish has been included in the dose assessment for anglers.

The Grove Centre discharges liquid waste to Maple Lodge Sewage Treatment Works (STW), and the proximity to raw sewage and sludge experienced by sewage treatment workers is a likely exposure pathway (National Dose Assessment Working Group, 2004). The dose received by these workers in 2012 was modelled using the methods described in Appendix 1. The dose from a combination of external exposure to contaminated raw sewage and sludge and the inadvertent ingestion and inhalation of re-suspended radionuclides was less than 0.005 mSv.

Gaseous discharges and terrestrial monitoring

The Amersham facility is permitted to discharge gaseous radioactive wastes via stacks on the site. Discharges of radon-222 decreased in 2012, in comparison to those in 2011; other gaseous discharges were generally similar. Radon-222 discharges were higher in 2011 following unexpected releases (Environment Agency, Food Standards Agency, Northern Ireland Environment Agency and Scottish Environment Protection Agency, 2012). Activity concentrations in terrestrial samples were generally below the limits of detection (Table 6.2). Sulphur-35 was positively detected at low concentrations in some crop samples in 2012. As in previous years, caesium-137 activities were detected in soil near the site, and this is likely to be due to global fallout from testing of weapons or from the Chernobyl accident.

Liquid waste discharges and aquatic monitoring

Radioactive liquid wastes are discharged to sewers serving the Maple Lodge STW; treated effluent subsequently enters the Grand Union Canal and the River Colne. The results of the aquatic monitoring programme are given in Table 6.2. Activity concentrations in freshwater, and effluent and sludge from Maple Lodge STW, were mostly below, or near, the LoD. The caesium-137 detected in sediments upstream of the sewage treatment works outfall is likely to be derived from weapons test fallout or the Chernobyl accident. Gross alpha and beta activities in water were below the WHO screening levels for drinking water. Gamma dose rates (given in footnote, Table 6.2) above the banks of the Grand Union Canal remained low in 2012, and reduced in comparison to those in 2011.

6.2 Maynard Centre, Cardiff

GE Healthcare Limited operates a second establishment, on the Forest Farm industrial estate near Whitchurch, Cardiff. GE Healthcare Limited ceased manufacturing a range of radio-labelled products containing tritium in 2009 and products containing carbon-14 in 2010. The site is being decommissioned and the bulk of the site will be de-licensed (subject to approval from the ONR), leaving a small licensed area for storage of historical radioactive wastes. Gaseous discharges from the Maynard Centre are now the result of out-gassing of tritium and carbon-14 from stored wastes with only small amounts originating from decommissioning.

GE Healthcare Limited's custom radio-labelling division was acquired by Quotient Bioresearch, (a division of Quotient Bioscience) which operates from different premises in Cardiff (a purpose-built laboratory at Trident Park). This non-nuclear facility also discharges carbon-14 and tritium to atmosphere and in liquid wastes. These are at much reduced levels in comparison to when the Maynard Centre was manufacturing radio-labelled products. The effluents discharged from the site are also treated to ensure that organic matter present is destroyed prior to discharge.

The Food Standards Agency and the Environment Agency conduct a routine monitoring programme on behalf of the Welsh Government. This includes sampling of locally produced food, fish and shellfish, and external dose rate measurements over muddy, intertidal areas (Figure 6.1). These are supported by analyses of intertidal sediment. Environmental materials including seawater, freshwater, seaweed, soil and grass provide additional information. The most recent habits survey was undertaken in 2003 (McTaggart *et al.*, 2004a).

Past monitoring data from Cardiff has been reviewed in order to compare the apparent enhancement of tritium concentrations on uptake by marine biota with bioaccumulation at other UK sites (Hunt *et al.*, 2010). The observed enhancement factor at Cardiff remains at least an order of magnitude greater than at the other sites studied, although the organically bound fractions were uniformly high. Various earlier monitoring and research efforts have targeted organically bound tritium (OBT) in foodstuffs (Food Standards Agency, 2001b; Swift, 2001; Williams *et al.*, 2001; Leonard *et al.*, 2001 and McCubbin *et al.*, 2001).

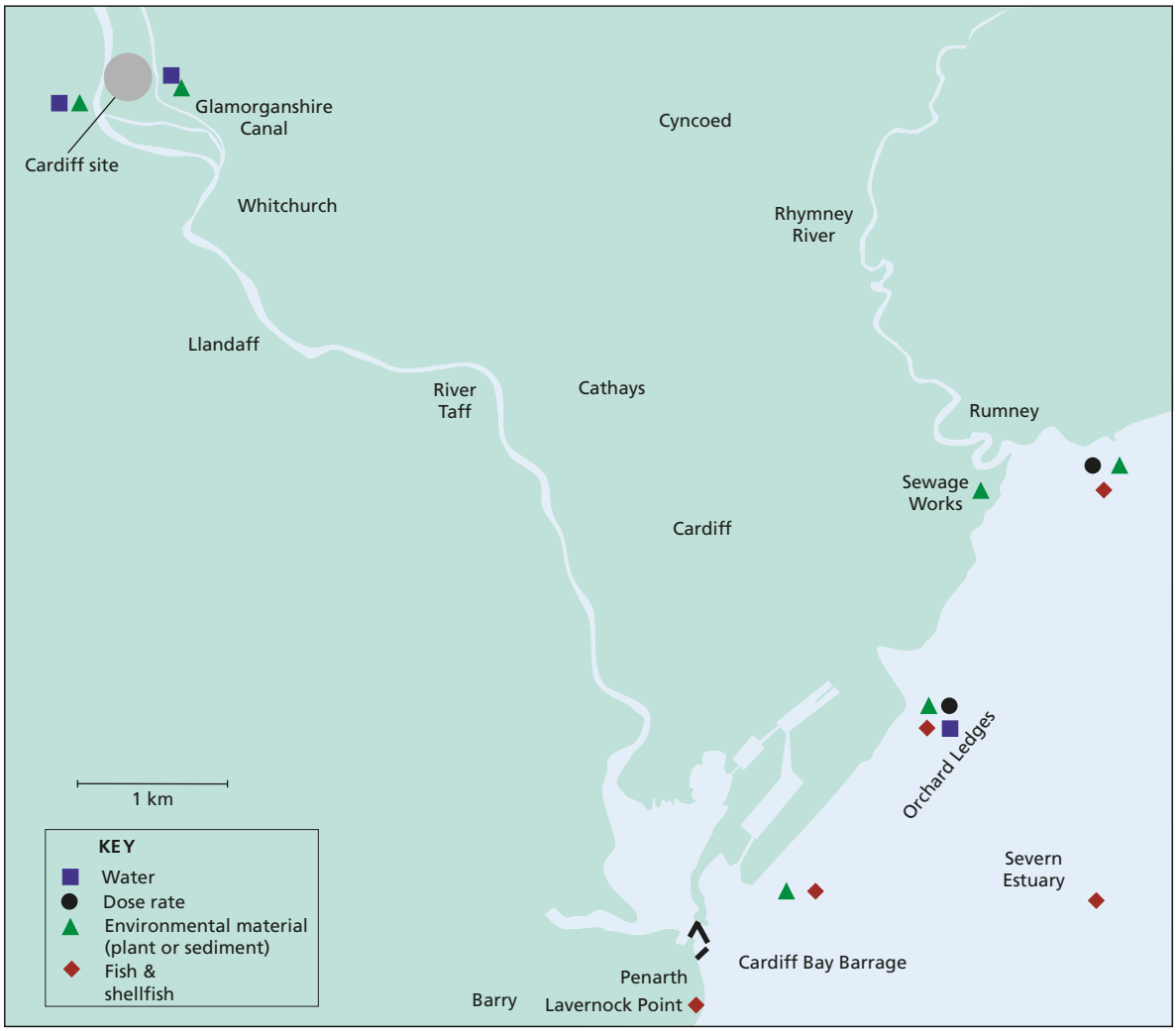


Figure 6.1. Monitoring locations at Cardiff, 2012 (not including farms)

Doses to the public

In 2012, the *total dose* from all pathways and sources was 0.005 mSv (Table 6.1), or 0.5 per cent of the dose limit, compared with 0.006 mSv in 2011. This dose estimates take into account the increased dose coefficients for OBT derived for discharges from the Maynard Centre and includes consideration of prenatal children. The dominant contributions to this exposure were the low levels of external radiation emitted from radionuclides in intertidal sediment and mostly due to radioactive sources other than from the GE Healthcare Limited site in Cardiff. The prenatal children of adults who spend time over intertidal sediments were the most exposed people. In 2012, the dose included small decreased contributions from both gamma dose rates and seafood consumption (tritium in fish) compared to those contributions in 2011. Trends in *total doses* over time (2003 – 2012) in the Severn Estuary (and areas of the south coast) are shown in Figure 6.2. At Cardiff, the most significant reductions in the *total dose*, prior to 2007, were largely due to lower concentrations of tritium and carbon-14 in seafood. Since 2007, the *total doses* continued to decrease over time, and in recent years were consistently low. In 2012, the *total dose* was the lowest reported value over the whole period (2003 - 2012).

Source specific assessments for consumers of locally grown foods (that consumed crops grown in soil treated with sludge pellets), for recreational users of the River Taff, and for workers at Cardiff East Waste Water Treatment Works (WWTW), give exposures that were less than 0.005 mSv in 2012 (Table 6.1). The dose to high-rate consumers of locally grown foods was 0.007 mSv, and the increase in dose (from 0.005 mSv in 2011) was due to higher carbon-14 concentrations in milk in 2012. The dose to high-rate consumers of seafood was 0.009 mSv, compared with 0.010 mSv in 2011. The reason for the decrease in dose in 2012 is the same as that for *total dose*.

The dose coefficients for OBT differ from those for tritiated water (see Appendix 1, A3.4) and the estimates of dose to members of the public account for this. For ingestion of seafood caught near Cardiff, an area taken to be equivalent to the Bristol Channel, a dose coefficient based on a site-specific study of the consumption of fish caught in Cardiff Bay is used. An experimental study by Hunt *et al.* (2009) suggests that this raised dose coefficient is conservative, but it is retained for

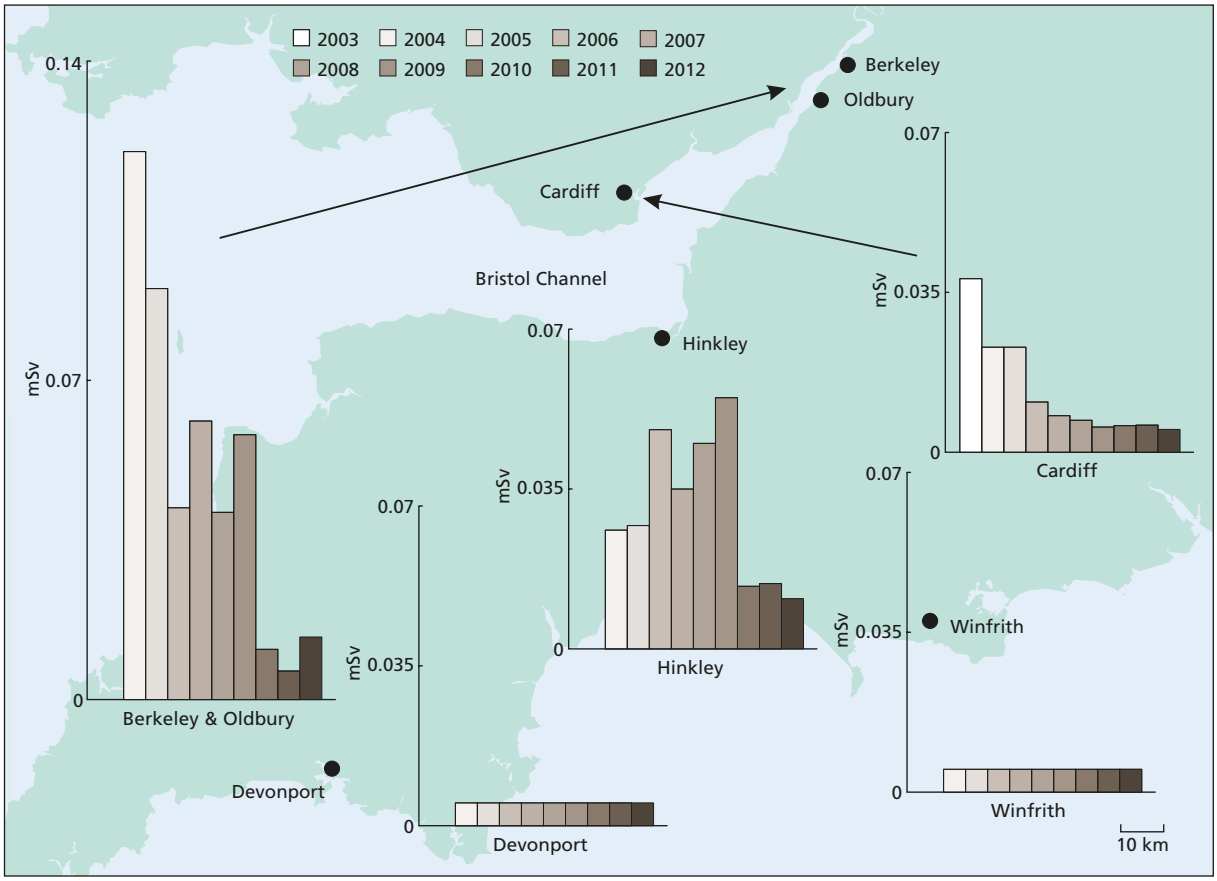


Figure 6.2. *Total dose* for major sites in the Severn Estuary and south coast, 2003-2012
(Small doses, less than or equal to 0.005 mSv, are recorded as being 0.005 mSv)

2012 dose assessments on the advice of PHE. For ingestion of other food, the ICRP dose coefficient for OBT is applied.

Gaseous discharges and terrestrial monitoring

The Maynard Centre discharges radioactivity to the atmosphere via stacks on the site. This is predominantly tritium and carbon-14. As a result of reduced commercial operations, in relation to the site's planned shutdown, discharges of tritium (and other discharged radionuclides) continued to be low in 2012. Carbon-14 discharges were lower in 2012, compared to those releases in recent years.

The main focus of the terrestrial sampling was for the content of tritium, carbon-14 and sulphur-35 in milk, crops, freshwater, soil and grass. The Environment Agency also analysed samples of sewage products from the Cardiff East WWTW for tritium and carbon-14. This enabled an assessment of exposure from eating crops grown on land fertilised with sludge pellets to be undertaken. The constraints of the Sludge (Use in Agriculture) Regulations (United Kingdom – Parliament, 1989) (commonly referred to as the Safe Sludge Matrix) require that crops cannot be harvested within 10 months of the application of sludge pellets. A Food Standards Agency research project (Ham *et al.*, 2007) investigated the transfer of tritium from treated soil to crops, under the Safe Sludge Matrix conditions, and concluded that the transfer of tritium to each of the crops considered was small.

Tritium concentrations in terrestrial food samples were below, or just above, the LoD in 2012 (Table 6.3(a)). These values were generally similar to those in 2010 and 2011 and are consistent with progressive discharge reductions in recent years. Carbon-14 concentrations in foodstuffs were generally higher in comparison to those in 2011, including a small enhancement in milk in 2012. Low concentrations of sulphur-35, which is not discharged by the site, were detected in foods and were similar to those in 2011. Phosphorus-32 and iodine-125 concentrations were below the LoD in all terrestrial samples.

Samples of raw and treated sewage and associated products from Cardiff East WWTW were analysed for tritium and carbon-14 in 2012. The results (Table 6.3(a)) show enhanced concentrations of tritium in sludge pellets. However, the value for sludge pellets was similar to that in 2011 and significantly decreased from those in years prior to 2011 (by at least an order of magnitude). In 2012, the carbon-14 concentration in sludge pellets was the lowest reported value in recent years.

Relatively low levels of tritium continued to be detected in sediment and freshwater from the Glamorganshire Canal; however, this is not used as a source of water for the public

water supply. The trend of discharges, with sediment concentrations from the marine and freshwater environments, over time (2004 – 2012) are shown in Figure 6.3. The overall decline in activity concentrations generally replicates that of the tritium discharges, although the decrease in marine levels (east/west of the pipeline) is less pronounced than that in the canal sediments over the whole time period. In 2012 (for the second consecutive year), the tritium concentrations from site run-off water into the River Taff were below the LoD.

Liquid waste discharges and aquatic monitoring

The Maynard Centre discharges liquid wastes into the Ystradyfodwg and Pontypridd (YP) public sewer. This joins the Cardiff East sewer, which after passing through a waste water treatment works discharges into the Severn Estuary near Orchard Ledges. During periods of high rainfall, effluent from the YP sewer has been known to overflow into the River Taff. In addition, there is run-off from the site into the river via surface water drains.

The bulk of the radioactivity discharged to the YP sewer is tritium and carbon-14. The amounts of these radionuclides released to the sewer were both very low in 2012 (as in 2011). Over the longer term both discharge rates have decreased substantially (Figures 6.4 and 6.5).

Marine sampling included locally caught seafood, and indicator materials (e.g. seaweed). These were supported by external dose rate measurements over intertidal areas. The results of routine monitoring in 2012 are given in Tables 6.3(a) and (b). The effects of liquid discharges remained evident in enhanced tritium and carbon-14 concentrations in fish samples. Further analysis of these samples showed that a high proportion of the tritium was still associated with organic matter, a situation that has been observed since the late 1990s (McCubbin *et al.*, 2001; Leonard *et al.*, 2001; Williams *et al.*, 2001). The tritium is strongly bound to organic matter and has the potential to transfer through the marine food chain from small organisms to accumulate in fish. In 2012, tritium concentrations in most fish (cod, flounder, and sole and dogfish) decreased (whilst skates/rays increased) as compared with concentrations of their respective species in 2011. The continued overall decline in tritium concentrations in fish from the Cardiff area is likely to be a direct response to the decreasing inputs from the Maynard Centre, as well as a shift in the composition of this discharge away from organically bound compounds. However, the annual uncertainty and variation in certain species in recent years suggests that complex indirect uptake mechanisms continue to affect tritium concentrations in the region.

Figure 6.4 indicates that the overall tritium concentrations in mollusc samples have decreased significantly over the last decade. Tritium was also detected in marine sediment samples at similar levels to those in recent years. The mean concentrations of carbon-14 in fish and molluscs in 2012 were generally similar to those in 2011. The longer term trend in concentrations and the relationship to discharges is shown in Figure 6.5 (overall, concentrations in both species declining). Concentrations of caesium-137 in marine samples remain low and can largely be explained by other sources such as Chernobyl, weapon test fallout and discharges from other establishments such as the Hinkley Point, Berkeley and Oldbury nuclear licensed sites. Gamma dose rates over sediment (Table 6.3(b)) were generally comparable to those observed in 2011 but are not (in the main) attributable to discharges from the Maynard Centre or the laboratory at Trident Park.

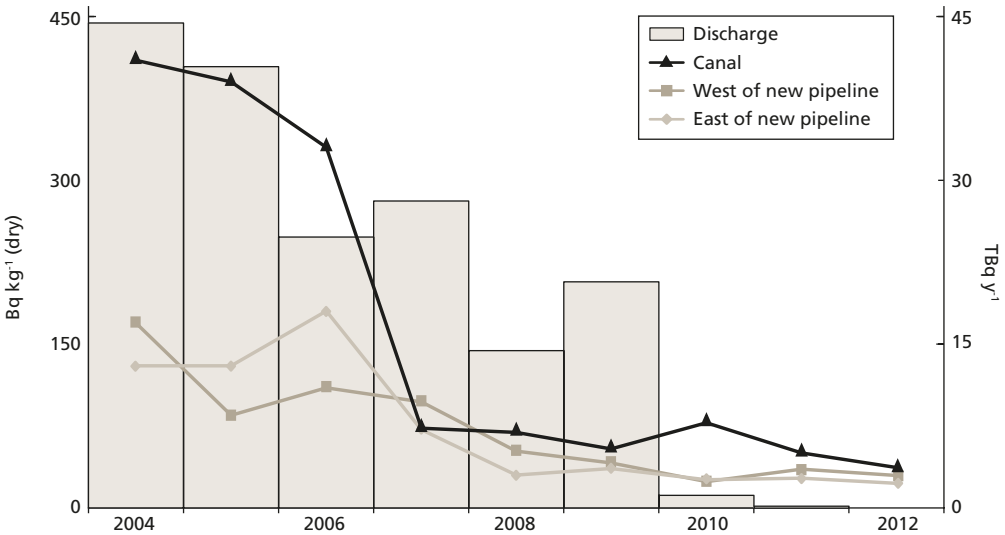


Figure 6.3. Tritium liquid discharge from Cardiff and mean concentrations in sediment near Cardiff, 2004-2012

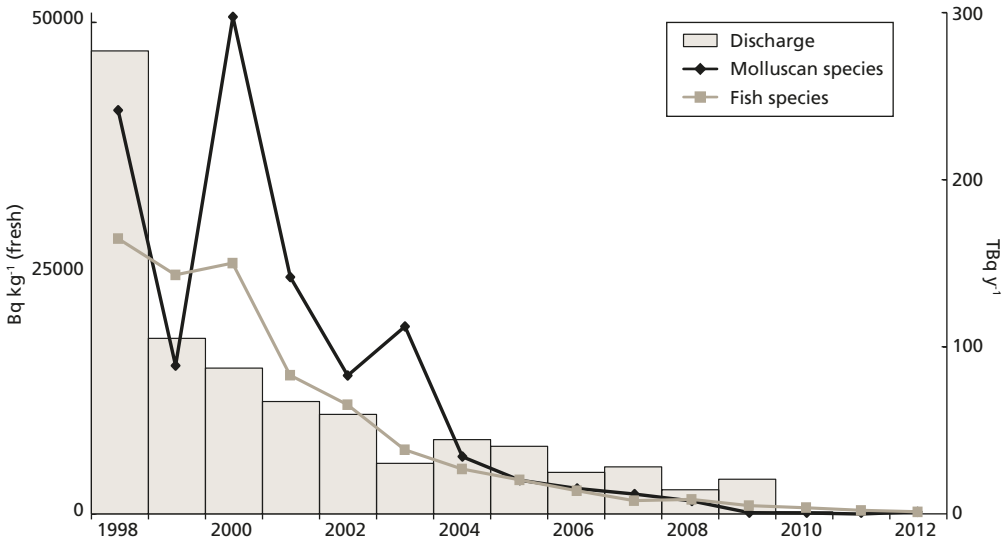


Figure 6.4. Tritium liquid discharge from Cardiff and mean concentrations in fish and molluscs near Cardiff, 1998-2012 (species include all those reported in RIFE for the given year)

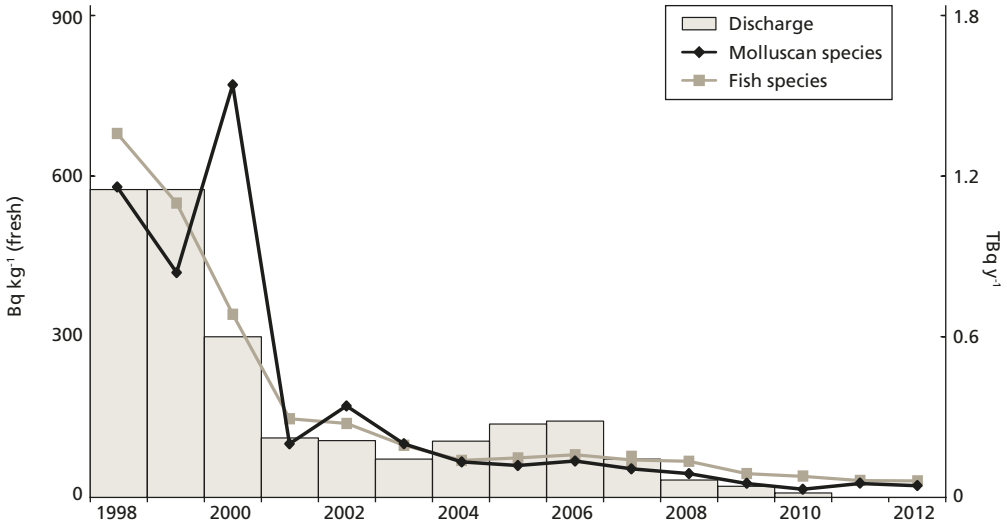


Figure 6.5. Carbon-14 liquid discharge from Cardiff and mean concentrations in fish and molluscs near Cardiff, 1998-2012 (species include all those reported in RIFE for the given year)

Table 6.1. Individual doses – radiochemical sites, 2012

Site	Exposed population[a]	Exposure, mSv per year						
		Total	Fish and shellfish	Other local food	External radiation from intertidal areas or river banks	Intakes of sediment or water	Gaseous plume related pathways	Direct radiation from site
Amersham								
***Total dose* – all sources**	**Local adult inhabitants (0-0.25km)**	**0.22**	**–**	**<0.005**	**<0.005**	**–**	**<0.005**	**0.22**
Source specific doses	Anglers	<0.005	<0.005	–	<0.005	–	–	–
	Infant consumers of locally grown food	0.009	–	<0.005	–	–	0.006	–
	Workers at Maple Lodge STW	<0.005	–	–	<0.005[b]	<0.005[c]	–	–
Cardiff								
***Total dose* – all sources**	**Prenatal children of occupants over sediment**	**0.005**	**<0.005**	**–**	**0.005**	**–**	**–**	**–**
Source specific doses	Prenatal children of seafood consumers	0.009	<0.005	–	0.008	–	–	–
	Recreational users of River Taff	<0.005	–	–	<0.005	<0.005	–	–
	Infant consumers of locally grown food	0.007	–	0.007	–	–	<0.005	–
	Workers at Cardiff East WWTW	<0.005	–	–	<0.005[b]	<0.005[c]	–	–
	Prenatal children of consumers of crops grown in soil treated with sludge pellets	<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. Adults are the most exposed group unless otherwise stated

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

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

Table 6.2. Concentrations of radionuclides in food and the environment near Amersham, 2012[g]

Material	Location	No. of sampling observations	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}								
			^{3}H	^{32}P	^{35}S	^{125}I	^{131}I	^{137}Cs	^{241}Am	Gross alpha	Gross beta
Freshwater samples											
Flounder	Woolwich Reach	1	<25				<0.10	0.08	<0.05		
Sediment	River Colne (Grand Union Canal)	2[E]				<2.3	<1.9	5.0		180	280
Sediment	Upstream of outfall (Grand Union Canal)	2[E]				<2.5	<1.8	5.4		<120	260
Freshwater	Maple Cross	2[E]	<3.0			<0.22	<0.31	<0.23		<0.049	0.42
Freshwater	Upstream of outfall (Grand Union Canal)	2[E]	<3.0			<0.27	<0.30	<0.20		<0.043	0.16
Freshwater	River Chess	1[E]	<2.9			<0.22	<0.30	<0.26		<0.036	0.077
Freshwater	River Misbourne – upstream	1[E]	<4.0			<0.32	<0.29	<0.20		<0.041	<0.032
Freshwater	River Misbourne – downstream	1[E]	<2.9			<0.22	<0.26	<0.20		<0.045	<0.060
Crude effluent[d]	Maple Lodge Sewage Treatment Works	4[E]	<12	<0.36	<1.1	<0.30		<0.21	<0.29	<0.072	0.66
Digested sludge[e]	Maple Lodge Sewage Treatment Works	4[E]	<13	<0.35	<1.6	<0.30	0.76	<0.20	<0.29	<1.9	4.2
Final effluent[f]	Maple Lodge Sewage Treatment Works	4[E]	<9.0	<0.48	<1.4	<0.30		<0.20		<0.069	0.63

Material	Location or selection[b]	No. of sampling observations[c]	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}						
			^{3}H	^{35}S	^{125}I	^{131}I	^{137}Cs	Gross alpha	Gross beta
Terrestrial samples									
Milk		2	<4.3	<0.26	<0.022	<0.0065	<0.20		
Milk	max			<0.30	<0.029	<0.0083			
Blackberries		1	<4.0	<0.10	<0.051		<0.20		
Broad beans		1	<4.0	0.60	<0.058		<0.20		
Carrots		1	<5.0	<0.10	<0.036		<0.20		
Chard		1	<4.0	<0.20	<0.036		<0.20		
Potatoes		1	<5.0	0.50	<0.034		<0.20		
Raspberries		1	<4.0	<0.10	<0.041		<0.10		
Spinach		1	<5.0	0.40	<0.045		<0.20		
Wheat		1	<7.0	0.60	<0.076		<0.20		
Grass	Next to site	1[E]		<3.8	<0.91	<1.3	<0.93	<1.4	140
Grass	Orchard next to site	1[E]			<0.85	<1.5	<1.2	<2.2	180
Grass	Water Meadows (River Chess)	1[E]		<1.8	<1.4	<1.6	<0.99	<2.3	170
Soil	Next to site	1[E]			<0.75	<0.42	9.6	250	400
Soil	Orchard next to site	1[E]			<0.82	<0.50	3.6	320	560
Soil	Water Meadows (River Chess)	1[E]			<0.92	<0.49	9.6	<160	260

[a] *Except for milk, water and effluent where units are Bq l^{-1} and for sediment and soil where dry concentrations apply*
[b] *Data are arithmetic means unless stated as 'max' in this column. 'Max' data are selected to be maxima. If no 'max' value is given the mean value is the most appropriate for dose assessments*
[c] *The number of farms from which milk is sampled. The number of analyses is greater than this and depends on the bulking regime*
[d] *The concentration of ^{3}H as tritiated water was <3.0 Bq l^{-1}*
[e] *The concentration of ^{3}H as tritiated water was <4.0 Bq l^{-1}*
[f] *The concentration of ^{3}H as tritiated water was <3.8 Bq l^{-1}*
[g] *The gamma dose rates in air at 1m over grass and stones, and grass on the bank of the Grand Union Canal were 0.060 and 0.062 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 6.3(a). Concentrations of radionuclides in food and the environment near Cardiff, 2012

Material	Location	No. of sampling observ-ations	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}						
			Organic ^{3}H[e]	^{3}H	^{3}H[f]	^{14}C	^{125}I	^{131}I	^{137}Cs
Marine samples									
Cod	East of new pipeline	1		84		29		<0.47	0.29
Flounder	East of new pipeline	4	180	210		35		*	0.33
Sole	East of new pipeline	2		160		27		*	0.18
Lesser spotted dogfish	Off Orchard Ledges	2	560	590		26		*	0.32
Skates/Rays	Off Orchard Ledges	3	280	300		49		*	0.74
Whiting	East of new pipeline	1		<25		20		<0.57	0.31
Limpets	Lavernock Point	2	<25	<27		18		<1.0	0.23
Mussels	Orchard Ledges	1	140	150		25			
Seaweed[d]	Orchard Ledges	2[E]		<10	<5.5	<15	<0.47		<0.42
Sediment	East of new pipeline	2[E]		22		10	<4.4		12
Sediment	West of new pipeline	2[E]		29	<8.0	<6.8	<5.5		22
Seawater	Orchard Ledges	2[E]		<17	<3.5	<6.2	<0.51		<0.19

Material	Location or selection[b]	No. of sampling observ-ations[c]	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}									
			Organic ^{3}H[e]	^{3}H	^{3}H[f]	^{14}C	^{35}S	^{125}I	^{131}I	^{137}Cs	Gross alpha	Gross beta
Terrestrial samples												
Milk[g]		6	<4.7	<4.7		20	<0.36	<0.017		<0.20		
Milk[g]	max		<5.0	<5.0		22	<0.50	<0.021				
Barley		1		<7.0		110	2.1	<0.083		<0.20		
Beetroot		1	<7.0	7.0		17	0.40	<0.058		<0.20		
Blackberries		1	9.0	15		17	0.40	<0.036		<0.20		
Cabbage		1	<4.0	<4.0		16	1.3	<0.044		<0.20		
Honey		1		<7.0		71	<0.20	<0.049		<0.20		
Leeks		1	12	15		13	0.70	<0.052		<0.20		
Onions		1	5.0	8.0		13	<0.10	<0.038		<0.20		
Potatoes		1	<5.0	<5.0		22	0.30	<0.037		<0.20		
Rape oil		1		<7.0		110	4.1	<0.044		<0.20		
Strawberries		1	<4.0	<4.0		8.0	<0.20	<0.043		<0.20		
Grass		5	<6.6	<6.6		21				<0.17		
Grass	max		<12	12						<0.20		
Silage		2	<5.0	<5.0		59						
Silage	max					68						
Soil		3								5.0		
Soil	max									6.7		
Sediment	Canal	2[E]		37		16		<4.2		11		
Freshwater	River Taff upstream	2[E]		<9.9	<4.0	<3.6		<0.27	<1.6	<0.20	<0.051	0.15
Freshwater	River Taff downstream	2[E]		<8.3	<3.9	<3.5		<0.26	<1.6	<0.19	<0.037	0.20
Freshwater	Canal	2[E]		<11	7.0	<3.6		<0.26	<1.5	<0.19	<0.050	<0.16
Crude effluent	Cardiff East WWTW	1[E]	<11	<11	<5.4	3.2						
Final effluent	Cardiff East WWTW	1[E]	<11	<11	<6.5	<3.0						
Sludge pellets	Cardiff East WWTW	1[E]		220		64						

* *Not detected by the method used*

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

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

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

[d] *The concentration of ^{99}Tc was 4.5 Bq kg^{-1}*

[e] *The organic fraction may be higher than the total tritium value for some analyses due to uncertainties in the analytical methods* for tritium. For dose assessments in this report, the higher of the two values has been used

[f] *As tritiated water*

[g] *The concentration of ^{32}P was <0.27 (max <0.29) Bq l^{-1}*

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

Table 6.3(b). Monitoring of radiation dose rates near Cardiff, 2012

Location	Ground type type	No. of sampling observations	μGy h^{-1}
Mean gamma dose rates at 1m over substrate			
East of Pipeline	Mud	2	0.080
West of Pipeline	Mud	2	0.098
Peterstone Wentlooge	Mud and salt marsh	2	0.089

7. Industrial and landfill sites

This section considers the effects of (i) the main disposal site on land for solid radioactive wastes in the UK, at the LLWR near Drigg in Cumbria, as well as other landfill sites which have received small quantities of solid wastes and (ii) other sites where industries or incidents may have introduced radioactivity into the environment.

7.1 Low Level Waste Repository near Drigg, Cumbria

The Low Level Waste Repository (LLWR) is the UK's national low level waste disposal facility and is located on the west Cumbrian coast, approximately 7 km south east of Sellafield. The main function of the LLWR is to receive low-level solid radioactive wastes from all UK nuclear licensed sites (except Dounreay) and many non-nuclear sites. Where possible the waste is compacted, and then most waste is grouted within containers before disposal. Wastes are now 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 operated by LLW Repository Limited on behalf of the NDA. From 1 April 2008, a consortium, UK Nuclear Waste Management Limited (UKNWM), took over as the Parent Body Organisation for LLW Repository Limited. The operators submitted an Environmental Safety Case (ESC) to the Environment Agency in May 2011. The purpose of this submission is to demonstrate to the Environment Agency that the continued use of the site, and in particular the disposal of waste into vault 9, is safe for people and the environment both now and in the long term.

The Environment Agency is providing significant effort into its review of the LLWR ESC submitted by the operators in May 2011. Once the technical review is completed, the Environment Agency expects LLW Repository Limited to seek a variation to their permit to allow further disposals at the site. At that point the Environment Agency will consult widely. As part of the technical review the Environment Agency has identified a number of areas where further information is required. Therefore, full completion of the review is not anticipated until late 2013 (Environment Agency, 2013). These timescales will impact upon any final decision date on permitting further disposals. Further information is available at: www.environment-agency.gov.uk/llwr

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 2012, be distinguished from those due to Sellafield. A new habits survey was published in 2013 and the results have been included in the dose assessments for the site (Clyne *et al.*, 2013).

Key points

LLWR, near Drigg

- Disposals of solid waste resumed in 2012
- Concentrations and dose rates at the LLWR were similar to those in 2011
- Doses were dominated by the effects of the legacy of discharges into the sea at Sellafield and Whitehaven

Other sites

- Tritium found in leachate from other landfill sites. Probably due to disposal of Gaseous Tritium Light Devices. Doses were less than 0.5 per cent of dose limit
- A new permit was granted relating to the disposal of LLW at Clifton Marsh
- Very small discharges from the Studsvik Metals Recycling Facility were made in 2012
- Enhancement in natural radionuclides at Whitehaven from phosphate processing is now very difficult to detect. However the radiation dose from the enhancement, taken with effects of disposal of other local wastes, was estimated to be 30 per cent of the dose limit
- The investigation into the radium-226 contamination near Dalgety Bay, Fife continued in 2012
- Discharges from other non-nuclear sites (hospitals, universities etc.) were all within limits set in regulations. Limited monitoring of such sites was undertaken and no significant effects were found

Small disposals of solid radioactive waste were made at the LLWR in 2012 (in contrast to no disposals in 2011). The low volume of disposals in recent years is a consequence primarily of national efforts to divert LLW to alternative treatment or disposal routes. Waste may continue to be disposed in Vault 8 in accordance with the Environmental Permit and the National LLW-Strategy. Future waste disposals will depend on the completion of the ESC review process and the subsequent permitting of any future disposal capacity.

Although the permit for disposal to the Drigg Stream has been revoked, reassurance monitoring of samples of water and sediment has continued. The results are given in Table 7.2. The gross alpha and beta concentrations were below the WHO screening levels for drinking water from the Drigg stream. Although the stream is not known to be used as a source of drinking water, it is possible that occasional use could occur, for example by campers. If the stream was used as a drinking water supply for three weeks, the dose would be less than 0.005 mSv. Concentrations of radionuclides in sediment from the Drigg stream were similar to those for 2011. They reflect the legacy of direct discharges of leachate from the disposal site into the stream (BNFL, 2002). This practice stopped in 1991.

In the past, groundwater from some of the trenches on the LLWR site moved eastwards towards a railway drain along the perimeter of the site. Radioactivity from the LLWR was detected in the drain water. The previous operators of the site (BNFL) took steps in the early 1990s to reduce ingress of water from the trenches by building a "cut-off wall" to reduce lateral migration of leachate. The results of monitoring in the drain in 2012 have shown that the activity concentrations are now very low and have reduced significantly since the "cut-off wall" was constructed. Both gross alpha and gross beta concentrations were below or just above the relevant WHO screening limit. Concentrations of tritium were below the limit of detection.

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. Results for 2012 are given in Table 7.2. Evidence in support of the proposition that radioactivity in leachate from the LLWR might be transferring to foods was very limited in 2012, as it was in 2011. In general, concentrations of radionuclides detected were similar to or lower than those found near Sellafield (Section 2). The *total dose* from all pathways and sources, including a component due to Chernobyl and weapon test fallout, was 0.30 mSv, or 30 per cent of the dose limit for members of the public of 1 mSv (Table 7.1). This was dominated by the effects of the legacy of discharges into the sea at Sellafield and Whitehaven, which are near to the LLWR site. If these effects were to be excluded, and the sources of exposure from the LLWR are considered, the people most exposed were represented by children aged 1 year spending time near the site. Their *total dose* in 2012 was 0.040 mSv (Table 1.2), mostly due to direct radiation. Source specific assessments of exposures for consumers of water from Drigg stream and of locally grown terrestrial food were less than 0.012 mSv.

7.2 Other landfill sites

Some organisations are granted authorisations or permits by SEPA (in Scotland) or the Environment Agency (in England and Wales) respectively to dispose of solid wastes containing low levels of radioactivity to approved landfill sites. In Northern Ireland, this type of waste is transferred to Great Britain for incineration. Waste with very low levels of radioactivity can also be disposed of in general refuse. Radioactivity in wastes can migrate into leachate and in some cases can enter the groundwater. SEPA and the Environment Agency carry out monitoring of leachates. The distribution of landfill sites considered in 2012 is shown in Figure 7.1 and the results are presented in Tables 7.3 and 7.4. The programme in England and Wales reduced significantly in 2007 because the data from the previous, larger programme, collected over many years, showed that any enhancements in concentrations were predictable and gave rise to doses of very low significance. The remaining programme in England and Wales constitutes continued monitoring in relation to sites near Springfields where solid LLW has been disposed of (e.g. Clifton Marsh), and at a few other landfill sites where disposals of radioactive waste are ongoing. In June 2011, the Environment Agency conducted a public consultation, on an application made by Sita (Lancashire) Limited, to allow Clifton Marsh landfill to accept waste containing low levels of radioactivity from a range of sources. A new permit was issued in 2012 (Environment Agency, 2012d).

The results, in common with previous years, showed evidence for migration of tritium from some of the discharge sites. The reported tritium concentrations vary from year to year. The variation is thought to be related to changes in rainfall quantity and resulting leachate production and the use of different boreholes for sampling. A possible source of the tritium is thought to be due to disposal of Gaseous Tritium Light Devices (Mobbs *et al*., 1998). Inadvertent ingestion of leachate (2.5 l per year) from the site with the highest observed concentration of tritium would result in a dose of less than 0.005 mSv or less than 0.5 per cent of the dose limit for members of the public of 1 mSv (Table 7.1). Similarly the dose from ingestion of uranium isotopes in leachate from Clifton Marsh was also less than 0.005 mSv.

In March 2007, the Government introduced a more flexible framework for the disposal of certain categories of LLW to landfill. Further details and information are provided on DECC's 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.

The Environment Agency's website describes how the agency regulates radioactive waste going to landfill: http://www.environment-agency.gov.uk/business/sectors/100241.aspx.

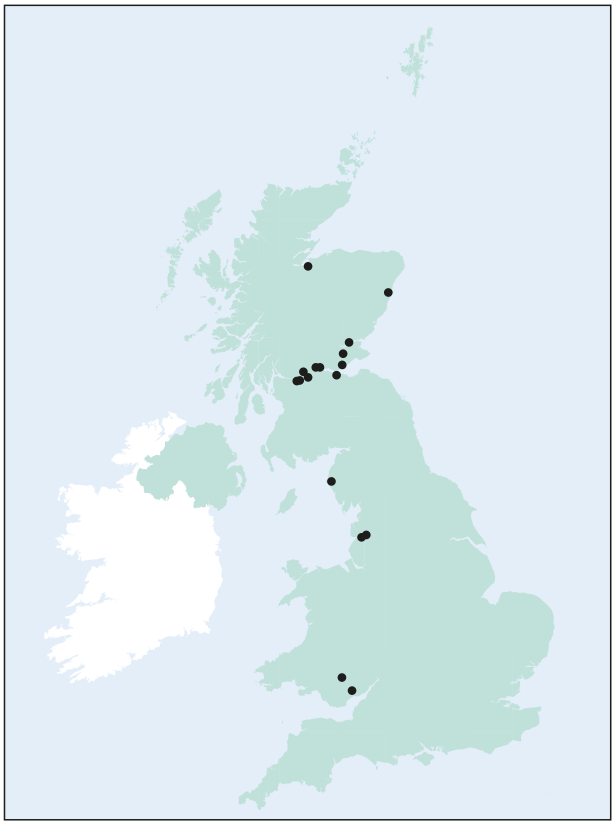


Figure 7.1. Landfill sites monitored in 2012

In England and Wales, disposal of LLW at landfill sites requires both landfill companies and nuclear operators to hold permits to dispose of LLW. 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 (WRG) Limited at the Lillyhall Landfill Site in Cumbria. Their permit, issued in 2011, allows them to dispose of VLLW
- Augean at the East Northants Resource Management Facility, near Kings Cliffe, Northamptonshire. Their permit, issued in 2011, allows them to dispose of low activity LLW and VLLW.
- Sita (Lancashire) Limited at Clifton Marsh in Lancashire. They received a permit to dispose of LLW in September 2012. This permit replaced previous arrangements authorising disposals at Clifton Marsh by operators at the Springfields and Capenhurst nuclear licensed sites, whose permits used to allow disposal of solid LLW at Clifton Marsh in their own right. The varied permits now allow those operators to transfer LLW to landfill operators who hold an appropriate EPR permit.

Disposals of LLW at the Augean site began in December 2011 and were from non-nuclear site remediation works. The first consignment from a nuclear licensed site was from Harwell in March 2012. This first nuclear consignment comprised of 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 Augean landfill site. This will establish current levels of radioactivity around the site to provide a baseline and allow any future changes to be detected. This monitoring will continue into 2013 and the results will be compiled and reported in future years. In addition in 2012, the Environment Agency carried out some assurance monitoring and sampling of wastes at the Harwell site prior to dispatch to the Augean site. This work is also ongoing and will be reported in future years.

Disposals of LLW at Clifton Marsh have continued under the new permitting arrangements.

SEPA continued its programme of monitoring at the Stoneyhill Landfill Site in Aberdeenshire. The initial purpose of the programme was to gather data on the environmental baseline around the site prior to the landfill consigning conditioned Naturally-Occurring Radioactive Material (NORM) waste from the oil and gas industry. However, the landfill has now started accepting conditioned NORM waste and the SEPA monitoring programme has been continued to gather further data. This programme is complementary to, but independent of, the operator's monitoring programme.

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. Sita UK Limited, who operates Stoneyhill Landfill, has constructed a descaling facility adjacent to the landfill in partnership with Nuvia Limited. This facility will descale oil and gas industry equipment (such as pipes) using pressurised water. The solid scale removed from the equipment will be then grouted into drums and consigned to Stoneyhill Landfill in accordance with their authorisation granted in May 2012.

The SEPA monitoring programme involves the collection and analysis of landfill leachate, groundwater and surface water on a quarterly basis and analysing for radium-226 and radium-228 with results so far being close to or at the limit of detection

7.3 Metals Recycling Facility, Lillyhall, Cumbria

The Metals Recycling Facility (MRF), operated by Studsvik UK Limited, first commenced operations in September 2009. The facility is located on the north-eastern edge of the Lillyhall Industrial Estate, about 4 km south-east of Workington. The main function of the MRF is to receive, sort, segregate, monitor and size reduce metallic low level radioactive waste (LLW) before either treating it on site by surface decontamination, or sending the metal to a sister plant in Sweden for melting. The intent of the process is, as far as possible, to decontaminate the metal, such that it can be returned to the open market as exempt from control as radioactive waste, for recycling. Secondary wastes from the metal treatment containing radioactivity, as either LLW or very low level waste (VLLW), are disposed of to the LLWR or to landfills.

A permit for disposal of radioactive waste from the site was issued by the Environment Agency in March 2008, although no radioactive waste disposals were made until September 2009. The permit allows discharges of gaseous waste to the environment via a main stack and aqueous waste to the sewer. Low discharge limits are set for both aqueous and gaseous discharges. Very small discharges were made during 2012 (Appendix 2). The permit includes conditions requiring Studsvik UK Limited to monitor discharges and undertake environmental monitoring.

7.4 Phosphate processing, Whitehaven, Cumbria

Previous surveys (Rollo *et al*., 1992) have established that an important man-made source of naturally-occurring radionuclides in the marine environment has been the chemical plant at Whitehaven in Cumbria, which used to manufacture phosphoric acid from imported phosphate ore. Phosphogypsum, containing thorium, uranium and their daughter products, was discharged as a liquid slurry by pipeline to Saltom Bay. Processing of phosphate ore ceased in 1992 and processing of phosphoric acid at the plant ceased at the end of 2001. However, there is an environmental legacy from past operations. Such sources are said to give rise to Technologically enhanced Naturally-Occurring Radioactive Material (TNORM). Decommissioning of the plant was undertaken in 2002 and released small quantities of uranium to sea, but discharges were very much lower than in previous years. The plant was subsequently demolished in 2004 and the permit to discharge radioactive wastes revoked by the Environment Agency.

The results of routine monitoring for naturally-occurring radioactivity near the site in 2012 are shown in Table 7.5. Analytical effort has focused on lead-210 and polonium-210, which concentrate in marine species and are the important radionuclides in terms of potential dose to the public. Concentrations of polonium-210 and other naturally-occurring radionuclides were slightly enhanced near Whitehaven but quickly reduce to background levels further away. Figures 7.2 and 7.3 show how concentrations of polonium-210 in winkles and crabs have generally decreased since 1998. Concentrations in the early 1990s were in excess of 100 Bq kg^{-1} (fresh weight). There were some changes in concentrations of polonium-210 in local samples in 2012 compared with 2011. In particular, concentrations in crab at Parton and Sellafield increased above the expected background concentrations. However, the other changes were small, and taking into account the ranges of values observed, it is now difficult to distinguish between the total naturally-occurring radionuclide concentrations and the range of concentrations normally expected from naturally sourced radioactivity. These are shown in Figures 7.2 and 7.3 and in Appendix 1 (Annex 4). There were small enhancements for some other samples above the expected natural background median levels for marine species, but the majority were within the ranges observed in the undisturbed marine environment. It is nevertheless considered prudent to continue to estimate doses based on the difference between observed concentrations and median levels indicative of natural background.

The critical radiation exposure pathway was internal irradiation, due to the ingestion of naturally-occurring radioactivity in local fish and shellfish. Centred on the Sellafield site to the south of Whitehaven, the group included people with habits relating to the immediate area around Whitehaven, including Saltom Bay and Parton. It is identical to the group used to assess the marine impacts of the Sellafield and LLWR (near Drigg) sites (Sections 2 and 7). An additional, smaller group limited to the immediate area around Saltom Bay is no longer assessed separately because the larger group provides adequate protection and a more robust assessment. The estimated contribution due to background median concentrations of naturally-occurring radionuclides is subtracted. In 2012, estimates of background concentrations of cod and plaice were introduced in addition to the general category of 'fish' so as to provide a better discrimination for round and flat fish. Consumption rates for people who eat at high-rates were reviewed and revised in 2012. 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 local high rate consumers of seafood was 0.30 mSv in 2012 (Table 7.1), below the dose limit for members of the public of 1 mSv. The value for 2011 was 0.18 mSv. The dose includes the effects of all sources near the site, enhanced naturally-occurring radionuclides from the non-nuclear industrial activity (i.e. TNORM), and Sellafield operations. The source specific assessment of dose, targeted directly at high-rate seafood consumers confirmed the total dose assessment and gives a similar result in 2012, 0.33 mSv. The contribution to the *total dose* from enhanced natural radionuclides was 0.22 mSv in 2012, compared with 0.11 mSv in 2011. The change was largely due to (i) an increase in the concentration of polonium-210 in locally caught crustaceans and (ii) an increase in the consumption rate of crustaceans taken to be representative of those most exposed. The longer term trend in dose, shown in Figure 7.4, is one of a steady reduction in exposures.

7.5 Aberdeen

Scotoil operates a cleaning facility for equipment from the oil and gas industry contaminated with enhanced concentrations of radionuclides of natural origin. Prior to their operations, a fertiliser manufacturing process was operated on the site, which made discharges to sea.

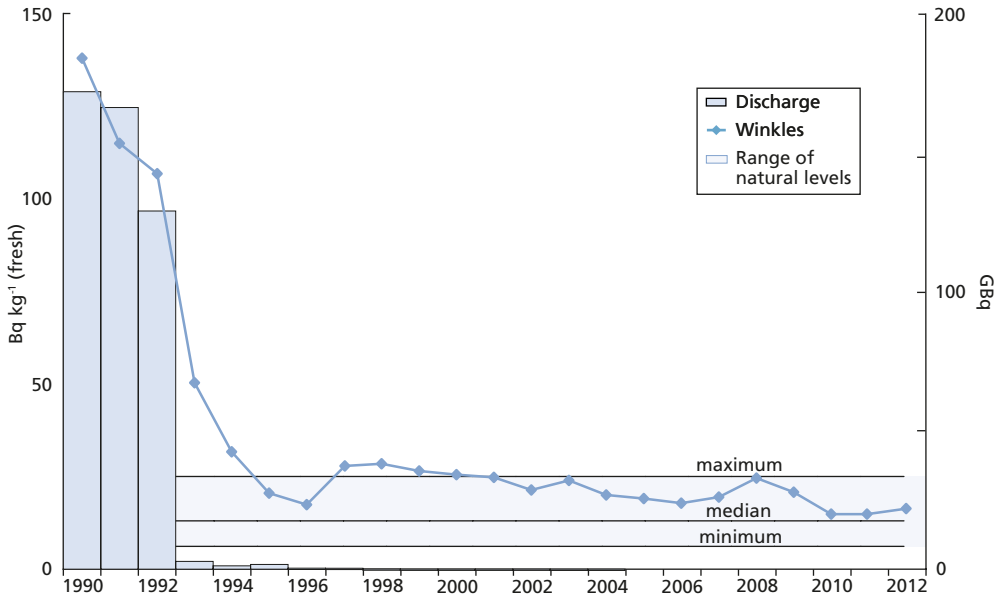


Figure 7.2. Polonium-210 discharge from Whitehaven and concentration in winkles at Parton, 1990-2012

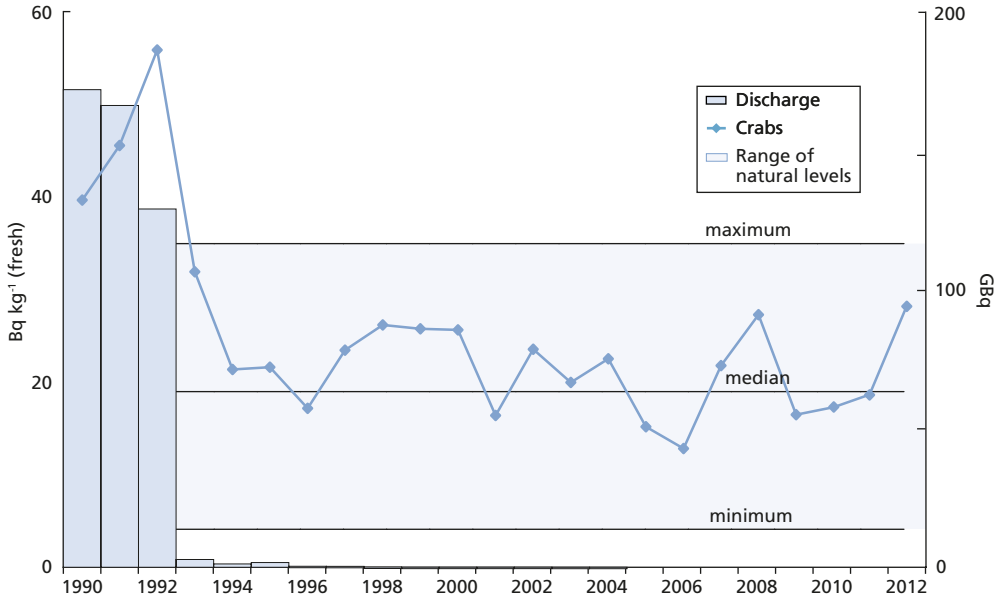


Figure 7.3. Polonium-210 discharge from Whitehaven and concentration in crabs at Parton, 1990-2012

As reported in RIFE-17 Scotoil ceased the discharging of solid waste to sea in October 2011 upon the development of a waste treatment facility, however liquid effluent to sea continues to be discharged in accordance with their authorisation. The primary discharge is of radium-226 and radium-228, with lead-210 and polonium-210 in smaller quantities. The authorisation includes conditions requiring Scotoil to undertake environmental monitoring.

Seaweed (*Fucus vesiculosus*) and sediment samples from Aberdeen Harbour were monitored in 2012. Technetium-99 was detected in seaweed (13 Bq kg^{-1}, fresh), in line with the expected effect from Sellafield discharges (as the releases become diluted or mixed in moving further afield). Gamma-emitting radionuclides were all below the LoD. In 2012, the dose rate on sediment was 0.068 µGy h^{-1} and similar to background. The dose rate was lower than the results in previous years, reflecting the effects of current and earlier discharges.

7.6 Dalgety Bay, Fife

Radioactive items containing radium-226 and associated daughter products have been detected at Dalgety Bay in Fife since at least 1990. It is thought that the contamination is associated with historical disposals of waste from past military operations at the Royal Naval Air Station (RNAS) Donibristle,

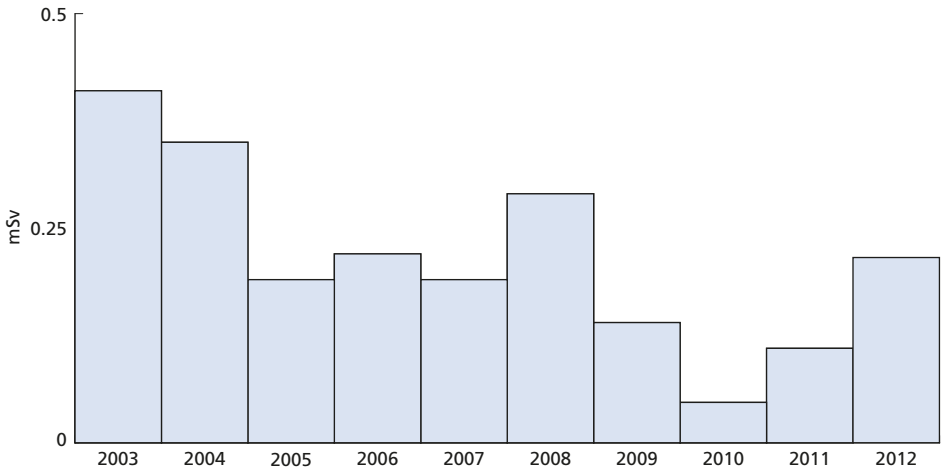


Figure 7.4. Trend in *total dose* to seafood consumers from naturally-occurring radionuclides near Whitehaven, 2003-2012

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 June 1990, environmental monitoring showed elevated radiation levels in the Dalgety Bay area. The monitoring was undertaken as part of the routine environmental monitoring programme for Rosyth Royal Dockyard conducted in accordance with the dockyard's authorisation to dispose of liquid radioactive effluent to the Firth of Forth. Some material was removed for analysis, which indicated the presence of radium-226. Further investigation confirmed that the contamination could not have originated from the dockyard and was most likely to be associated with past practices related to the nearby former RNAS Donibristle/HMS Merlin military airfield. Since this initial discovery, there have been several monitoring exercises to determine the extent of this contamination.

Following the increased number of particle finds and the discovery of the high activity particles in 2011, the public protection measures established in 2011 were maintained during 2012 and into 2013. 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 discovered remains in place, as well as the information signs advising the public of the contamination and precautions to be taken. In addition, the FEPA Order issued by the Food Standards Agency in Scotland prohibiting the collection of seafood from the Dalgety Bay area remains in force. SEPA continued with its programme of shellfish monitoring during which no particles were detected in the shellfish. All shellfish samples collected were analysed for the presence of radium-226 and all were found to be less than the LoD. The continuation of these protection measures is reducing the risks to members of the public whilst further work continues to characterise the nature of the contamination.

In October/November 2012, a contractor on behalf of the MoD conducted an intrusive site investigation of Dalgety Bay to determine the extent of the contamination. The investigation involved the digging of trial pits and drilling of boreholes across the site. This work revealed that further radioactive sources remain in the made ground which over time may erode onto the beach area. A factual report published by the MoD contractor detailing the work undertaken during the investigation is available from SEPA's website (www.sepa.org.uk).

In October 2012, SEPA commissioned a habits survey to be undertaken at Dalgety Bay to gather information and data on the habits of people that use the affected area; such as where they spend time and for how long, the activities that they undertake when in the area and whether they collect and consume any marine foodstuffs. The habits survey report was published in May 2013 (Clyne *et al.*, 2013). These data are then used to calculate the probability that a member of the public will come into contact with a radioactive particle which, coupled with data regarding the hazard posed by the particles, can inform on the overall risk to the public from the contamination.

The Risk Assessment Report was published by SEPA in May 2013, which concluded that there is a significant possibility of significant harm being caused via skin contact and inadvertent ingestion from particles found on the beach from the currently demarcated area to the slipways (Dale, 2013). This constitutes a "significant pollutant linkage", which means that these areas of Dalgety Bay could be designated as Radioactive Contaminated Land (RCL) under the RCL (Scotland) Regulations 2007 and require remediation. In June 2013, Public Health England reported that "we agree that radium-226 contaminated objects recovered from Dalgety Bay include objects that could give rise to radiation doses that

exceed the relevant criteria for the Radioactive Contaminated Land (RCL) (Scotland) Regulations 2007; specifically the effective dose criterion of 100 mSv".

Following the conclusions of the risk assessment it was necessary to identify who is responsible for the significant pollutant linkages and consequently any remediation that may be required (i.e. the appropriate person). The Appropriate Person Report was published in June 2013 and utilised a wide variety of evidence including, but not limited to, historical maps, aerial photographs, witness statements and data from the intrusive site investigation to conclude that the MoD is the sole appropriate person responsible for the significant pollutant linkages identified in the risk assessment report (Patton, 2013).

At its meeting on 10 July 2013, the Committee on Medical Aspects of Radiation in the Environment (COMARE) considered five recommendations from the COMARE Contaminations Working Group (which met on 9 July 2013) and considered documents relating to Dalgety Bay prepared by MoD contractors, SEPA and PHE, together with the interim COMARE report to the Scottish Government dated December 2012. The recommendations received had been agreed by the Working Group.

Following reports from members of the Working Group and extensive discussion, COMARE agreed unanimously that:

1) Based on concordant data from SEPA, the University of Stirling and PHE, taken in conjunction with data from the habits survey, the sources present at Dalgety Bay pose a potential risk to public health in terms of committed effective dose estimates.
2) Given the dynamic nature of the contamination, the indefinite continuation of a monitoring and recovery programme, allied to demarcation of affected areas is not regarded as best practice or in compliance with ALARA.
3) Scottish Government should take steps to ensure that effective remediation of the affected area is undertaken as soon as is possible.
4) In the interim period before remediation, the present monitoring programme being carried out by the MoD at Dalgety Bay should continue, with the coverage and frequency to be determined by the regulator. It should be carried out to at least the standard specified by the Working Group.
5) The Committee should seek authority from Government and the devolved authorities to obtain information from appropriate bodies in order to create a UK-wide list of sites which are known to have been, or thought to be potentially, contaminated with radium. This should incorporate details of any monitoring and/or remediation known to have been carried out.

Given COMARE's recommendations the next stage is the development of remediation options by the appropriate person either on a voluntary basis or via designation as RCL. Work in this area is ongoing and an update will be provided in next year's RIFE report.

For further information on the work at Dalgety Bay and to access copies of the reports referred to in this section please visit the Radioactive Substances pages on SEPA's website (www.sepa.org.uk).

7.7 Other non-nuclear sites

Routine discharges of small quantities of radioactive wastes to air and water are made from a wide range of other non-nuclear sites in the UK on land, and from offshore oil and gas installations.

A summary of the most recent data for the quantities discharged under regulation is given in Tables 7.6 and 7.7. 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 (on-shore)
- Oil and gas (off-shore)
- Education (Universities and Colleges)
- Hospitals
- Other (research, manufacturing and public sector)

Discharges may also occur without an authorisation or permit when the quantities are considered to be below the need for specific regulatory control. For example discharges of natural radionuclides are made from coal-fired power stations because of the presence of trace quantities of uranium and thorium and their decay products in coal.

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 2012, SEPA undertook a small-scale survey (as part of the annual programme) of the effects of discharges from non-nuclear operators by taking and analysing samples of mussels and other materials from the River Clyde and sludge pellets from a sewage treatment works. The results are given in Table 7.8 and show the expected effects of Sellafield discharges at this distance. The results were generally similar to those in 2011. An assessment of the dose to a hypothetical group of high-rate mollusc consumers was undertaken. The dose was less than 0.005 mSv or less than 0.5 per cent of the dose limit.

Table 7.1. Individual doses – industrial and landfill sites, 2012

Site	Exposed population[a,b]	Exposure, mSv per year					
		Total	Seafood (nuclear industry discharges)	Seafood (other discharges)[e]	Other local food	External radiation from intertidal areas	Intakes of sediment and water
***Total dose* – all sources**							
Whitehaven	**Adult mollusc consumers**	**0.30[d]**	**0.066**	**0.22**	**-**	**0.016**	**–**
Source specific doses							
LLWR near Drigg	Infant consumers of locally grown food	0.012	–	–	0.012	–	–
	Consumers of water from Drigg stream	<0.005	–	–	–	–	<0.005
Landfill sites for low-level radioactive wastes	Inadvertent leachate consumers[c]	<0.005	–	–	–	–	<0.005
Whitehaven (habits averaged 2008-12)	Seafood consumers	0.33[d]	0.11	0.19	–	0.032	–

[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. Adults are the most exposed group unless otherwise stated

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

[c] *Infants*

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

[e] *Enhanced naturally occuring radionuclides from Whitehaven*

Table 7.2. Concentrations of radionuclides in terrestrial food and the environment near Drigg, 2012

Material	Location or selection[a]	No. of sampling observ-ations[c]	Mean radioactivity concentration (fresh)[b], Bq kg^{-1}								
			^{3}H	^{14}C	^{60}Co	^{90}Sr	^{95}Zr	^{95}Nb	^{99}Tc	^{106}Ru	^{125}Sb
Milk		1	<6.5	17	<0.19	0.038	<0.28	<0.23	<0.0045	<1.1	<0.34
Beetroot		1	<4.0	15	<0.20	0.22	<0.30	<0.20		<1.1	<0.40
Blackberries		1	<4.0	22	<0.10	0.24	<0.30	<0.20		<1.1	<0.20
Cabbage		1	<5.0	6.0	<0.20	0.17	<0.30	<0.20	<0.031	<0.90	<0.50
Deer muscle		1	<5.0	12	<0.20	0.015	<0.30	<0.20	<0.023	<1.0	<0.30
Duck		1	<6.0	44	<0.20	0.046	<0.20	<0.20	<0.032	<0.60	<0.40
Eggs		1	5.0	40	<0.20	0.020	<0.30	<0.20		<1.5	<0.50
Potatoes		1	<5.0	11	<0.20	0.030	<0.30	<0.20	<0.030	<1.3	<0.20
Sheep muscle		1	<5.0	26	<0.20	0.045	<0.20	<0.20	<0.022	<1.2	<0.20
Sheep offal		1	<8.0	27	<0.10	0.58	<0.20	<0.20	<0.024	<1.0	<0.40
Grass		2							<0.086		
Grass	max								0.15		
Sediment	Drigg Stream	4[E]			<0.52	<4.2	<1.2	<0.30		<3.8	<1.9
Freshwater	Drigg Stream	4[E]	<4.3		<0.27	<0.070					
Freshwater	Railway drain	1[E]	<3.5		<0.24	0.37					

Material	Location or selection[a]	No. of sampling observ-ations[c]	Mean radioactivity concentration (fresh)[b], Bq kg^{-1}								
			^{129}I	^{134}Cs	^{137}Cs	Total Cs	^{144}Ce	^{210}Po	^{228}Th	^{230}Th	^{232}Th
Milk		1	<0.0075	<0.19	<0.18		<0.82				
Beetroot		1	<0.023			0.25	<0.90				
Blackberries		1	<0.042			0.10	<0.60				
Cabbage		1	<0.019			0.15	<0.60				
Deer muscle		1	<0.041			2.1	<0.60				
Duck		1	<0.019			0.14	<0.70				
Eggs		1	<0.027			0.079	<1.1				
Potatoes		1	0.026			0.18	<0.60				
Sheep muscle		1	<0.024			0.39	<0.60				
Sheep offal		1	<0.040			0.21	<0.80				
Sediment	Drigg Stream	4[E]		<0.41	350		<2.3	12	19	16	14
Freshwater	Drigg Stream	4[E]		<0.29	<0.23			<0.0050	<0.0045	<0.0045	<0.0048
Freshwater	Railway drain	1[E]		<0.24	<0.20			<0.0080	<0.0050	<0.0050	<0.0050

Material	Location or selection[a]	No. of sampling observ-ations[c]	Mean radioactivity concentration (fresh)[b], Bq kg^{-1}								
			^{234}U	^{235}U	^{238}U	^{238}Pu	^{239}Pu + ^{240}Pu	^{241}Pu	^{241}Am	Gross alpha	Gross beta
Milk		1				<0.00010	<0.00015	<0.036	0.00010		
Beetroot		1				0.00020	0.0011	<0.071	0.0043		
Blackberries		1				<0.00020	<0.00030	<0.076	0.00090		
Cabbage		1				<0.00010	<0.00030	<0.063	0.00020		
Deer muscle		1				<0.00010	<0.00030	<0.098	<0.00020		
Duck		1				<0.00020	0.00030	<0.084	<0.00010		
Eggs		1				<0.00010	<0.00030	<0.065	0.00020		
Potatoes		1				<0.00010	<0.00030	0.14	0.00040		
Sheep muscle		1				<0.00010	0.00050	<0.10	0.00050		
Sheep offal		1				0.00090	0.0077	<0.13	0.0073		
Grass		2	0.13	0.0047	0.12						
Grass	max		0.14	0.0053	0.13						
Soil		1	6.7	0.27	6.7						
Sediment	Drigg Stream	4[E]	81	4.4	73	17	120	430	160	460	810
Freshwater	Drigg Stream	4[E]	<0.010	<0.0040	0.0089	<0.0048	<0.0045	<0.13	<0.0073	<0.067	0.42
Freshwater	Railway drain	1[E]	0.012	<0.0038	0.011	<0.0050	<0.0050	<0.10	<0.010	<0.060	1.2

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

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

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

[E] *Measurements are made on behalf of the Food Standards Agency unless labelled "E". In that case they are made on behalf of the Environment Agency*

Table 7.3. Concentrations of radionuclides in surface water leachate from landfill sites in Scotland, 2012

Area	Location	No. of sampling observations	Mean radioactivity concentration, Bq l^{-1}			
			^{3}H	^{14}C	^{137}Cs	^{241}Am
Aberdeen City	Ness Tip	1	<5.0	<15	<0.05	<0.05
City of Glasgow	Summerston Tip	1	150	<15	<0.05	<0.05
City of Glasgow	Cathkin	1	79	<15	<0.05	<0.05
Clackmannanshire	Black Devon	1	14	<15	<0.05	<0.05
Dunbartonshire	Birdstone	1	7.2	<15	<0.05	<0.05
Dundee City	Riverside	1	34	<15	<0.05	<0.05
Edinburgh	Braehead	1	<5.0	<15	<0.05	<0.08
Fife	Balbarton	1	59	<15	<0.05	<0.07
Fife	Melville Wood	1	210	<15	<0.05	<0.06
Highland	Longman Tip	1	<5.0	<15	<0.05	<0.05
North Lanarkshire	Dalmacoulter	1	310	<15	<0.05	<0.05
North Lanarkshire	Kilgarth	1	<5.0	<15	<0.05	<0.05
Stirling	Lower Polmaise	1	630	<15	<0.05	<0.05

Table 7.4. Concentrations of radionuclides in water from landfill sites in England and Wales, 2012

Location	Sample source	No. of sampling observ-ations	Mean radioactivity concentration, Bq l^{-1}						
			Total ^{3}H	^{3}H[a]	^{14}C	^{40}K	^{60}Co	^{137}Cs	^{228}Th
Glamorgan									
Trecatti Landfill, Merthyr Tydfil	Raw Leachate	2	1100	1000	<7.3				
Trecatti Landfill, Merthyr Tydfil	Treated leachate	2	840	860	<4.9				
Lancashire									
Clifton Marsh	Borehole 6	2		<5.8		<4.5	<0.23	<0.20	<0.0050
Clifton Marsh	Borehole 19	2		6.8		<4.2	<0.23	<0.20	<0.0045
Clifton Marsh	Borehole 40	2		<4.6		<5.4	<0.31	<0.26	<0.0078
Clifton Marsh	Borehole 59	2		<5.8		<5.4	<0.32	<0.25	<0.0081
Ulnes Walton	Pond	1		<3.4		<4.4	<0.25	<0.20	<0.0070
South Glamorgan									
Lamby Way Tip[b]	Borehole 1A	2		8.0	<3.3	<4.5	<0.27	<0.20	

Location	Sample source	No. of sampling observ-ations	Mean radioactivity concentration, Bq l^{-1}						
			^{230}Th	^{232}Th	^{234}U	^{235}U	^{238}U	Gross alpha	Gross beta
Lancashire									
Clifton Marsh	Borehole 6	2	<0.0040	<0.0050	0.058	<0.0047	0.059	<0.21	1.9
Clifton Marsh	Borehole 19	2	<0.0040	<0.0035	0.029	<0.0045	0.025	<0.56	4.3
Clifton Marsh	Borehole 40	2	<0.0035	<0.0035	<0.0062	<0.0040	<0.0055	<0.15	1.7
Clifton Marsh	Borehole 59	2	<0.0050	<0.0035	<0.0049	<0.0046	<0.0035	<0.14	1.8
Ulnes Walton	Pond	1	<0.0030	<0.0020	0.013	<0.0020	0.011	<0.039	0.25
South Glamorgan									
Lamby Way Tip[b]	Borehole 1A	2						<0.13	0.50

[a] *As tritiated water*
[b] *The concentrations of ^{125}I and ^{131}I were <0.26 and <1.3 Bq l^{-1} respectively*

Table 7.5. Concentrations of naturally occurring radionuclides in the environment, 2012

Material	Location	No. of sampling observ-ations	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}							
			^{210}Po	^{210}Pb	^{228}Th	^{230}Th	^{232}Th	^{234}U	^{235}U	^{238}U
Phosphate processing, Whitehaven										
Winkles	Saltom Bay	4	13	0.74						
Winkles	Parton	4	16	1.5	1.2	0.79	0.41	1.3	0.042	1.2
Winkles	North Harrington	1	19							
Winkles	Nethertown	4	12							
Winkles	Drigg	1			0.54	0.55	0.40			
Winkles	Tarn Bay	1	8.9							
Mussels	Parton	4	39	2.2						
Mussels	Nethertown	4	36	2.6						
Limpets	St Bees	2	14							
Cockles	Ravenglass	2	19							
Crabs	Parton	4	28	0.17	0.10	0.018	0.0087	0.066	0.0026	0.059
Crabs	Sellafield coastal area	4	20	0.15						
Lobsters	Parton	4	14	0.12	0.0085	0.00091	<0.00034	0.0063	0.00044	0.0070
Lobsters	Sellafield coastal area	4	8.4	0.053						
Cod	Parton	2	1.1	0.89	0.024	0.0015	<0.000082	<0.00055	0.00032	0.0015
Plaice	Whitehaven	1	3.4							
Other samples										
Winkles	South Gare (Hartlepool)	2	23	0.85						
Winkles	Kirkcudbright	1	5.1							
Limpets	Kirkcudbright	1	32							
Cockles	Ribble Estuary	1			0.39	0.42	0.20			
Cockles	Southern North Sea	1			0.36	0.22	0.26			
Cockles	Flookburgh	2	14							
Crabs	Kirkcudbright	1	11							
Lobsters	Kirkcudbright	1	2.2							
Shrimps	Ribble Estuary	2			0.0084	0.0042	0.0026			
Wildfowl	Ribble Estuary	1			0.0057	0.0045	0.0026			
Seaweed	Isle of Man	4						1.3	<0.23	1.1
Sediment	Kirkcudbright	1						12	0.46	10
Sediment	Rascarrel Bay	1						12	0.50	9.7
Sediment	Southerness	1	<0.10							

[a] *Except for sediment where dry concentrations apply*

Table 7.6. Discharges of gaseous radioactive wastes from non-nuclear establishments in the United Kingdom, 2011[a]

	Discharges during 2011, Bq								
	Education (Universities and Colleges)			Hospitals			Other (Research, manufacturing and public sector)		
	England and Wales	Northern Ireland	Scotland	England and Wales	Northern Ireland	Scotland	England and Wales	Northern Ireland	Scotland
^{3}H	3.1E+07						8.9E+11		9.3E+08
^{14}C	7.5E+04					5.1E+07	1.2E+11	1.1E+08	8.7E+09
^{18}F	4.8E+11						6.4E+10		
^{41}Ar	5.0E+07								
^{85}Kr							2.3E+07		
^{99m}Tc				8.7E+08			6.0E+08		
^{125}I	6.0E+05						1.6E+07		5.5E+06
^{129}I									
^{131}I				4.1E+08			1.3E+07		
^{222}Rn							2.0E+09		
Other Alpha particulate							1.0E+11		
Other Beta/Gamma					4.9E+11				
Other Beta/Gamma Particulate	6.6E+11		1.9E+10	7.2E+07		1.2E+09	7.4E+12		3.1E+09

[a] *Excludes nuclear power, defence and radiochemical manufacturing (Amersham and Cardiff) industries. Excludes discharges which are exempt from reporting. Northern Ireland and Scotland discharge data refers to 2012*

Table 7.7. Discharges of liquid radioactive waste from non-nuclear establishments in the United Kingdom, 2011[a]

	Discharges during 2011, Bq										
	Education (Universities and Colleges)			Hospitals			Other (Research, manufacturing and public sector)			Oil and gas (onshore)	Oil and gas (offshore)
	England and Wales	Northern Ireland	Scotland	England and Wales	Northern Ireland	Scotland	England and Wales	Scotland	Northern Ireland	Scotland	Scotland
^{3}H	1.6E+10	4.0E+08	1.7E+10	2.4E+09	8.6E+07	1.1E+08	3.6E+11	2.1E+09	9.3E+08		
^{14}C	1.1E+09	3.1E+05	1.7E+08	3.6E+08		7.3E+07	3.2E+11	3.8E+10	3.2E+08		
^{18}F	6.1E+11			1.9E+12	2.2E+11	3.2E+11	8.0E+11	1.2E+07			
^{22}Na	9.5E+06							3.0E+06			
^{32}P	1.4E+10	3.6E+07	2.8E+09	8.6E+09	3.7E+06	1.0E+09	9.0E+09	3.6E+08			
^{33}P	1.1E+09		1.2E+10				5.7E+09	1.9E+10			
^{35}S	7.7E+09	3.3E+07	4.3E+09	3.4E+09			6.0E+09	2.5E+08			
^{51}Cr	2.1E+09			3.9E+10	7.4E+08	2.3E+09	6.6E+08				
^{57}Co				2.0E+04	1.1E+04		2.0E+02				
^{58}Co					3.1E+04						
^{60}Co							2.5E+04				
^{67}Ga	1.9E+07			2.4E+10	3.6E+07	4.7E+08	1.3E+08				
^{75}Se				1.5E+09		5.5E+07	1.0E+07				
^{89}Sr				1.8E+10		3.2E+09					
^{90}Sr	7.6E+05						2.6E+06				
^{90}Y				3.1E+11	4.0E+06	7.7E+08					
^{99}Tc	2.0E+06										
^{99m}Tc	2.0E+09		1.2E+10	4.8E+13	1.8E+12	5.0E+12	4.9E+11				
^{111}In	2.2E+09		1.5E+07	3.2E+11	9.1E+09	3.8E+10	3.1E+09				
^{123}I	7.4E+04		5.9E+07	9.8E+11	8.6E+10	7.9E+10	7.9E+09				
^{125}I	6.9E+09	1.2E+08	1.0E+08	2.2E+08	1.9E+07	2.6E+08	6.3E+10	9.4E+07			
^{129}I	1.6E+04										
^{131}I	2.3E+08		2.7E+09	8.2E+12	6.0E+10	7.5E+11	1.3E+11				
^{137}Cs	8.3E+05						3.3E+05				
^{153}Sm				4.1E+10							
^{201}Tl				9.3E+10		2.5E+10	2.5E+08				
^{210}Pb										7.5E+08	
^{210}Po										3.3E+06	
^{226}Ra										3.3E+06	
^{228}Ra										1.4E+09	
^{232}Th							4.8E+09	1.2E+06			
Plutonium Alpha	3.1E+01										
Uranium Alpha	9.0E+00						8.7E+09				
^{241}Am	6.5E+05						1.1E+04				
Total Alpha	1.5E+05			2.0E+08			2.4E+10			1.5E+09	
Total Beta/Gamma (Excl Tritium)	7.0E+11			5.3E+13			1.1E+12			9.6E+08	
Other Alpha particulate	3.9E+02			1.5E+08			2.3E+08	1.6E+05			
Other Beta/ Gamma[b]	5.7E+10		9.7E+10	9.6E+11	6.8E+04	2.0E+10	1.1E+10	2.6E+08			
Other Beta/ Gamma particulate							4.6E+09				

[a] *Excludes nuclear power, defence and radiochemical manufacturing (Amersham and Cardiff) industries. Excludes discharges which are exempt from reporting. Northern Ireland and Scotland discharge data refers to 2012*

[b] *Excluding specific radionuclides*

Table 7.8. Monitoring in the River Clyde and near Glasgow, 2012[a]

Location	Material and selection[b]	No. of sampling observations	Mean radioactivity concentration (fresh)[c], Bq kg^{-1}					
			^{3}H	^{14}C	^{32}P	^{90}Sr	^{99}Tc	^{125}Sb
Between Finlaystone and Woodhall	Mussels	1		30	<2.3		4.3	<0.11
Between Finlaystone and Woodhall	*Fucus vesiculosus*	1			<3.0		8.8	<0.13
14 km downstream of Dalmuir	Sediment	1		<15	<1.4			<0.15
Downstream of Dalmuir	Freshwater	4			<0.046			<0.14
River Clyde	Freshwater	4	<1.0			<0.0054		
Daldowie	Sludge pellets	4			<32			<0.34

Location	Material and selection[b]	No. of sampling observations	Mean radioactivity concentration (fresh)[c], Bq kg^{-1}				
			^{131}I	^{137}Cs	^{155}Eu	^{241}Am	Gross beta
Between Finlaystone and Woodhall	Mussels	1	<0.59	0.37	<0.11	<0.10	
Between Finlaystone and Woodhall	*Fucus vesiculosus*	1	7.1	0.39	<0.14	<0.10	
14 km downstream of Dalmuir	Sediment	1	<0.33	10	0.63	0.61	
Downstream of Dalmuir	Freshwater	4	<0.32	<0.10	<0.11	<0.10	
River Clyde	Freshwater	4		<0.10			<0.60
Daldowie	Sludge pellets	4	250	4.4	<1.2	<0.42	

[a] *Results are available for other radionuclides detected by gamma spectrometry, All such results are less than the limit of detection*
[b] *Data are arithmetic means unless stated as 'max' in this column. 'Max' data are selected to be maxima*
[c] *Except for water where units are Bq l^{-1}, and sludge pellets and sediment where dry concentrations apply*

8. Overseas incidents

8.1 Chernobyl (1986)

This accident occurred in April 1986 at Chernobyl, Ukraine, in the former USSR. After the accident, radiocaesium was detected in sheep grazing certain upland areas in the UK, where heavy rain fell in the days following the accident. Restrictions were put in place on moving, selling and slaughtering sheep from the affected areas to prevent meat from animals above the action level of 1,000 Bq kg^{-1} of radiocaesium, a level based on the recommendations of an EU expert committee in 1986, from entering the food chain.

A programme of monitoring live animals, known as the Mark and Release Scheme, was put in place to protect the safety of food, while allowing established sheep farming practices to continue. A farmer wishing to move sheep out of a restricted area had to have them tested using an external monitor held against the sheep. Any sheep that was assessed to have levels of contamination exceeding 1,000 Bq kg^{-1} was marked on the back of the head with coloured paint. Painted sheep could be moved off restricted areas, but could not be sold for slaughter nor returned to the restricted areas for a minimum of three months, allowing time for the radiocaesium to pass out of the body.

In January 2011, 338 farms or part farms (eight in England, and 330 in Wales) and 190,000 sheep were still subject to restrictions. This represented a reduction of over 95 per cent since 1986, when approximately 9,700 farms and 4,225,000 sheep were under restriction across the UK. All remaining restrictions in Northern Ireland were lifted in 2000 and the final controls were removed in Scotland in 2010.

In 2011, the Food Standards Agency reviewed the controls to assess whether these protective measures were still required to maintain food safety (Food Standards Agency, 2011a). The review included an assessment of the potential radiation dose to people eating sheep meat. In summer 2010 and 2011, surveys were carried out to monitor sheep on selected farms in the restricted areas of England and Wales to provide data to inform this dose assessment.

Figure 8.1 shows the distribution of doses that an adult consuming sheep meat at high-rates would receive if they were to consume their annual supply from each monitored farm in Cumbria and North Wales.

The results of the dose assessment showed that doses to the representative person ranged from < 0.05 to 0.21 mSv per year, with an average of < 0.09 mSv per year. This was significantly below the 1 mSv per year limit for members of the public exposed to radiation from routine planned exposures and the 1 mSv per year reference level typically used in existing exposure situations.

Key points

- In 2012, contamination of sheep and fish with caesium-137 from the accident at Chernobyl in 1986 remained at low but still detectable levels. Concentrations in fish are now less than 10 per cent of those observed in the immediate aftermath of the accident. Restrictions of sheep movement on farms, due to Chernobyl caesium in sheep meat, have now been withdrawn due to the low consumer risks involved
- The UK governments reacted quickly to the Fukushima Dai-ichi accident in 2011 to ensure the safety of UK citizens, especially those overseas, and to monitor the effects in the UK. These effects were found to be of no radiological significance in the UK in 2011 and no Fukushima Dai-ichi derived radioactivity was identified in the UK environment in 2012. Monitoring of imported food from Japan continued in 2012. No shipments were withdrawn because of high levels
- Monitoring at ports of entry to the UK for non-specific contamination detected two food shipments which required further investigation

The results of the sheep monitoring survey and the consumer dose assessment demonstrate that, although there were still low levels of radiocaesium in sheep throughout the restricted areas of Cumbria and North Wales, the risks to consumers were very low.

In November 2011, the Food Standards Agency launched a public consultation based on the results of this risk assessment, where it proposed to remove all remaining post-Chernobyl sheep controls (Food Standards Agency, 2011b). After carefully considering the consultation responses it received, the Food Standards Agency Board met on 20 March 2012 and agreed to accept this proposal (Food Standards Agency, 2012b). As a result, all post-Chernobyl restrictions on farm holdings in the UK were lifted on 31 May 2012.

Sampling locations for freshwater fish affected by Chernobyl are now limited to Cumbria in England, which had areas of relatively high fallout from the accident. Samples from areas of low deposition in England are also obtained for

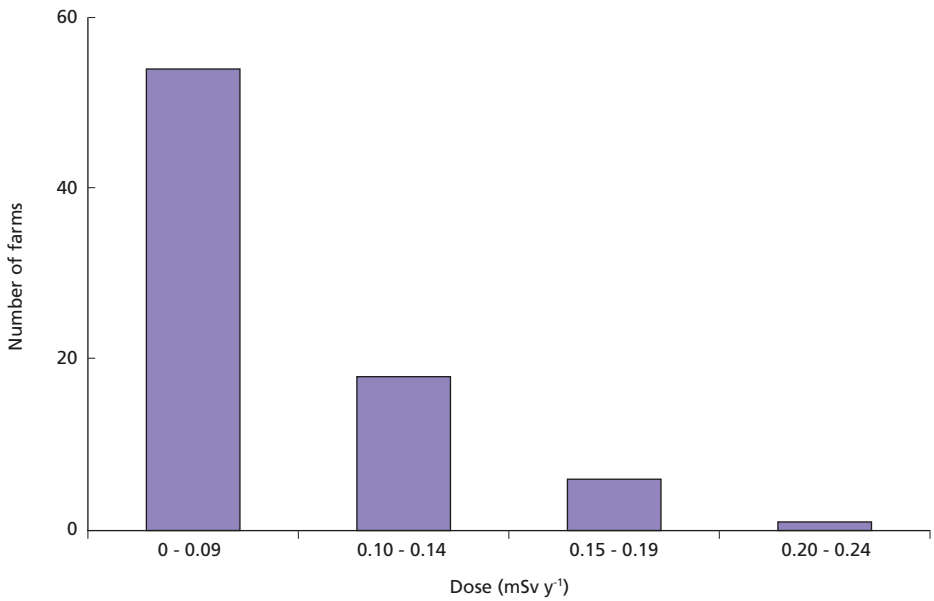


Figure 8.1. Distribution of doses to the representative person from consuming sheep meat from each monitored farm in Cumbria and North Wales

comparison. Table 8.1 shows concentrations of caesium-134 and caesium-137 in fish in 2012. Other artificial radionuclides from the Chernobyl accident are no longer detectable. In 2012, the highest concentration of caesium-137 was 96 Bq kg^{-1} in perch from Devoke Water, less than 130 Bq kg^{-1} in 2011. Levels in fish from other locations were generally similar to those in recent years, and substantially less (by orders of magnitude) than the 1,000 Bq kg^{-1} level reached shortly after the accident. Caesium-134 concentrations were below or near to detection limits in all samples. The long-term trend of radiocaesium in freshwater fish has been reviewed (Smith *et al*., 2000) and the effective ecological half-life of radiocaesium during the late 1990s has been shown to be between six and 30 years. Monitoring results for Devoke Water for perch and trout, over the period 1986 – 2012, are shown in Figure 8.2.

A cautious assessment has been made of the dose received from consuming fish contaminated with radiocaesium following the Chernobyl accident. A consumption rate of 37 kg a year, sustained for one year, was taken to be an upper estimate for adults subject to the highest exposure. In 2012, estimated doses were less than 0.1 mSv. Actual exposure is likely to be much lower, not only because this consumption rate is higher than expected (Leonard *et al*., 1990), but also because, in practice, people are likely to eat mostly hatchery-reared or farmed fish that have a much lower radiocaesium concentration.

8.2 Fukushima Dai-ichi (2011)

On 11 March 2011 Japan suffered its worst recorded earthquake (Tohoku, magnitude 9.0). The epicentre was 110 miles east-northeast from the Fukushima Dai-ichi (Fukushima-1) nuclear power site. The three operating reactors at Fukushima Dai-ichi were shut down safely during the earthquake. Within an hour, a 14m tsunami caused by the earthquake inundated the site. This resulted in the loss of all but one diesel generator, some direct current supplies and essential instrumentation, and caused massive damage around the site. Due to loss of cooling, some fuel melted, leading to fission products being released into the atmosphere, followed later by contaminated water leaking into the sea. Fission products released into the atmosphere included iodine-131, caesium-137, caesium-134 and tellurium-132. These began to circulate globally, with small amounts reaching Western Europe and the UK towards the end of March 2011. Actions taken in the UK included:

- Enhanced monitoring across the UK, measuring air, rain, grass and food to check for the effects of atmospheric transport and deposition from Japan
- Implementing EU controls on importing food from Japan

After the initial detection of iodine-131 by the routine monitoring programmes, the environment agencies and the Food Standards Agency undertook additional monitoring but concentrations of iodine-131 were very low and of minimal risk to public health. The additional monitoring ceased in July 2011 and monitoring returned to normal frequencies. Further information is available in RIFE 17 (Environment Agency, Food Standards Agency, Northern Ireland Environment Agency and Scottish Environment Protection Agency, 2012).

On 25 March 2011, the European Commission (EC) implemented controls (Regulation EU/297/2011) on the import of food and feed originating in or consigned from Japan (European Commission, 2011). Various amendments have been made to legislative controls since that time and the current Regulation (EU/996/2012) was issued in October 2012 (European Commission, 2012c) and amended by Regulation EU/495/2013 in May 2013 (European Commission, 2013). All food and feed imported from Japan has to be certified

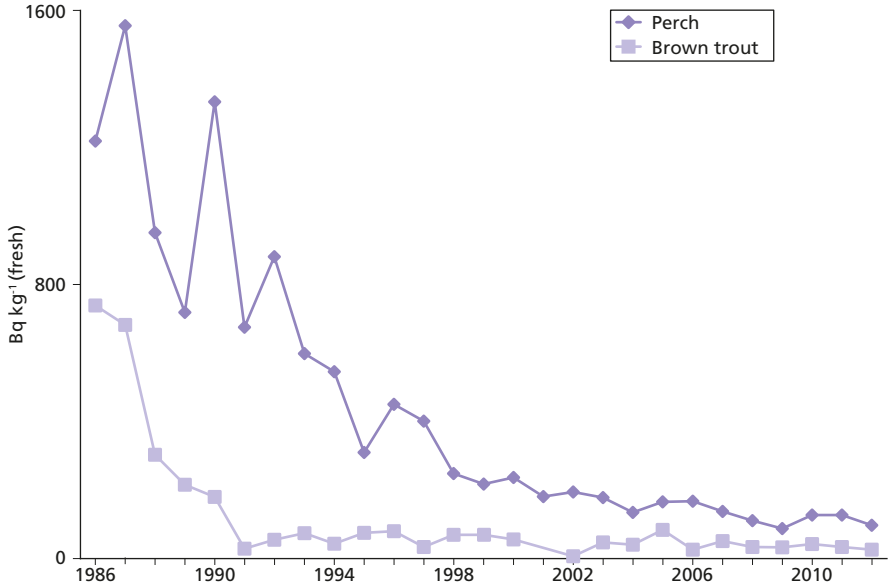


Figure 8.2. Caesium-137 concentrations in freshwater fish from Devoke Water, Cumbria 1986-2012

by the Japanese authorities. As part of this certification, certain food and feed types from specified prefectures (regions) of Japan known to have been affected by radioactive contamination have to be tested to confirm contamination is below the maximum permissible levels for caesium-134 and caesium-137. Further information is available on the Food Standards Agency's website: http://food.gov.uk/business-industry/imports/banned_restricted/japan.

A percentage of Japanese imports into the EU are monitored at ports of entry and this work continued in 2012. Some imports of seafood from other nations from the region where contamination might be expected in the western Pacific were also monitored. The results of monitoring Japanese imports to the UK have been published by the EC (http://ec.europa.eu/energy/nuclear/radiation_protection/fukushima_en.htm). None of the imports to the UK have contained radioactivity exceeding the maximum permissible levels; most results have been below the limits of detection, with very few being above 10 Bq kg^{-1}. The doses received due to the imports were of negligible radiological significance.

8.3 General monitoring at importation points of entry to the UK

Screening instruments are used at importation points of entry to the UK as a general check on possible contamination from unknown sources. In 2012, the instruments were triggered at Harwich and Hull by the presence of caesium-137 in consignments of food being brought into the UK. The samples of wild blueberries and blueberry juice concentrate from Ukraine were analysed and the activity concentrations were 166 and 580 Bq kg^{-1} respectively. At these concentrations, the Food Standards Agency considered that there was no food safety requirement to limit their placement on the market for human consumption.

Table 8.1. Concentrations of radiocaesium in the freshwater environment, 2012

Location	Material	No. of sampling observations	Mean radioactivity concentration (fresh), Bq kg^{-1}	
			^{134}Cs	^{137}Cs
England				
Cogra Moss	Rainbow trout	2	<0.08	<0.10
Narborough[a]	Rainbow trout	1	<0.07	0.13
Devoke Water	Brown trout	1	0.19	25
Devoke Water	Perch	1	0.45	96
Gilcrux	Rainbow trout	1	<0.07	0.17
New Mills	Rainbow trout	1	<0.07	0.14

[a] *The concentrations of ^{14}C, ^{238}Pu, $^{239+240}$Pu and ^{241}Am were 43, <0.000076, <0.00032 and 0.000031 Bq kg^{-1} respectively*

9. Regional monitoring

Regional monitoring in areas remote from nuclear licensed sites has continued in 2012 (i) to establish long distance transport of radioactivity from UK and other nuclear licensed sites, (ii) to indicate general contamination of the food supply and the environment and (iii) to provide data under UK obligations under Article 36 of the Euratom Treaty and the OSPAR Convention.

The routine component parts of this programme are:

- Channel Islands, the Isle of Man and Northern Ireland
- General diet
- Milk and crops
- Airborne particulates, rain, drinking water and groundwater
- Seawater

Key points

- Monitoring in areas remote from nuclear licensed sites continued (i) to establish the effect of long distance transport of radioactivity from UK and other nuclear licensed sites, (ii) to detect any general contamination of the food supply and the environment and (iii) to provide data under UK obligations under Article 36 of the Euratom Treaty and the OSPAR Convention
- Sampling of marine life from the Channel Islands continued to monitor possible effects from French nuclear facilities discharging radioactivity into the English Channel. Doses were less than one per cent of the limit
- Monitoring in Northern Ireland and the Isle of Man showed low concentrations of man-made radionuclides from Sellafield and other UK nuclear facilities. Doses were approximately one per cent of the dose limit
- Samples from the UK food supply, air, rain and drinking water were analysed. Natural radionuclides dominated the doses due to consumption of general diet and drinking water
- Surveys of seas around the UK supported international assessments for the OSPAR Treaty and showed the extent of tritium and caesium-137 contamination
- Overall, caesium-137 levels in the North Sea were the lowest values reported in 2012

9.1 Channel Islands

Samples of marine environmental materials provided by the Channel Island states have been analysed for levels of radioactivity. The programme monitors the effects of radioactive discharges from the French reprocessing plant at La Hague and the power station at Flamanville. It also monitors any effects of historical disposals of radioactive waste in the Hurd Deep, a natural trough in the western English Channel. Fish and shellfish are monitored to determine exposure from the internal radiation pathway; sediment is analysed for external exposures. Seawater and seaweeds are sampled as environmental indicator materials and, in the latter case, because of their use as fertilisers. A review of marine radioactivity in the Channel Islands from 1990 to 2009 has been published (Hughes *et al*., 2011).

Table 9.1 shows analysis results for 2012. There was evidence of routine releases from the nuclear industry in some samples (cobalt-60 and 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 weapon testing, due to the low levels detected. No evidence for significant releases of activity from the Hurd Deep site was found.

An assessment of the dose to people who consume large amounts of fish and shellfish was carried out. In 2012, they were estimated to receive less than 0.005 mSv, which is 0.5 per cent of the dose limit for members of the public. The assessment included a contribution from external exposure. The concentrations of artificial radionuclides in the marine environment of the Channel Islands and the effects of discharges from local sources, therefore, continued to be of negligible radiological significance.

Milk and crop samples from the Channel Islands were also analysed. The results are included in Tables 9.2 and 9.3, respectively, and form part of the programmes considered in Sections 9.5 and 9.6.

9.2 Isle of Man

The Food Standards Agency carries out an ongoing programme of radioactivity monitoring on behalf of the Department of Environment, Food and Agriculture (DEFA) on the Isle of Man for a range of food grown on the land (Table 9.4). The results complement the Isle of Man Government's own independent radiation monitoring programme (www.gov.im/dlge/enviro/govlabs) and provide a comprehensive

assessment of environmental radioactivity levels on the Isle of Man. Results of aquatic monitoring are presented in Section 2 of this report because of their significance in relation to Sellafield, but are also included here for completeness (Table 9.4).

Radioactivity is monitored on the island for two reasons. Firstly, to monitor the continuing effects of radiocaesium deposition resulting from the Chernobyl accident in 1986. Secondly, to respond to public concern over the effects of the nuclear industry. The potential sources of exposure from the UK nuclear industry are: (i) liquid discharges into the Irish Sea and sea-to-land transfer; and (ii) gaseous discharges of tritium, carbon-14 and sulphur-35 and atmospheric transport.

Many of the analyses carried out showed that levels of radionuclides were below the limit of detection of the method used. Carbon-14 concentrations were similar to those expected from natural background, and concentrations of sulphur-35, strontium-90, radiocaesium, plutonium isotopes and americium-241 detected in local milk and crops were all similar to the values observed in the regional networks of UK dairies and crop sampling locations remote from nuclear licensed sites. The results demonstrate that there was no significant impact on Manx foodstuffs from the operation of mainland nuclear installations in 2012.

Table 2.18 shows radiation doses to people on the Isle of Man from different exposure pathways. The dose to local people from consuming large amounts of food grown on the land monitored in 2012 was 0.008 mSv (0.006 mSv in 2011). This is less than 1 per cent of the dose limit for members of the public of 1 mSv. The effects of liquid discharges from Sellafield into the Irish Sea are discussed fully in Section 2. The dose to people consuming large quantities of Manx fish and shellfish was less than 0.005 mSv in 2012, which is unchanged from the 2011 dose. Residents that spent a typical amount of time on sandy beaches were assessed to receive 0.006 mSv from external exposure to radionuclides entrained on the sand.

9.3 Northern Ireland

The Northern Ireland Environment Agency monitors the far-field effects of liquid discharges from Sellafield into the Irish Sea. The programme involves sampling fish, shellfish and indicator materials from a range of locations along the coastline (Figure 9.1). The external exposure pathway is

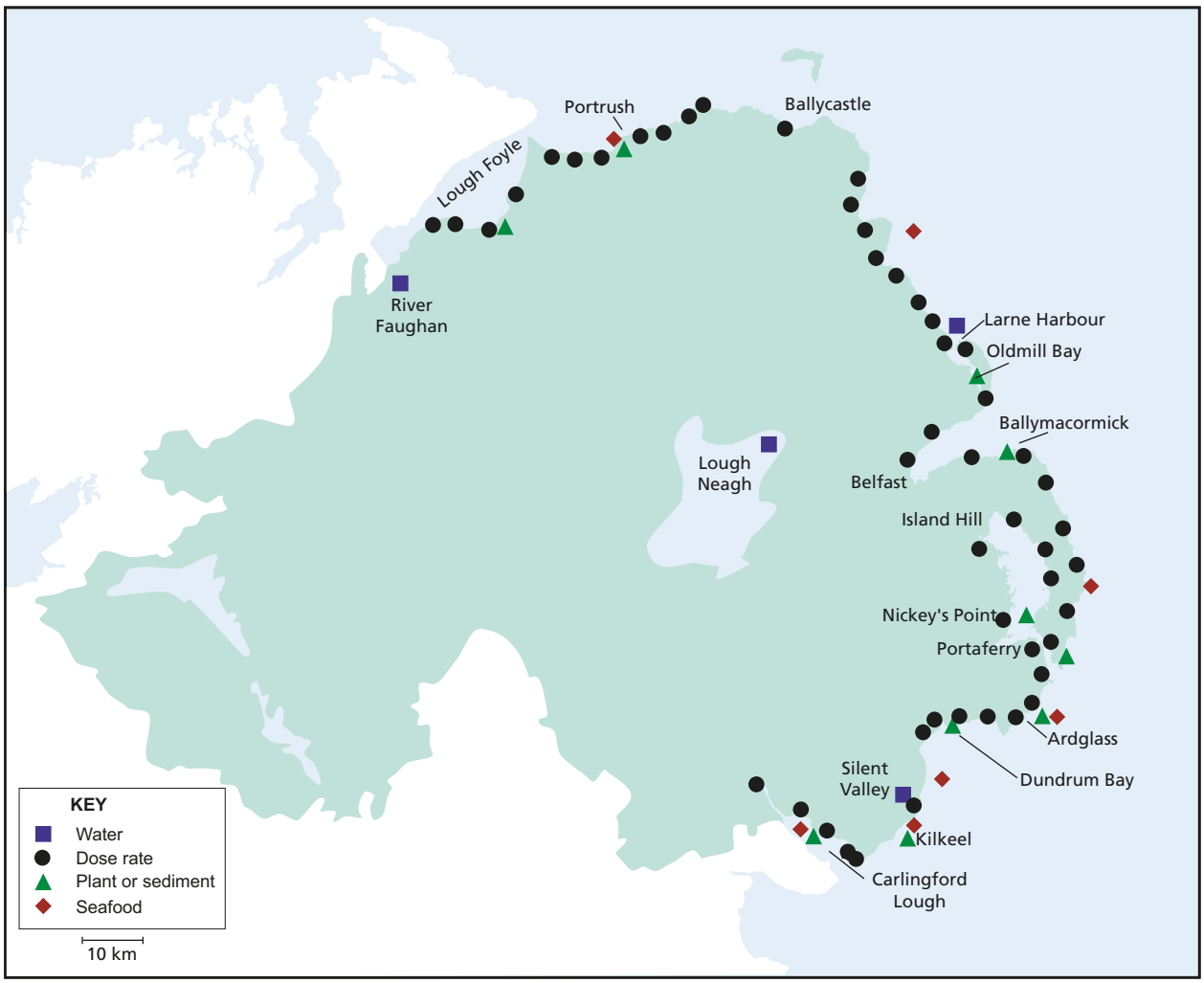


Figure 9.1. Monitoring locations in Northern Ireland, 2012

studied by monitoring gamma dose rates over intertidal areas. The results are presented in Tables 9.5(a) and (b).

In 2012, the main effect of discharges from Sellafield was observed in concentrations of technetium-99 in shellfish and seaweed samples. These were generally similar to those in 2011, reflecting the considerably decreased inputs to the Irish Sea in recent years (see also Section 2.3.3). Caesium-137 concentrations were low and similar to 2011 levels, and trace amounts of transuranic nuclides were detected. Observed concentrations were less than those found nearer to Sellafield. The radiation dose rates over intertidal areas were similar to those in previous years.

A survey of consumption and occupancy in coastal regions of Northern Ireland (Smith *et al*., 2002) established habits representative of people consuming large quantities of fish and shellfish. Based on the monitoring results from the marine environment in 2012, the dose to the people most exposed was 0.011 mSv, which is approximately one per cent of the dose limit for members of the public.

Monitoring results for the terrestrial environment of Northern Ireland are included in the following parts of Section 9.

9.4 General diet

As part of the UK governments' general responsibility for food safety, concentrations of radioactivity are determined in regional diets. These data (and data on other dietary components in Sections 9.5 and 9.6) form the basis of the UK submission to the EC under Article 36 of the Euratom Treaty to allow comparison with data from other EU member states (for example, Joint Research Centre, 2009). Concentrations of radioactivity in the general diet are reported to the EC by the Food Standards Agency (for England, Northern Ireland and Wales), and by SEPA (for Scotland) under a sampling programme run on behalf of the Food Standards Agency.

In 2012, the concentrations found in a survey of radioactivity in diet, as represented by canteen meals collected across the UK (Table 9.6), were very low or typical of natural sources. Similar values were observed in 2011.

9.5 Milk

The programme of milk sampling across dairies in the UK continued in 2012. Its aim is to collect and analyse samples on a monthly basis for their radionuclide content. This programme, together with the programme for crops presented in Section 9.6, provides useful information with which to compare data from farms close to nuclear licensed sites and other establishments that may enhance concentrations above background levels. Milk data is reported by the Food Standards Agency (for England, Northern Ireland and Wales) and SEPA (for Scotland) as part of the UK submission to the EC under Article 36 of the Euratom Treaty (for example, Joint Research Centre, 2009).

The results are summarised in Table 9.2. The majority of measurements, where comparable, are similar to those in previous years. Carbon-14 concentrations are very close to the expected background concentration in milk (see Appendix 1, Annex 4). Tritium results were again below detection limits. The mean concentration of strontium-90 detected was about 0.04 Bq l^{-1}. In the past, the concentrations of radiocaesium in milk were highest from those regions that received the greatest amounts of Chernobyl fallout. However, the concentrations are now very low and it is less easy to distinguish this trend. The highest concentrations of caesium-137 were found in Northern Ireland though at levels of negligible radiological significance.

Radiation dose from consuming milk at average rates was assessed for various age groups. In 2012, the maximum dose was to one-year-old infants. For the range of radionuclides analysed, the dose was less than 0.005 mSv. Previous surveys (for example, Food Standards Agency and Scottish Environment Protection Agency, 2002) have shown that if a full range of nuclides are analysed and assessed, the dose is dominated by naturally-occurring lead-210 and polonium-210, whereas man-made radionuclides contribute less than 10 per cent.

9.6 Crops

The nationwide programme of monitoring naturally-occurring and man-made radionuclides in crops continued in 2012 as a check on general food contamination (Table 9.3). Tritium activity was below the LoD in most samples. Carbon-14 was generally detected at levels close to those expected to occur through natural processes. Levels of other naturally-occurring radionuclides varied from region to region. Plutonium isotopes and americium-241 were detected at trace levels in some samples. However, within the variability observed, the concentrations of all radionuclides in crops were similar to those observed in 2011.

9.7 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. These data are reported on behalf of the Department of Energy and Climate Change (DECC), NIEA and the Scottish Government, as part of the UK submission to the EC under Article 36 of the Euratom Treaty (for example, Joint Research Centre, 2009). The results are given in Table 9.7. The routine programme comprised two components (i) regular sampling and analysis on a quarterly basis and (ii) supplementary analysis on an *ad hoc* basis by gamma-ray spectrometry. Caesium-137 concentrations were all below the limits of detection. These levels in air, typical of recent years, remain less than 0.01 per cent of those observed in 1986, the year of the Chernobyl reactor accident (see Section 8.1).

Concentrations of beryllium-7, a naturally-occurring radionuclide formed by cosmic ray reactions in the upper atmosphere, were detected at similar levels at all sampling locations. Peak air concentrations of this radionuclide tend to occur during spring and early summer as a result of seasonal variations in the mixing of stratospheric and tropospheric air (Environment Agency, 2002a). Tritium concentrations in rainwater were similar to those in 2011. Concentrations 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 2012 (Figure 9.2). These water data are reported by the Environment Agency (for England and Wales), NIEA (for Northern Ireland) and SEPA (for Scotland) as part of the UK submission to the EC under Article 36 of the Euratom Treaty (for example, Joint Research Centre, 2009). 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 in Tables 9.8, 9.9 and 9.10 show that concentrations of tritium were all substantially below the EU indicator limit of 100 Bq l^{-1}. The highest value in Scotland was found at Gullielands Burn, which is near to the Chapelcross nuclear licensed site. The origin of the local source is being investigated (see Section 4). Concentrations of gross alpha and gross beta were all below the WHO screening levels for drinking water of 0.5 and 1.0 Bq l^{-1}, respectively.

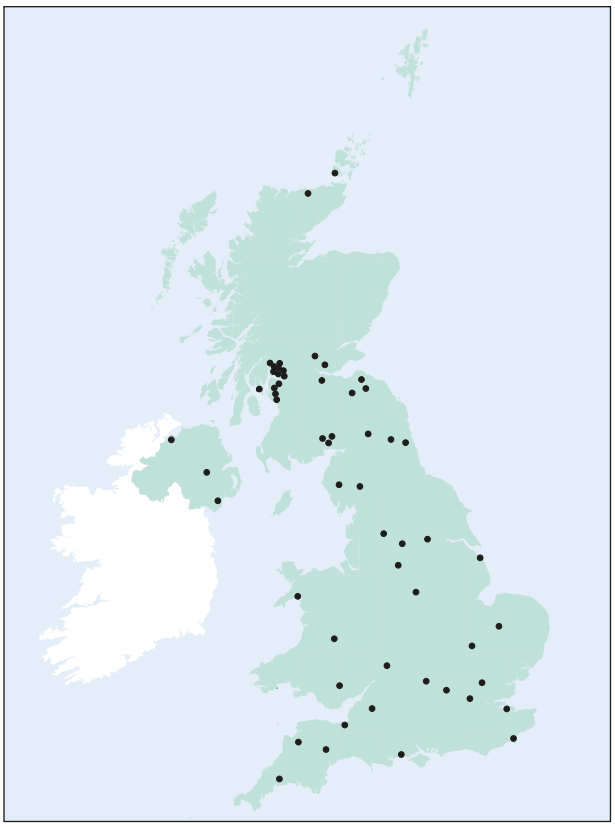


Figure 9.2. Drinking water sampling locations, 2012

The mean annual dose from consuming drinking water in the UK was assessed as 0.027 mSv in 2012 (Table 9.11). The estimated doses were dominated by naturally-occurring radionuclides. The annual dose from artificial radionuclides in drinking water was less than 0.001 mSv. The highest annual dose was estimated to be 0.027 mSv due to radionuclides in a source of drinking water from Silent Valley in Co. Down.

9.8 Seawater surveys

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

The seawater surveys reported here also support international studies concerned with the quality status of coastal seas (for example, OSPAR, 2010b). In 2006, OSPAR adopted the Periodic Evaluation of the Progress in Implementing the OSPAR Radioactive Substances Strategy (concerning progressive and substantial reductions in discharges of radioactive substances, as compared with the agreed baseline) (OSPAR, 2009b). The programme of radiological surveillance work provides the source data and, therefore, the means to monitor and make an assessment of progress in line with the UK's commitments towards OSPAR's 1998 Strategy for Radioactive Substances target for 2020. The surveys also provide information that can be used to distinguish different sources of man-made radioactivity (for example, Kershaw and Baxter, 1995). Data have been used to examine the long distance transport of activity to the Arctic (Leonard *et al.*, 1998; Kershaw *et al.*, 1999) and to derive dispersion factors for nuclear licensed sites (Baxter and Camplin, 1994). In addition, the distribution of radioactivity in seawater around the British Isles is a significant factor in determining the variation in individual exposures at coastal sites, as seafood is a major contribution to food chain doses. Evidence to help gauge progress towards achieving the Government's vision for radionuclides and other hazardous substances is set out in a report (Department for Environment, Food and Rural Affairs, 2010).

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 2012 are given in Figures 9.3 – 9.7. Shoreline sampling was also carried out around the UK, and the data are given in Table 9.13. Much of the shoreline sampling was directed at establishing whether the impacts of discharges from individual sites are detectable. Where appropriate, commentary is found in the relevant site section.

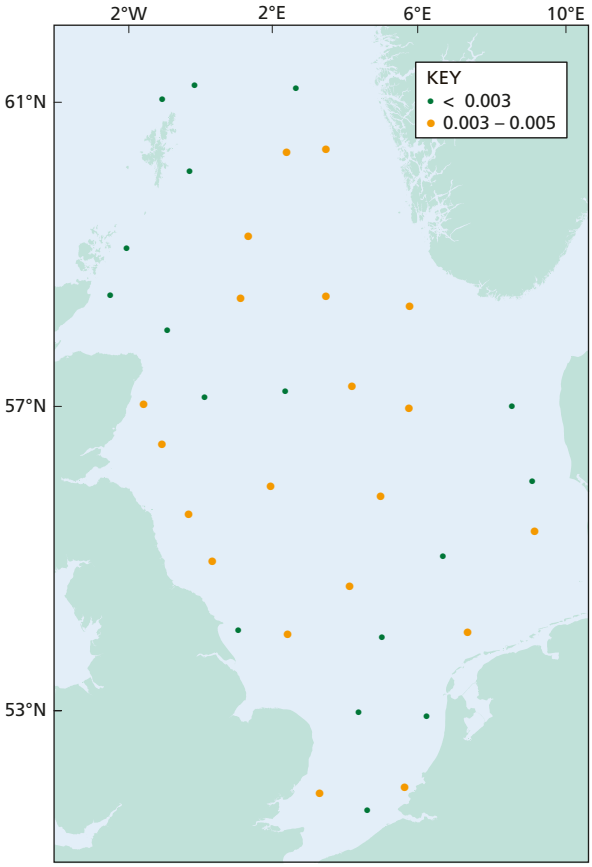


Figure 9.3. Concentrations (Bq l^{-1}) of caesium-137 in filtered surface water from the North Sea, August–September 2012

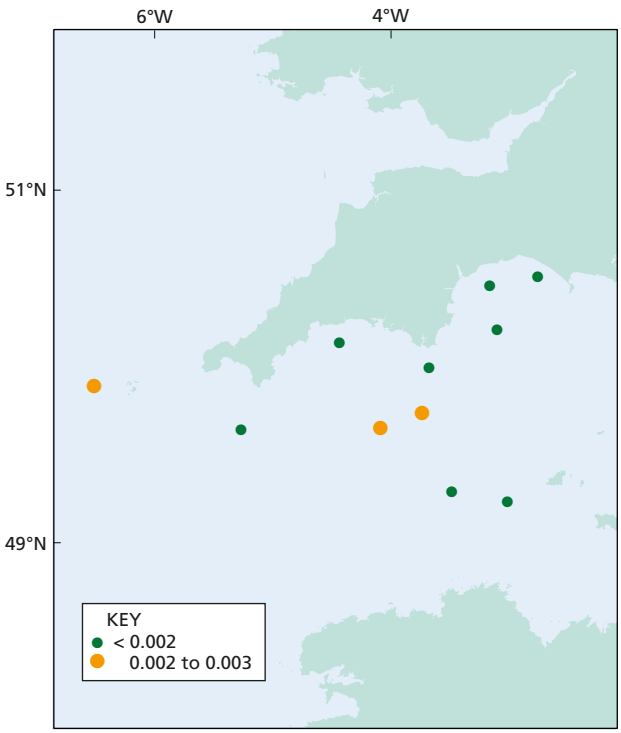


Figure 9.4. Concentrations (Bq l^{-1}) of caesium-137 in filtered surface water from the western English Channel, March-April 2012

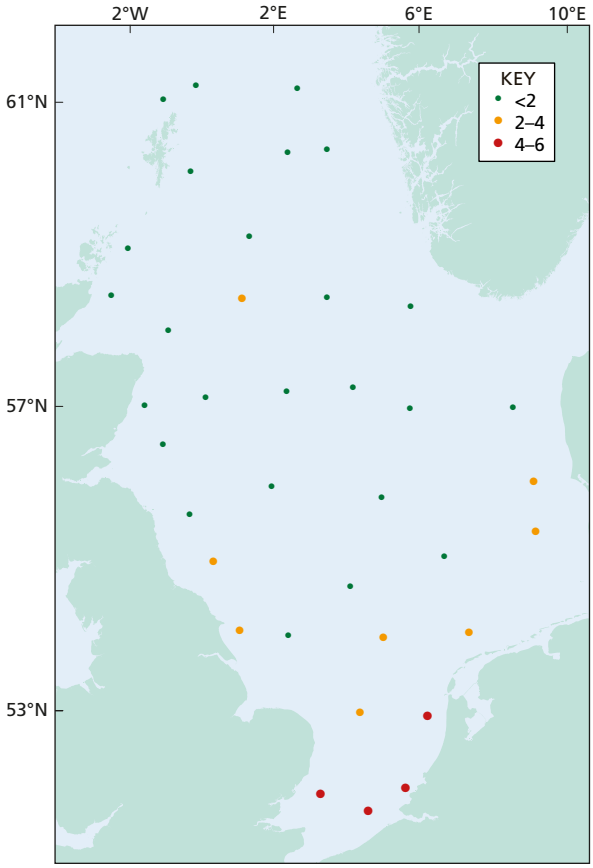


Figure 9.5. Concentrations (Bq l^{-1}) of tritium in surface water from the North Sea, August-September 2012

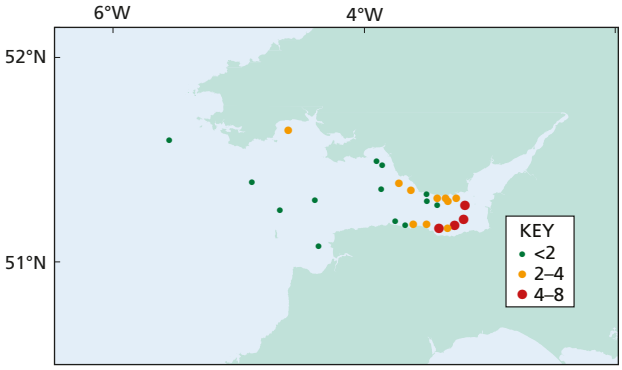


Figure 9.6. Concentrations (Bq l^{-1}) of tritium in surface water from the Bristol Channel, September 2012

A seawater survey of the North Sea was carried out in 2012. Caesium-137 data (given in Figure 9.3) show that the concentrations were very low (up to 0.005 Bq l^{-1}) throughout the survey area, and these were only slightly above those observed for global fallout levels in surface seawaters (0.0001- 0.0028 Bq l^{-1}, Povinec *et al.*, 2005). Overall, in 2012, caesium-137 levels were the lowest values measured (not exceeding 0.005 Bq l^{-1}) in comparison with those of previously reported surveys of the North Sea. The distribution in the North Sea is characteristic of that observed in previous surveys, with generally higher concentrations along the coast. As in 2010, there was no definitive evidence of input of Chernobyl-derived caesium-137 from the Baltic (via the Skaggerak) close

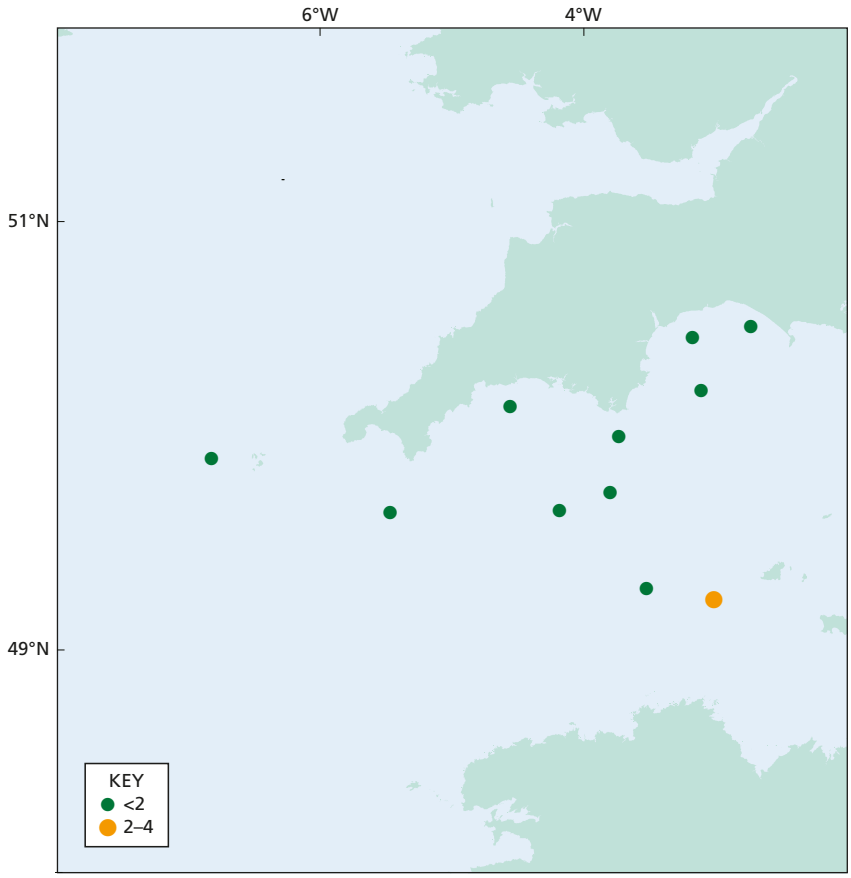


Figure 9.7. Concentrations (Bq l^{-1}) of tritium in surface water from the western English Channel, March-April 2012

to the Norwegian Coast. The 2012 survey also showed the higher levels at some locations in the central North Sea and approaching the Norwegian Coast. These were likely to be the outcome of complex water circulation from an unknown source (possibly Chernobyl-derived).

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

Caesium-137 concentrations in the Irish Sea were only a small percentage of those prevailing in the late 1970s (typically up to 30 Bq l^{-1}; Baxter et al., 1992), when discharges were substantially higher. The 2011 seawater survey recorded concentrations of up to 0.12 Bq l^{-1} in the eastern Irish Sea, and concentrations elsewhere were generally below 0.03 Bq l^{-1}.

The predominant source of caesium-137 to the Irish Sea is now considered to be remobilisation into the water column from activity associated with seabed sediment. This was re-confirmed in a recent study (Hunt *et al*., 2013). Discharges from Sellafield have decreased substantially since the commissioning of the SIXEP waste treatment process in the mid 1980s, and this has been reflected in a near exponential decrease in shoreline seawater concentrations at St Bees (Figure 9.8). In more recent years, the rate of decline of caesium-137 concentrations with time has been decreasing at St Bees. Longer time series showing peak concentrations in the Irish Sea and, with an associated time-lag, the North Sea are also shown in Figure 9.8.

Concentrations of caesium-137 (< 0.003 Bq l^{-1}) in the western English Channel (Figure 9.4) were not distinguishable from the background levels of global fallout (within experimental error) in 2012. Activity concentrations near the Channel Islands were lower in 2012 (compared to those in 2011), but similar to previous years, and lower than concentrations in both the Irish and North Seas. Near the Channel Islands the activity concentrations may be partly due to discharges from the nuclear fuel reprocessing plant at La Hague in France.

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

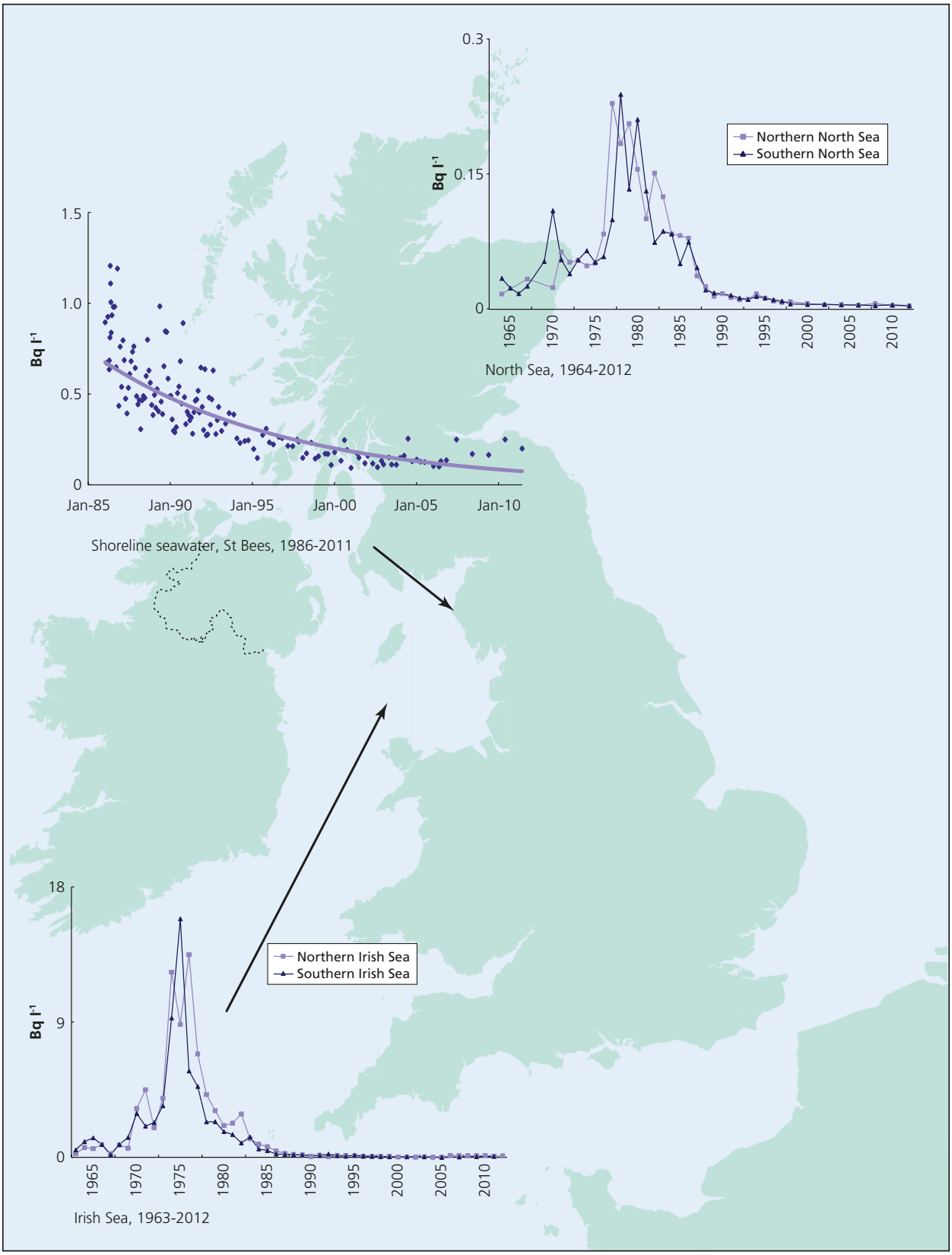


Figure 9.8. Concentration of caesium-137 in the Irish Sea, North Sea and in shoreline seawater close to Sellafield (at St. Bees)

Tritium concentrations in North Sea seawater, in 2012, are shown in Figure 9.5, and were generally lower compared to those in the Irish Sea in 2011 (Environment Agency, Food Standards Agency, Northern Ireland Environment Agency and Scottish Environment Protection Agency, 2012) due to the influence of discharges from Sellafield and other nuclear licensed sites. As in previous North Sea surveys, the concentrations of tritium were elevated (but still very low) along, and close to, the coastline of main-land Europe (South-east North Sea). The most probable source of this is from the authorised discharges of tritium from the French nuclear power plants located on the coast of the English Channel.

In the Bristol Channel, the combined effect of tritium discharges from Cardiff, Berkeley, Oldbury and Hinkley Point is shown in Figure 9.6. Overall, the general level of tritium concentrations in the Bristol Channel was very low in 2012. Tritium concentrations in samples taken close to these installations were higher than those in the 2011 survey, but were lower than levels in the North-east Irish Sea (Environment Agency, Food Standards Agency, Northern Ireland Environment Agency and Scottish Environment Protection Agency, 2011). Tritium concentrations in the western English Channel were also very low (Figure 9.7).

Technetium-99 concentrations in seawater are now decreasing following the substantial increases observed from 1994 to their most recent peak in 2003. The results of research cruises to study this radionuclide have been published by Leonard *et al*. (1997a, b; 2004) and McCubbin *et al*. (2002; 2008). Trends in plutonium and americium concentrations in seawater of the Irish Sea have been considered by Leonard *et al*. (1999). Full reviews of the quality status of the north Atlantic and a periodic evaluation of progress towards internationally agreed targets have been published by OSPAR (2000b; 2009b; 2010b).

Samples of seawater were also collected as part of routine site and regional monitoring programmes. These are reported in the relevant sections of this report, and the analysis results are collated in Table 9.12. Most radionuclides are below limits of detection, and tritium and caesium-137 levels remote from site discharge points are consistent with those in Figures 9.3 – 9.7.

In 2012, SEPA took a series of marine sediment samples from across Scotland and the results are displayed in Table 9.13. Various radionuclides were detected. The results are consistent with those to be expected from measurements at nuclear licensed sites in this report (see, for example, Table 2.8). They exhibit a reducing trend in concentration with distance from the Sellafield site, albeit confounded by natural variability due to sediment type.

Table 9.1. Concentrations of radionuclides in seafood and the environment near the Channel Islands, 2012

Location	Material	No. of sampling observ-ations	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}							
			Organic ^{3}H	^{3}H	^{14}C	^{60}Co	^{90}Sr	^{99}Tc	^{106}Ru	^{129}I
Guernsey										
	Mackerel	1				<0.04			<0.38	
	Bass	1				<0.06			<0.48	
	Crabs	1				<0.07			<0.77	
	Lobsters	1				<0.08			<0.89	
	Limpets	1				<0.16			<1.6	
	Scallops	1				<0.06			<0.48	
	Ormers	1				<0.15			<1.5	
Fermain Bay	*Porphyra*	2				<0.08			<0.79	
Fermain Bay	*Fucus serratus*	2				<0.04	0.038	3.7	<0.31	
St. Sampson's Harbour	Mud and sand	1				<0.22			<2.3	
Jersey										
	Mackerel	1				<0.05			<0.46	
	Pollack	2				<0.06			<0.52	
	Bass	1				<0.06			<0.54	
	Crabs	1				<0.06			<0.53	
	Spiny spider crabs	1				<0.04			<0.33	
	Lobsters	1				<0.04		1.2	<0.37	
	Scallops[b]	2				<0.07			<0.43	
La Rocque	Oysters	1				<0.03			<0.28	
La Rozel	Limpets	1				<0.03			<0.21	
Plemont Bay	*Porphyra*	2				<0.03			<0.25	
La Rozel	*Fucus vesiculosus*	4				<0.07	0.043	6.3	<0.51	
Gorey	*Ascophyllum nodosum*	3				<0.06			<0.47	
Gorey	*Fucus spiralis*	1				<0.06			<0.47	
St Helier	Mud	1				2.0			<3.0	
Alderney										
	Crabs	2	<25	<25	47	<0.07		<0.26	<0.56	
	Spiny spider crabs	1				0.32			<0.79	
	Lobsters	1				<0.07			<0.61	
	Toothed winkles	1	<25	30	28	<0.14	0.039		<1.3	
	Fucus vesiculosus	2								0.67
Quenard Point	*Fucus serratus*	4				<0.08	<0.090	2.3	<0.65	
Quenard Point	*Laminaria digitata*	4				<0.08			<0.64	
Little Crabbe Harbour	Sand	1				0.33			<2.2	
	Seawater	3		<1.5						

Table 9.1. continued

Location	Material	No. of sampling observ-ations	Mean radioactivity concentration (fresh)[a], Bq kg^{-1}							
			^{137}Cs	^{155}Eu	^{238}Pu	^{239}Pu + ^{240}Pu	^{241}Am	^{242}Cm	^{243}Cm+ ^{244}Cm	Gross beta
Guernsey										
	Mackerel	1	0.12	<0.08	0.000025	0.00016	0.00036	*	*	150
	Bass	1	0.22	<0.09	0.000012	0.000073	0.00015	*	*	150
	Crabs	1	<0.07	<0.13	0.00025	0.00085	0.0029	*	0.00025	76
	Lobsters	1	<0.07	<0.13			<0.07			130
	Limpets	1	<0.13	<0.22			<0.11			73
	Scallops	1	<0.05	<0.09	0.0011	0.0043	0.0044	0.000056	0.00028	160
	Ormers	1	<0.13	<0.20			<0.10			73
Fermain Bay	*Porphyra*	2	<0.07	<0.18	0.0017	0.0072	0.010	*	0.00066	86
Fermain Bay	*Fucus serratus*	2	<0.03	<0.06	0.0040	0.019	0.013	*	0.00097	180
St. Sampson's Harbour	Mud and sand	1	0.39	<0.48	0.020	0.072	0.073	*	0.0042	420
	Seawater	4	0.002							
Jersey										
	Mackerel	1	0.14	<0.10	0.000040	0.00022	0.00030	*	*	
	Pollack	2	0.16	<0.11			<0.06			170
	Bass	1	0.14	<0.10			<0.06			150
	Crabs	1	<0.05	<0.09	<0.0017	0.00024	0.0028	*	0.00023	130
	Spiny spider crabs	1	<0.03	<0.07			<0.04			96
	Lobsters	1	<0.04	<0.07	0.00023	0.00063	0.0049	*	0.00039	87
	Scallops[b]	2	<0.05	<0.12	0.015	0.044	0.060	0.00027	0.0050	120
La Rocque	Oysters	1	<0.03	<0.06	0.0021	0.0063	0.0095	0.000070	0.00090	91
La Rozel	Limpets	1	<0.02	<0.03	0.0033	0.0090	0.017	0.000089	0.0014	71
Plemont Bay	*Porphyra*	2	<0.03	<0.04			<0.02			88
La Rozel	*Fucus vesiculosus*	4	<0.05	<0.14	0.0049	0.015	0.0064	0.000063	0.00058	220
Gorey	*Ascophyllum nodosum*	3	<0.06	<0.10			<0.06			280
Gorey	*Fucus spiralis*	1	<0.05	<0.10			<0.06			120
St Helier	Mud	1	1.5	<0.70	0.41	1.2	2.3	0.013	0.15	710
St Catherine's Bay	Seawater	1	0.0009							
Alderney										
	Crabs	2	<0.06	<0.11	0.00021	0.00061	0.0020	*	0.00021	95
	Spiny spider crabs	1	<0.08	<0.14	0.0013	0.0038	0.0056	0.000019	0.00062	130
	Lobsters	1	<0.06	<0.11	0.000089	0.00075	0.0053	0.000039	0.00054	160
	Toothed winkles	1	0.12	<0.18	0.0094	0.029	0.054	*	0.0052	45
Quenard Point	*Fucus serratus*	4	<0.06	<0.12	0.0036	0.014	0.0088	*	0.00077	220
Quenard Point	*Laminaria digitata*	4	<0.06	<0.12			<0.09			330
Little Crabbe Harbour	Sand	1	1.3	<0.75			<0.89			700
	Seawater	3	0.002							

* *Not detected by the method used*

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

[b] *The concentration of ^{108m}Ag was 0.05 Bq kg^{-1}*

Table 9.2. Concentrations of radionuclides in milk remote from nuclear sites, 2012

Location	Selection[a]	No. of farms/ dairies[b]	Mean radioactivity concentration , Bq l^{-1}			
			^{3}H	^{14}C	^{90}Sr	Total Cs
Co. Antrim		1	<4.5	21	0.016	0.12
Co. Armagh		1	<4.0	23	0.022	0.066
Cambridgeshire		1	<3.0	18	0.016	0.060
Ceredigion		1	<4.0	17	0.034	0.070
Cheshire		1	<6.0	16	0.016	0.11
Clwyd		1	<2.3	17	0.022	0.073
Cornwall		1	<4.5	23	0.021	0.067
Devon		1	<4.5	20	0.030	0.066
Dorset		1	<5.5	25	0.018	0.072
Co. Down		1	<4.5	20	0.022	0.11
Dumfriesshire		1	<5.0	<15	<0.10	<0.05[c]
Essex		1	<5.5	15	0.017	0.059
Co. Fermanagh		1	<4.5	18	0.019	0.081
Gloucestershire		1	<4.5	12	0.021	0.067
Guernsey		1	<2.3	13	0.019	0.063
Gwynedd		1	<7.5	14	0.027	0.074
Hampshire		1	<4.5	23	0.029	0.071
Humberside		1	<4.0	15	0.019	0.063
Kent		1	<5.0	22	0.018	0.064
Lanarkshire		1			0.020	<0.03[c]
Lancashire		1	<4.0	19	0.021	0.068
Leicestershire		1	<4.0	15	0.018	0.057
Middlesex		1	<4.0	17	0.016	0.056
Midlothian		1	<5.0	<15	<0.10	<0.05[c]
Nairnshire		1	<5.0	<18	<0.10	<0.05[c]
Norfolk		1	<5.8	18	0.020	0.063
North Yorkshire		1	<4.0	16	0.080	0.020
Renfrewshire		1	<5.0	<14	<0.10	<0.05[c]
Co. Tyrone		2	<3.4	17	0.020	0.092
Co. Tyrone	max		<5.5	20	0.021	0.093
Mean Values						
Channel Islands			<2.3	13	0.019	0.063
England			<4.6	18	0.024	0.064
Northern Ireland			<4.2	20	0.020	0.094
Wales			<4.6	16	0.028	0.072
Scotland			<5.0	<16	<0.084	<0.05[c]
United Kingdom			<4.6	<18	<0.034	<0.067

[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*

[c] *^{137}Cs only*

Table 9.3. Concentrations of radionuclides in animals and crops remote from nuclear sites, 2012[a]

Location	Material	No. of samples	Mean radioactivity concentration (fresh), Bq kg^{-1}						
			^{3}H	^{14}C	^{90}Sr	Total Cs	^{210}Pb	^{210}Po	^{226}Ra
Berkshire									
Wokingham	Cabbage	1	<4.0	9.0	0.29	0.028	0.23	0.14	0.096
	Potatoes	1	<4.0	24	0.038	0.043	0.061	0.012	0.010
Channel Islands									
Guernsey	Blackberries	1	5.0	20	0.14	0.044	0.20	0.051	0.032
	Lettuce	1	7.0	8.0	0.029	0.047	<0.031	0.025	<0.0080
Jersey	Potatoes	1	9.0	27	0.040	0.049			
	Strawberries	1	6.0	16	0.037	0.055			
Clwyd									
Denbigh	Chard	1	8.0	6.0	0.92	0.039	1.1	0.37	0.029
	Potatoes	1	<5.0	19	0.031	0.067	<0.034	0.0041	<0.0050
Cornwall									
Port Isaac	Lettuce	1	<4.0	15	0.32	0.044	0.63	0.31	0.069
	Strawberries	1	<5.0	14	0.14	0.036	0.11	0.061	<0.0050
County Durham									
Brancepeth	Potatoes	1	<5.0	27	0.11	0.046	<0.034	0.019	<0.0050
	Spinach	1	<4.0	14	0.77	0.057	1.2	0.45	0.18
Cumbria									
Cockermouth	Potatoes	1	<5.0	29	0.039	0.16	<0.041	0.0023	<0.0050
Workington	Lettuce	1	<4.0	4.0	0.035	0.10	<0.032	0.011	0.018
Devon									
Otterly St Mary	Carrots	1	<4.0	15	0.12	0.021	<0.038	0.014	0.020
	Kale	1	<4.0	26	0.58	0.29	0.35	0.089	0.039
Dumfriesshire									
Dumfries	Mixed diet	4			<0.10	<0.05[b]			
East Lothian									
North Berwick	Mixed diet	4			<0.10	<0.05[b]			
Gloucestershire									
Cheltenham	Carrots	1	<4.0	13	0.068	0.096	<0.032	0.010	0.015
	Leafy green vegetables	1	<4.0	8.0	0.26	0.080	0.38	0.15	0.032
Herefordshire									
Leominster	Lettuce	1	<4.0	8.0	0.15	0.030	0.23	0.090	0.041
	Raspberries	1	<4.0	14	0.094	<0.013	0.075	0.035	0.026
Lancashire									
Ormskirk	Lettuce	1	<4.0	10	0.10	0.042	0.17	0.067	0.014
	Potatoes	1	<5.0	16	0.0080	0.023	<0.030	0.0068	0.0050
Lincolnshire									
Lincoln	Cabbage	1	7.0	18	0.64	0.075	0.28	0.11	0.033
	Strawberries	1	<4.0	10	0.046	<0.013	<0.032	0.019	0.018
Norfolk									
King's Lynn	Lettuce	1	7.0	13	0.057	0.083	0.97	0.35	0.065
	Strawberries	1	6.0	11	0.31	<0.013	0.055	0.038	0.044
Northumberland									
Morpeth	Strawberries	1	<4.0	11	0.11	<0.013	0.049	0.035	0.026
Wallsend	Lettuce	1	<4.0	12	0.34	0.032	0.47	0.21	0.040
North Yorkshire									
Northallerton	Spinach	1	5.0	11	0.32	0.034	0.53	0.23	0.15
	Strawberries	1	4.0	13	0.050	0.015	<0.033	0.019	0.022
Powys									
Montgomery	Cabbage	1	<4.0	11	1.1	0.043	0.12	0.013	0.17
Newtown	Strawberries	1	5.0	16	0.13	0.10	<0.039	0.013	0.0030
Renfrewshire									
Paisley	Mixed diet	4			<0.10	<0.05[b]			
Ross-shire									
Dingwall	Mixed diet	4			<0.10	<0.14[b]			
Shropshire									
Market Drayton	Spinach	1	<4.0	11	0.43	0.025	1.1	0.44	0.10
	Strawberries	1	<4.0	11	0.063	0.016	<0.036	0.020	<0.0050
Somerset									
Farrington Gurney	Carrots	1	<4.0	9.0	0.14	<0.013	<0.048	0.0072	0.058
	Leafy green vegetables	1	<4.0	11	0.26	<0.013	0.86	0.41	0.16
Surrey									
Weybridge	Beef Kidney	1	<8.0	30	0.19	0.17			
	Beef Liver	1	<7.0	26	0.13	0.23			
	Beef Muscle	1	<5.0	20	0.013	0.13			
	Sheep Kidney/Liver	1	<8.0	42	0.11	0.55			
	Sheep Muscle	1	<5.0	36	<0.0060	0.29			
Wiltshire									
Salisbury	Cabbage	1	5.0	3.0	0.19	0.024	0.098	0.060	0.021
	Soft fruit	1	<4.0	17	0.10	<0.013	0.19	0.11	0.028
Mean Values[c]									
Channel Islands			6.8	18	0.062	0.049	<0.12	<0.038	<0.020
England			<4.8	16	<0.19	<0.082	<0.28	0.12	<0.045
Wales			<5.5	13	0.55	0.062	<0.32	0.10	<0.052
Scotland					<0.10	<0.07[b]			
Great Britain			<5.1	15	<0.28	<0.072[b]	<0.30	<0.11	<0.048

Table 9.3. continued

Location	Material	No. of samples	Mean radioactivity concentration (fresh), Bq kg^{-1}						
			^{232}Th	^{234}U	^{235}U	^{238}U	^{238}Pu	^{239}Pu+ ^{240}Pu	^{241}Am
Berkshire									
Wokingham	Cabbage	1							
	Potatoes	1	0.0053	0.0042	0.00030	0.0047			
Channel Islands									
Guernsey	Blackberries	1	<0.00080	0.00050	0.00040	<0.00060	<0.00010	<0.00010	0.00020
	Lettuce	1	<0.00090				<0.00010	0.00010	0.00030
Jersey	Potatoes	1					<0.00020	0.00010	<0.00010
	Strawberries	1					<0.00010	0.00010	0.00020
Clwyd									
Denbigh	Chard	1	0.0081	0.0054	<0.00030	0.0043			
	Potatoes	1	0.0031						
Cornwall									
Port Isaac	Lettuce	1	0.038						
	Strawberries	1	0.0019	<0.00060	0.00040	<0.00050			
County Durham									
Brancepeth	Potatoes	1	0.020						
	Spinach	1	0.011	0.0092	0.00060	0.0093			
Cumbria									
Cockermouth	Potatoes	1	0.0034	0.0023	<0.00020	0.0026			
Workington	Lettuce	1	0.0030						
Devon									
Otterly St Mary	Carrots	1	0.0037						
	Kale	1	0.0077						
Gloucestershire									
Cheltenham	Carrots	1	0.0052						
	Leafy green vegetables	1	0.0047	0.0036	0.00020	0.0035			
Herefordshire									
Leominster	Lettuce	1	0.027						
	Raspberries	1	<0.00070						
Lancashire									
Ormskirk	Lettuce	1	<0.00080						
	Potatoes	1	0.00090	0.0013	<0.00030	0.0016			
Lincolnshire									
Lincoln	Cabbage	1	<0.0017	0.0011	<0.00030	0.0012			
	Strawberries	1	<0.00080						
Norfolk									
King's Lynn	Lettuce	1	0.017						
	Strawberries	1	0.0027	0.0021	<0.00030	0.0023			
Northumberland									
Morpeth	Strawberries	1	0.0037						
Wallsend	Lettuce	1	0.011						
North Yorkshire									
Northallerton	Spinach	1	0.023						
	Strawberries	1	<0.00080						
Powys									
Montgomery	Cabbage	1	0.0046						
Newtown	Strawberries	1	0.00060						
Shropshire									
Market Drayton	Spinach	1	0.040						
	Strawberries	1	0.00080						
Somerset									
Farrington Gurney	Carrots	1	0.0017						
	Leafy green vegetables	1	0.024						
Surrey									
Weybridge	Beef Kidney	1		0.0037	0.00060	0.0022	<0.00020	0.00030	0.00030
	Beef Liver	1					<0.00010	<0.00010	0.00020
	Beef Muscle	1					<0.00010	<0.00010	0.00020
	Sheep Kidney/Liver	1					<0.00020	0.00050	<0.00010
	Sheep Muscle	1					<0.00010	0.00020	0.00020
Wiltshire									
Salisbury	Cabbage	1	<0.0010						
	Soft fruit	1	<0.0010	0.00070	<0.00030	0.00060			
Mean Values[c]									
Channel Islands			<0.00085	0.00050	0.00040	<0.00060	<0.00013	<0.00010	<0.00020
England			<0.0091	<0.0029	<0.00035	<0.0029	<0.00014	<0.00024	<0.00020
Wales			0.0041	0.0054	<0.00030	0.0043			
Great Britain			<0.0066	<0.0041	<0.00033	<0.0036	<0.00014	<0.00024	<0.00020

[a] *Results are available for other artificial nuclides detected by gamma spectroscopy. All such results are less than the limit of detection*
[b] *^{137}Cs only*
[c] *Great Britain mean excludes Channel Islands. Mean values include crops and animals*

Table 9.4. Concentrations of radionuclides in food and the environment from the Isle of Man, 2012[a]

Material	No. of sampling observations	Mean radioactivity concentration (fresh)[b], Bq kg^{-1}							
		^{60}Co	^{95}Zr	^{95}Nb	^{99}Tc	^{106}Ru	^{125}Sb	^{134}Cs	^{137}Cs
Aquatic samples									
Cod	4	<0.06	<0.15	<0.13		<0.54	<0.14	<0.06	1.2
Herring	4	<0.09	<0.49	<0.13		<0.89	<0.21	<0.10	0.38
Lobsters	4	<0.07	<0.15	<0.12	24	<0.67	<0.16	<0.07	0.28
Scallops	4	<0.07	<0.19	<0.24		<0.61	<0.14	<0.06	<0.26
Seaweed[c]	4[E]	<0.76	<0.95	<0.50	94	<4.5	<2.6	<0.65	<0.60
Sediment	1[E]	<0.34	<0.97	<0.26		<2.2	<1.1	<0.33	7.0

Material	No. of sampling observations	Mean radioactivity concentration (fresh)[b], Bq kg^{-1}							
		^{144}Ce	^{238}Pu	^{239}Pu + ^{240}Pu	^{241}Am	^{242}Cm	^{243}Cm+ ^{244}Cm	Gross alpha	Gross beta
Aquatic samples									
Cod	4	<0.26	0.00032	0.0019	0.0041	*	*		
Herring	4	<0.41	0.000029	0.00018	0.00031	*	*		
Lobsters	4	<0.29			<0.10				130
Scallops	4	<0.25	0.015	0.086	0.031	*	*		
Seaweed[c]	4[E]	<2.2			<0.83				
Sediment	1[E]	<1.5			<0.55			<110	630

Material or selection[d]	No. of sampling observations[e]	Mean radioactivity concentration (fresh)[b], Bq kg^{-1}						
		^{3}H	^{14}C	^{35}S	^{60}Co	^{90}Sr	^{99}Tc	^{106}Ru
Terrestrial samples								
Milk	2	<4.5	17	<0.39	<0.19	<0.027	<0.0040	<1.1
Milk max			19	<0.48	<0.20	0.027		<1.3
Cabbage	1	<5.0	8.0	<0.30	<0.20	0.12	<0.022	<1.1
Potatoes	1	<5.0	25	0.40	<0.20	0.044	<0.064	<1.4
Strawberries	1	5.0	13	<0.10	<0.20	0.13		<0.90

Material or selection[d]	No. of sampling observations[e]	Mean radioactivity concentration (fresh)[b], Bq kg^{-1}						
		^{125}Sb	^{129}I	Total Cs	^{238}Pu	^{239}Pu + ^{240}Pu	^{241}Pu	^{241}Am
Terrestrial samples								
Milk	2	<0.36	<0.0080	0.060	<0.00010	<0.00010	<0.033	0.00010
Milk max		<0.40		0.071				
Cabbage	1	<0.30	0.061	0.14	<0.00010	<0.00030	<0.072	0.00020
Potatoes	1	<0.50	<0.026	0.091	<0.00010	<0.00020	<0.068	0.00030
Strawberries	1	<0.40		0.024				

* *Not detected by the method used*

a *The gamma dose rate in air at 1m over pebbles and sand at Ramsey[E] was 0.084 μGy h^{-1}*

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

c *The concentrations of ^{234}U, ^{235}U and ^{238}U were 1.3, <0.23 and 1.1 Bq kg^{-1} respectively*

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

e *The 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 9.5(a). Concentrations of radionuclides in seafood and the environment in Northern Ireland, 2012[a]

Material	Location	No. of sampling observ-ations	Mean radioactivity concentration (fresh)[b], Bq kg^{-1}					
			^{14}C	^{60}Co	^{99}Tc	^{125}Sb	^{134}Cs	^{137}Cs
Cod	Kilkeel	4	31	<0.06		<0.14	<0.06	1.3
Plaice	Kilkeel	4		<0.05		<0.12	<0.06	0.61
Haddock	Kilkeel	4		<0.06		<0.13	<0.06	0.58
Herring	Ardglass	2		<0.10		<0.25	<0.11	1.1
Lesser spotted dogfish	North coast	2		<0.08		<0.20	<0.08	1.6
Lesser spotted dogfish	Kilkeel	1		<0.21		<0.42	<0.20	1.1
Skates / rays	North coast	1		<0.07		<0.17	<0.07	1.5
Skates / rays	Kilkeel	3		<0.11		<0.26	<0.11	0.72
Spurdog	North coast	1		<0.17		<0.36	<0.18	1.8
Crabs	Kilkeel	4		<0.07		<0.16	<0.07	0.16
Lobsters	Ballycastle	2		<0.04	25	<0.10	<0.04	0.17
Lobsters	Kilkeel	4		<0.06	19	<0.14	<0.06	0.23
Nephrops	Kilkeel	4		<0.12	5.0	<0.26	<0.12	0.51
Winkles	Minerstown	4		<0.05		<0.11	<0.05	0.17
Mussels	Carlingford Lough	2		<0.10	6.1	<0.23	<0.10	<0.31
Scallops	Co. Down	2		<0.06		<0.13	<0.06	0.28
Ascophyllum nodosum	Carlingford Lough	1		<0.05		<0.08	<0.05	0.30
Fucus spp.	Carlingford Lough	3		<0.07	64	<0.15	<0.08	0.41
Fucus spp.	Portrush	4		<0.05		<0.10	<0.05	<0.13
Fucus vesiculosus	Ardglass	4		<0.15	54	<0.30	<0.16	0.54
Rhodymenia spp.	Portaferry	4		<0.11		<0.19	<0.09	0.71
Mud	Carlingford Lough	2		<0.70		<2.0	<0.88	58
Mud	Dundrum Bay	1		<0.56		<1.7	<0.84	32
Mud	Oldmill Bay	2		<0.50		<1.7	<0.74	35
Mud	Strangford Lough-Nicky's point	2		<0.58		<1.6	<0.73	22
Mud	Ballymacormick	1		<0.39		<1.1	<0.48	14
Mud and sand	Carrichue	1		<0.32		<1.0	<0.48	1.4
Mud and sand	Ballymacormick	1		<0.36		<1.2	<0.52	12
Mud and sand	Dundrum Bay	1		<0.47		<1.5	<0.71	4.5
Mud, sand and stones	Carrichue	1		<0.42		<1.3	<0.63	4.1
Sand	Portrush	2		<0.32		<0.96	<0.40	<0.53
Seawater	North of Larne	11			0.0018		*	0.01

Table 9.5(a). continued

Material	Location	No. of sampling observ-ations	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	<0.12			<0.09		
Plaice	Kilkeel	4	<0.12			<0.09		
Haddock	Kilkeel	4	<0.12			<0.12		
Herring	Ardglass	2	<0.22			<0.20		
Lesser spotted dogfish	North coast	2	<0.20			<0.23		
Lesser spotted dogfish	Kilkeel	1	<0.28			<0.15		
Skates / rays	North coast	1	<0.17			<0.20		
Skates / rays	Kilkeel	3	<0.22			<0.19		
Spurdog	North coast	1	<0.24			<0.12		
Crabs	Kilkeel	4	<0.14			<0.10		
Lobsters	Ballycastle	2	<0.11			<0.24		
Lobsters	Kilkeel	4	<0.12			<0.12		
Nephrops	Kilkeel	4	<0.20	0.0016	0.0098	0.028	*	*
Winkles	Minerstown	4	<0.11	0.028	0.17	0.10	*	*
Mussels	Carlingford Lough	2	<0.14			<0.11		
Scallops	Co. Down	2	<0.14			<0.17		
Ascophyllum nodosum	Carlingford Lough	1	<0.06			<0.04		
Fucus spp.	Carlingford Lough	3	<0.15			<0.16		
Fucus spp.	Portrush	4	<0.10			<0.10		
Fucus vesiculosus	Ardglass	4	<0.21			0.38		
Rhodymenia spp.	Portaferry	4	<0.14	0.049	0.31	0.55	*	*
Mud	Carlingford Lough	2	<1.8	2.3	15	12	*	*
Mud	Dundrum Bay	1	<2.2			8.9		
Mud	Oldmill Bay	2	<1.8			14		
Mud	Strangford Lough-Nicky's point	2	<1.7			<4.3		
Mud	Ballymacormick	1	<1.1			12		
Mud and sand	Carrichue	1	<1.4	0.12	0.81	1.3	*	*
Mud and sand	Ballymacormick	1	<1.5			10		
Mud and sand	Dundrum Bay	1	<2.1			<2.7		
Mud, sand and stones	Carrichue	1	<1.9			<2.4		
Sand	Portrush	2	<1.1			<1.0		

* *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 9.5(b). Monitoring of radiation dose rates in Northern Ireland, 2012[a]

Location	Ground type	No. of sampling observ-ations	Mean gamma dose rate in air at 1m, μGy h^{-1}
Lishally	Mud	1	0.061
Eglington	Shingle	1	0.052
Carrichue	Mud	1	0.068
Bellerena	Mud	1	0.059
Benone	Sand	1	0.059
Castlerock	Sand	1	0.055
Portstewart	Sand	1	0.061
Portrush, Blue Pool	Sand	1	0.059
Portrush, White Rocks	Sand	1	0.055
Portballintrae	Sand	1	0.064
Giant's Causeway	Sand	1	0.057
Ballycastle	Sand	1	0.055
Cushendun	Sand	1	0.059
Cushendall	Sand and stones	1	0.061
Red Bay	Sand	1	0.064
Carnlough	Sand	1	0.061
Glenarm	Sand	1	0.053
Half Way House	Sand	1	0.055
Ballygally	Sand	1	0.056
Drains Bay	Sand	1	0.056
Larne	Sand	1	0.057
Whitehead	Sand	1	0.062
Carrickfergus	Sand	1	0.059
Jordanstown	Sand	1	0.056
Helen's Bay	Sand	1	0.064
Groomsport	Sand	1	0.062
Millisle	Sand	1	0.064
Ballywalter	Sand	1	0.065
Ballyhalbert	Sand	1	0.064
Cloghy	Sand	1	0.066
Portaferry	Shingle and stones	1	0.087
Kircubbin	Sand	1	0.075
Greyabbey	Sand	1	0.074
Ards Maltings	Mud	1	0.072
Island Hill	Mud	1	0.066
Nicky's Point	Mud	1	0.071
Strangford	Shingle and stones	1	0.093
Kilclief	Sand	1	0.073
Ardglass	Mud	1	0.082
Killough	Mud	1	0.083
Rocky Beach	Sand	1	0.071
Tyrella	Sand	1	0.076
Dundrum	Sand	1	0.083
Newcastle	Sand	1	0.092
Annalong	Sand	1	0.11
Cranfield Bay	Sand	1	0.088
Mill Bay	Sand	1	0.11
Greencastle	Sand	1	0.084
Rostrevor	Sand	1	0.11
Narrow Water	Mud	1	0.098

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

Table 9.6. Concentrations of radionuclides in canteen meals, 2012[a]

Region	No. of sampling observ-ations	Mean radioactivity concentration (fresh), Bq kg^{-1}			
		^{14}C	^{40}K	^{90}Sr	^{137}Cs
England	8	41	110	<0.041	<0.05
Northern Ireland	5	42	94	<0.032	<0.05
Scotland	12[S]	39		0.046	<0.03
Scotland	2	45	81	0.060	<0.05
Wales	5	46	100	<0.038	<0.05

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

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

Table 9.7. Concentrations of radionuclides in rainwater and air 2012

Location		Sample	Number of sampling observations	Mean radioactivity concentration[a]					
				^{3}H	^{7}Be	^{7}Be[d]	^{90}Sr[b]	^{137}Cs	^{137}Cs[d]
Ceredigion									
	Aberporth	Rainwater	4	<1.1	<0.81			<0.016	
		Air	4		0.0019			<9.1 10^{-7}	
Co. Down									
	Conlig	Rainwater	4		<0.92			<0.015	
		Air	4		0.0014			<9.6 10^{-7}	
Dumfries and Galloway									
	Eskdalemuir	Rainwater	4	<1.2	<1.1			<0.012	
		Air	4		0.0013			<6.8 10^{-7}	
Glasgow									
	Glasgow	Air	12		0.0020			<0.010	
North Yorkshire									
	Dishforth	Rainwater	4		<0.99			<0.018	
		Air	4		0.0019			<9.1 10^{-7}	
Oxfordshire									
	Chilton	Rainwater	4		<0.90	1.8	<0.0020	<0.016	<0.0020
		Air	12		0.0014			<4.7 10^{-7}	
Shetland									
	Lerwick	Rainwater	4		<1.0			<0.017	
		Air	4		0.0010			<7.2 10^{-7}	
Suffolk									
	Orfordness	Rainwater	4	<1.1	<1.0			<0.030	
		Air	4		0.0012			<8.8 10^{-7}	

Location		Sample	Number of sampling observations	Mean radioactivity concentration[a]				
				^{238}Pu[c]	^{239}Pu+ ^{240}Pu[c]	^{241}Am[c]	Gross alpha[d]	Gross beta[d]
Ceredigion								
	Aberporth	Rainwater	4	<2.0 10^{-5}	<2.0 10^{-5}	<2.0 10^{-5}		
		Air	4	<3.0 10^{-9}	<3.0 10^{-9}	<3.0 10^{-9}		
Glasgow								
	Glasgow	Air	12					<0.0020
Oxfordshire								
	Chilton	Rainwater	4				<0.048	<0.067

[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 9.8. Concentrations of radionuclides in sources of drinking water in Scotland, 2012

Area	Location	No. of sampling observ-ations	Mean radioactivity concentration, Bq l^{-1}				
			^{3}H	^{90}Sr	^{137}Cs	Gross alpha	Gross beta
Angus	Loch Lee	4	<1.1	<0.0063	<0.01	<0.032	<0.043
Argyll and Bute	Auchengaich	1	<1.1		<0.01	<0.010	<0.010
Argyll and Bute	Helensburgh Reservoir	1	<1.0		<0.01	<0.010	<0.010
Argyll and Bute	Loch Ascog	1	<1.0		<0.01	<0.010	0.086
Argyll and Bute	Loch Eck	1	<1.0		<0.01	<0.013	0.020
Argyll and Bute	Lochan Ghlas Laoigh	1	<1.0		<0.01	<0.010	0.020
Argyll and Bute	Loch Finlas	1	<1.1		<0.01	<0.010	<0.010
Clackmannanshire	Gartmorn	1	<1.1		<0.01	<0.010	0.13
Dumfries and Galloway	Black Esk	1	1.8		<0.01	<0.010	<0.010
Dumfries and Galloway	Gullielands Burn	1	47		<0.01	<0.017	0.24
Dumfries and Galloway	Purdomstone	1	1.5		<0.01	<0.010	0.050
Dumfries and Galloway	Winterhope	1	2.0		<0.01	<0.010	0.040
East Lothian	Hopes Reservoir	1	<1.0		<0.01	<0.010	0.040
East Lothian	Thorters Reservoir	1	<1.0		<0.01	<0.013	0.020
East Lothian	Whiteadder	1	1.0		<0.01	<0.014	0.030
East Lothian	Thornton Loch Burn	1	<1.0		<0.01	<0.011	0.041
Fife	Holl Reservoir	1	<1.1		<0.01	<0.010	0.030
Highland	Loch Baligill	1	<1.0		<0.01	0.012	0.070
Highland	Loch Calder	1	<1.0		<0.01	0.011	0.050
Highland	Loch Glass	4	<1.1	<0.0061	<0.01	<0.032	<0.041
Highland	Loch Shurrerey	1	<1.0		<0.01	<0.010	0.090
North Ayrshire	Camphill	1	<1.0		<0.01	<0.010	0.020
North Ayrshire	Knockendon Reservoir	1	<1.0		<0.01	<0.0093	0.046
North Ayrshire	Munnoch Reservoir	1	<1.0		<0.01	<0.010	0.050
North Ayrshire	Outerwards	1	<1.0		<0.01	<0.010	0.040
Orkney Islands	Heldale Water	1	<1.0		<0.01	<0.010	<0.044
Perth and Kinross	Castlehill	1	<1.1		<0.01	<0.010	<0.010
Scottish Borders	Knowesdean	4	<1.1	<0.018	<0.01	<0.033	<0.054
Stirling	Loch Katrine	12	<1.2	<0.0030	<0.001	<0.0079	<0.020
West Dunbartonshire	Loch Lomond (Ross Priory)	1	<1.1		<0.01	<0.010	0.020
West Lothian	Morton No 2	1	<1.0		<0.01	<0.013	0.020

Table 9.9. Concentrations of radionuclides in sources of drinking water in England and Wales, 2012

Location	Sample source	No. of sampling observ-ations	Mean radioactivity concentration , Bq l^{-1}			
			^{3}H	^{40}K	^{90}Sr	^{125}I
England						
Buckinghamshire	Bourne End, Groundwater	4	<4.0	0.044	<0.0013	
Cambridgeshire	Grafham Water	4	<4.0	0.38	0.0026	
Cornwall	River Fowey	4	<4.0	0.045	0.0020	<0.014
Cornwall	Roadsford Reservoir, Dowrglann, St Austell	4	<4.0	0.068	0.0027	
County Durham	Honey Hill Water Treatment Works, Consett	4	<4.0	0.035	0.0041	
County Durham	River Tees, Darlington	4	<4.0	0.036	0.0035	<0.0026
Cumbria	Ennerdale Lake	4	<4.0	<0.020	0.0027	
Cumbria	Haweswater Reservoir	4	<4.0	<0.021	0.0036	
Derbyshire	Arnfield Water Treatment Plant	4	<4.0	0.021	0.0015	
Derbyshire	Matlock, Groundwater[a]	4	<4.0	0.036	<0.0010	
Devon	River Exe, Exeter	4	<4.0	<0.097	0.0027	<0.025
Gloucestershire	River Severn, Tewkesbury	4	<4.0	0.16	0.0029	<0.0021
Greater London	River Lee, Chingford	4	<4.0	0.29	0.0018	<0.0031
Hampshire	River Avon, Christchurch	4	<4.0	0.065	0.0015	<0.0025
Humberside	Littlecoates, Groundwater	4	<4.0	0.098	<0.0014	
Kent	Chatham, Deep Groundwater	4	<4.0	0.075	<0.0010	
Kent	Denge, Shallow Groundwater	4	<4.0	0.099	0.0034	
Lancashire	Corn Close, Groundwater	4	<4.0	0.084	<0.0010	
Norfolk	River Drove, Stoke Ferry	4	<4.0	0.088	0.0021	<0.0027
Northumberland	Kielder Reservoir	2	<4.0	<0.10	0.0048	
Oxfordshire	River Thames, Oxford	3	<4.0	0.16	0.0026	<0.0032
Somerset	Ashford Reservoir, Bridgwater	4	<4.0	0.086	<0.0011	
Somerset	Chew Valley Lake Reservoir, Bristol	4	<4.0	0.13	0.0025	
Surrey	River Thames, Chertsey	4	<4.0	0.20	0.0020	<0.0025
Surrey	River Thames, Walton	4	<4.0	0.20	0.0025	<0.0027
Yorkshire	Chellow Heights, Bradford	4	<4.0	<0.025	0.0033	
Yorkshire	Eccup No. 1, Washburn Valley, Leeds	3	<4.0	<0.028	0.0028	

Location	Sample source	No. of sampling observ-ations	Mean radioactivity concentration , Bq l^{-1}			
			^{137}Cs	Gross alpha	Gross beta[1]	Gross beta[2]
England						
Buckinghamshire	Bourne End, Groundwater	4	<0.0016	<0.021	0.060	0.047
Cambridgeshire	Grafham Water	4	<0.0010	<0.033	0.53	0.33
Cornwall	River Fowey	4	<0.0011	0.026	0.086	0.058
Cornwall	Roadsford Reservoir, Dowrglann, St Austell	4	<0.0011	<0.020	0.091	0.058
County Durham	Honey Hill Water Treatment Works, Consett	4	0.0036	0.040	0.098	0.061
County Durham	River Tees, Darlington	4	<0.0010	<0.018	0.079	0.053
Cumbria	Ennerdale Lake	4	<0.0010	<0.020	<0.050	<0.050
Cumbria	Haweswater Reservoir	4	<0.0010	<0.020	<0.048	<0.050
Derbyshire	Arnfield Water Treatment Plant	4	<0.0010	<0.020	<0.050	<0.050
Derbyshire	Matlock, Groundwater[a]	4	<0.0010	0.10	0.10	0.064
Devon	River Exe, Exeter	4	<0.0048	0.029	0.13	0.081
Gloucestershire	River Severn, Tewkesbury	4	<0.0010	0.055	0.21	0.13
Greater London	River Lee, Chingford	4	<0.0010	0.032	0.42	0.28
Hampshire	River Avon, Christchurch	4	<0.0010	0.023	0.11	0.067
Humberside	Littlecoates, Groundwater	4	<0.0010	0.022	0.15	0.096
Kent	Chatham, Deep Groundwater	4	<0.0010	<0.021	0.063	0.048
Kent	Denge, Shallow Groundwater	4	<0.0010	<0.020	0.16	0.10
Lancashire	Corn Close, Groundwater	4	<0.0010	<0.020	0.099	0.070
Norfolk	River Drove, Stoke Ferry	4	<0.0010	0.026	0.15	0.094
Northumberland	Kielder Reservoir	2	<0.0033	0.029	0.051	<0.050
Oxfordshire	River Thames, Oxford	3	<0.0010	<0.024	0.18	0.12
Somerset	Ashford Reservoir, Bridgwater	4	<0.0010	0.019	0.12	0.073
Somerset	Chew Valley Lake Reservoir, Bristol	4	<0.0010	0.024	0.17	0.11
Surrey	River Thames, Chertsey	4	<0.0010	0.022	0.26	0.17
Surrey	River Thames, Walton	4	<0.0010	0.025	0.29	0.19
Yorkshire	Chellow Heights, Bradford	4	<0.0014	<0.020	0.050	<0.050
Yorkshire	Eccup No. 1, Washburn Valley, Leeds	3	<0.0016	0.016	0.082	0.051

Table 9.9. continued

Location	Sample source	No. of sampling observ-ations	Mean radioactivity concentration , Bq l^{-1}		
			^{3}H	^{40}K	^{90}Sr
Wales					
Gwynedd	Cwm Ystradllyn Treatment Works	4	<4.0	<0.015	0.0035
Mid-Glamorgan	Llwyn-on Reservoir	4	<4.0	<0.015	0.0026
Powys	Elan Valley Reservoir	4	<4.0	<0.016	0.0021

Location	Sample source	No. of sampling observ-ations	Mean radioactivity concentration , Bq l^{-1}			
			^{137}Cs	Gross alpha	Gross beta[1]	Gross beta[2]
Wales						
Gwynedd	Cwm Ystradllyn Treatment Works	4	<0.0010	<0.020	<0.050	<0.050
Mid-Glamorgan	Llwyn-on Reservoir	4	<0.0010	<0.020	<0.050	<0.050
Powys	Elan Valley Reservoir	4	<0.0010	<0.020	<0.052	<0.050

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 <0.0090, 0.012, 0.043, <0.010 and 0.023 Bq l^{-1} respectively*

Table 9.10. Concentrations of radionuclides in sources of drinking water in Northern Ireland, 2012

Area	Location	No. of sampling observ-ations	Mean radioactivity concentration, Bq l^{-1}									
			^{3}H	^{90}Sr	^{137}Cs	^{210}Po	^{226}Ra	^{234}U	^{235}U	^{238}U	Gross alpha	Gross beta
Co. Londonderry	R Faughan	4	<1.1	0.0030	<0.050	<0.010		<0.010	<0.010	<0.010	<0.020	0.070
Co. Antrim	Lough Neagh	4	<1.1	0.0018	<0.050	<0.010	<0.010	<0.010	<0.010	<0.010	<0.020	0.090
Co. Down	Silent Valley	4	<1.1	0.0022	<0.050	<0.010	<0.010	0.012	<0.010	<0.011	<0.029	0.070

Table 9.11. Doses from radionuclides in drinking water, 2012[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	0.026	0.027	Matlock, Groundwater, Derbyshire	0.026
Wales[d]	<0.001			Cwm Ystradllyn Treatment Works, Gwynedd	<0.001[d]
Northern Ireland	<0.001	0.026	0.027	Silent Valley, Co. Down	0.027
Scotland[d]	<0.001			Gullielands Burn, Dumfries and Galloway	0.002[d]
UK	<0.001	0.026	0.027	Silent Valley, Co. Down	0.027

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 9.12. Concentrations of radionuclides in seawater, 2012

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
Dounreay (Sandside Bay)	4^{S}	<1.0		<0.10			<0.75	<0.10
Dounreay (Brims Ness)	4^{S}	<1.0		<0.10			<0.68	<0.10
Rosyth	2^{S}	<1.0		<0.10			<0.69	<0.10
Torness[a]	2^{S}	<1.0		<0.10			<0.51	<0.10
Hartlepool (North Gare)	2	<3.0		<0.24			<1.9	<0.31
Sizewell	2	<3.7		<0.24			<1.9	<0.30
Bradwell	2		<0.25				<1.8	<0.30
Dungeness south	2	<2.9		<0.24			<1.9	<0.30
Winfrith (Lulworth Cove)	1			<0.25			<1.8	<0.29
Alderney	3^{F}	<1.5						
Devonport (Millbrook Lake)	2	<3.3	<7.3	<0.25				
Devonport (Tor Point South)	2	<3.2	<5.0	<0.24				
Hinkley	2			<0.25	<0.040		<1.9	<0.31
Berkeley and Oldbury	2			<0.24			<1.9	<0.31
Cardiff (Orchard Ledges)[b]	2	<17	<6.2	<0.25				
Holyhead	4^{D}	<1.7						
Wylfa (Cemaes Bay)	2	<3.6		<0.24			<1.9	<0.32
Wylfa (Cemlyn Bay West)	2			<0.26			<1.9	<0.33
Heysham (inlet)	2	13		<0.25			<1.8	<0.30
Seascale (Particulate)	2			<0.05	<0.0080		<0.37	<0.06
Seascale (Filtrate)	2			<0.24	<0.065	<0.12	<1.8	<0.31
St. Bees	4	<6.3				<0.18		
St. Bees (Particulate)	2			<0.04	<0.0080		<0.38	<0.06
St. Bees (Filtrate)	2	<10		<0.18	<0.040	<0.045	<1.3	<0.22
Seafield	4^{S}	<3.0		<0.10			<0.65	<0.10
Southerness[c]	4^{S}	3.0		<0.10			<0.56	<0.10
Auchencairn	4^{S}	3.0		<0.10			<0.75	<0.10
Knock Bay	4^{S}	<1.1		<0.10			<0.58	<0.10
Knock Bay	4^{D}	<1.8						
Hunterston[d]	2^{S}	4.8		<0.10			<0.41	<0.10
Hunterston (South of pipeline)[e]	2^{S}	1.2		<0.10			<0.45	<0.10
North of Larne	11^{N}					0.0018		
Faslane (Carnban)	2^{S}	<1.0		<0.10			<0.54	<0.10

Table 9.12. continued

Location	No. of sampling observations	Mean radioactivity concentration, Bq l^{-1}					
		^{134}Cs	^{137}Cs	^{144}Ce	^{241}Am	Gross alpha	Gross beta
Dounreay (Sandside Bay)	4[S]	<0.10	<0.10	<0.42	<0.11		
Dounreay (Brims Ness)	4[S]	<0.10	<0.10	<0.41	<0.11		
Rosyth	2[S]	<0.10	<0.10	<0.41	<0.12		
Torness[a]	2[S]	<0.10	<0.10	<0.32	<0.10		
Hartlepool (North Gare)	2	<0.25	<0.20	<0.96	<0.30	<3.8	16
Sizewell	2	<0.27	<0.21	<0.94	<0.31	<3.4	15
Bradwell	2	<0.27	<0.20	<0.94	<0.31	<3.5	17
Dungeness south	2	<0.25	<0.21	<0.96	<0.31	<4.1	17
Winfrith (Lulworth Cove)	1	<0.25	<0.21	<0.91	<0.29	<4.6	20
Alderney	3[F]	*	0.002				
Jersey	1[F]	*	0.0009				
Guernsey	4[F]	*	0.002				
Hinkley	2	<0.24	<0.20	<0.95	<0.30	<2.9	12
Berkeley and Oldbury	2	<0.26	<0.20	<0.98	<0.30	<1.3	5.8
Cardiff (Orchard Ledges)[b]	2		<0.19				
Holyhead	4[D]	*	0.02				
Wylfa (Cemaes Bay)	2	<0.25	<0.20	<0.97	<0.31	<2.7	9.0
Wylfa (Cemlyn Bay West)	2	<0.25	<0.20	<1.0	<0.31	<4.2	21
Llandudno	1[D]	*	0.04				
Prestatyn	1[D]	*	0.05				
New Brighton	1[D]	*	0.04				
Ainsdale	1[D]	*	0.06				
Rossall	1[D]	*	0.07				
Heysham (inlet)	2	<0.24	<0.20	<0.92	<0.30	<3.3	9.7
Half Moon Bay	1[D]	*	0.09				
Silecroft	1[D]	*	0.06				
Seascale (Particulate)	2	<0.05	<0.04	<0.16	<0.17	0.091	0.10
Seascale (Filtrate)	2	<0.25	<0.20	<0.95	<0.30	<3.2	13
St. Bees	4	<0.20	<0.16				
St. Bees (Particulate)	2	<0.04	<0.04	<0.19	<0.06	0.036	0.073
St. Bees (Filtrate)	2	<0.18	<0.15	<0.69	<0.23	<2.2	7.8
Whitehaven	1[D]	*	0.05				
Maryport	1[D]	*	0.05				
Silloth	1[D]	*	0.07				
Seafield	4[S]	<0.10	<0.11	<0.44	<0.11		
Southerness[c]	4[S]	<0.10	<0.12	<0.36	0.0020		
Auchencairn	4[S]	<0.10	<0.10	<0.42	<0.11		
Ross Bay	1[D]	*	0.02				
Isle of Whithorn	1[D]	*	0.02				
Drummore	1[D]	*	0.01				
Knock Bay	4[S]	<0.10	<0.10	<0.35	<0.10		
Knock Bay	4[D]	*	0.02				
Hunterston[d]	2[S]	<0.10	<0.10	<0.26	<0.10		
Hunterston (South of pipeline)[e]	2[S]	<0.10	<0.10	<0.26	<0.10		
North of Larne	11[N]	*	0.01				
Faslane (Carnban)	2[S]	<0.10	<0.10	<0.31	<0.10		

* *Not detected by the method used*
[a] *The concentration of ^{35}S was <0.77 Bq l^{-1}*
[b] *The concentrations of ^{3}H as tritiated water and ^{125}I were <3.5 Bq l^{-1} and <0.51 Bq l^{-1} respectively*
[c] *The concentrations of ^{238}Pu and $^{239+240}Pu$ were 0.00046 and 0.0028 Bq l^{-1} respectively*
[d] *The concentration of ^{35}S was <0.63 Bq l^{-1}*
[e] *The concentration of ^{35}S was <0.55 Bq l^{-1}*
[D] *Measurements labelled "D" are made by Cefas on behalf of Defra*
[F] *Measurements labelled "F" are made on behalf of the Food Standards Agency and the Channel Islands States*
[N] *Measurements labelled "N" are made on behalf of the Northern Ireland Environment Agency*
[S] *Measurements labelled "S" are made on behalf of the Scottish Environment Protection Agency*

Table 9.13. Concentrations of radionuclides in marine sediments - background survey in Scotland, 2012[a]

Location	Sample source	No. of sampling observ-ations	Mean radioactivity concentration, Bq kg^{-1} (dry)							
			^{3}H	^{60}Co	^{125}Sb	^{137}Cs	^{155}Eu	^{241}Am	Gross alpha	Gross beta
Cromarty Firth	Cullicudden	1	<5.0	<0.12	<0.28	0.54	<0.30	<0.20	48	1600
Cromarty Firth	Udale	1	<5.0	<0.15	<0.44	11	<0.44	2.1	110	1500
Cromarty Firth	Off Foulis	1	<5.0	<0.22	<0.61	2.4	<0.63	<0.40	76	1900
Firth of Clyde	Irvine Bay	1	<5.0	<0.10	<0.32	43	1.3	9.2	130	1500
Firth of Clyde	Largs	1	<5.0	0.33	1.0	49	1.1	14	140	1600
Firth of Clyde	Cloch Point	1	<5.0	<0.10	0.49	45	1.2	5.9	130	1500
Forth Estuary	South Alloa	1	<5.0	<0.23	<0.59	7.8	<0.60	<0.41	170	1500
Forth Estuary	Stirling road bridge	1	<5.0	<0.20	<0.54	11	3.0	1.2	210	1700
Forth Estuary	Kinneil mud flats	1	<5.0	<0.22	<0.63	11	2.2	1.3	150	1900

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

10. References

(Includes references from Appendix 1: CD supplement)

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

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

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

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

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

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

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

Brown, J., Hammond, D., Wilding, D., Wilkins, B.T., and Gow, C., 2009. Transfer of radioactivity from seaweed to terrestrial foods and potential radiation exposures to members of the public: 2009. HPA-RPD-059. HPA, Chilton.

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

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

Camplin, W.C., Rollo, S. and Hunt, G.J., 2000. Surveillance related assessments of sea-to-land transfer. In Proceedings of the Second RADREM - TESC Workshop held in London 21 January 1999. Edited by Ould-Dada, Z. DETR/RADREM/00.001. DETR, London.

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

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

Clyne, F.J., Tipple, J.R., Garrod, C.J. and Smedley, C.A., 2008b. Radiological Habits Survey: Berkeley and Oldbury, 2007. Project C2848. RL 06/08. Cefas, Lowestoft.

Clyne, F.J., Tipple, J.R. Garrod, C.J., and Jeffs, T.M., 2009. Radiological Habits Survey: Sellafield 2008. Project C2448. RL 02/09. Cefas, Lowestoft.

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

Clyne, F.J., Garrod, C.J. and Elliott, J., 2010b. Radiological Habits Survey: Amersham 2009. Project C2848. RL 04/10. Cefas, Lowestoft.

Clyne, F.J., Garrod, C.J., Tipple, J.R. and Jeffs, T.M., 2011a. Radiological Habits Survey: Dounreay 2008. Project C3635. RL 03/11. Cefas, Lowestoft.

Clyne, F.J., Elliott, J. and Garrod, C.J., 2011b. Radiological Habits Survey: Dunnet Bay Beach Occupancy, 2009. Project C3615. RL 10/11. Cefas, Lowestoft

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

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

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

Hinkley Point, 2010. Project C2848. RL 01/11. Cefas, Lowestoft.

Clyne, F.J., Garrod, C.J., Ly, V.E., and Rumney, P., 2012. Radiological Habits Survey: Devonport, 2011. RL 01/12. Cefas, Lowestoft.

Clyne, F.J., Garrod, C.J., Rumney. P. and Ly, V.E., (*in press/a*). Radiological Habits Survey: Chapelcross, 2010. Cefas, Lowestoft.

Clyne, F.J., Garrod, C.J., and Ly, V.E., (*in press/b*). Radiological Habits Survey: Torness, 2011. Cefas, Lowestoft.

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

Clyne, F.J., Garrod, C.J. and Ly, V.E., 2013. Radiological Habits Survey: Dalgety Bay, 2012. RL 13/13. Cefas, Lowestoft.

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

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

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

Commission of the European Communities, 1996. Council Directive 96/29/Euratom of 13 May 1996 laying down basic safety standards for the protection of the health of workers and the general public against the dangers arising from ionising radiation. OJ 39(L159): 1 – 114.

Commission of the European Communities, 1998. Council Directive 98/83/EC of 3 November 1998 on the quality of water intended for human consumption. OJ L330: 32 – 54.

Commission of the European Communities, 1999a. Council Directive 1999/2/EC of the European Parliament and of the Council of 22 February 1999 on the approximation of the laws of Member States concerning foods and food ingredients treated with ionising radiation. OJ L 66, 13.3.99, 16.

Commission of the European Communities, 1999b. Council Directive 1999/3/EC of the European Parliament and of the Council of 22 February 1999 on the establishment of a Community list of foods and food ingredients treated with ionising radiation. OJ L 66, 13.3.99, 24.

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

Commission of the European Communities, 2000b. Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy. OJ L327 22/12/2000 1 – 73.

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

Committee on Radioactive Waste Management, 2012. Proposed programme of work 2012-2015. CoRWM, London.

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

Copeland Borough Council *et al.*, 1999. The radiological implications of contaminated feral pigeons found at Sellafield and Seascale. CBC, DH, Environment Agency, HSE, MAFF and NRPB, Penrith.

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

Dale, P., 2013. Dalgety Bay Radioactive Contaminated Land Risk Assessment, May 2013. SEPA, Stirling.

Department for Business, Enterprise and Regulatory Reform, 2008. Meeting the energy challenge. A White Paper on Nuclear Power. Cmnd.7296. HMSO, London.

Department for Environment, Food and Rural Affairs, 2002. UK strategy for radioactive discharges 2001 – 2020. Defra, London.

Department for Environment, Food and Rural Affairs, 2004a. National report on compliance with the obligations of the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management. Defra, London.

Department for Environment, Food and Rural Affairs, 2004b. Contribution of aerial radioactive discharges to radionuclide concentrations in the marine environment. DEFRA/RAS/04.002. Defra, London.

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

Department for Environment, Food and Rural Affairs, 2005b. 5: Integrated Regional Assessment. Report 5 of 5 contributing to Charting Progress: an Integrated Assessment of the State of UK Seas. Defra, London.

Department for Environment, Food and Rural Affairs, 2005c. The United Kingdom's second national report on compliance with the obligations of the joint convention on the safety of spent fuel management and on the safety of radioactive waste management. Defra, London.

Department for Environment, Food and Rural Affairs, 2005d. Water Environment Reports Submitted to the European Commission. News Release 142/05. Defra, London.

Department for Environment, Food and Rural Affairs, 2006. Industry profile. Industrial activities which have used materials containing radioactivity. Defra, London.

Department for Environment, Food and Rural Affairs, 2007a. Low level radioactive waste policy announced. News release 26 March 2007. Defra, London.

Department for Environment, Food and Rural Affairs, 2007b. Miliband announces radioactive waste disposal plan. News release 2006. Defra, London.

Department for Environment, Food and Rural Affairs, 2008. Summary of responses to the consultation on the standardised reporting of radioactive discharges, 22 August to 23 November 2007. Defra, London.

Department for Environment, Food and Rural Affairs, 2010. Charting Progress 2. Defra, London.

Department for Environment, Food and Rural Affairs and Welsh Government, 2013. Closed Consultation Draft Environmental Permitting (England and Wales) (Amendment) Regulations 2013. Defra and Welsh Government, London and Cardiff.

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

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

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

Department of Energy and Climate Change, 2008. The United Kingdom's third national report on compliance with the obligations of the joint convention on the safety of spent fuel management and on the safety of radioactive waste management. DECC, London.

Department of Energy and Climate Change, 2009. Summary of responses to the consultation on the draft UK Strategy for radioactive discharges 2006-2030. DECC, London.

Department of Energy and Climate Change, 2010. The United Kingdom's fifth national report on compliance with the convention on nuclear safety obligations. DECC, London.

Department of Energy and Climate Change, 2011a. Managing Radioactive Waste Safely: Implementing geological disposal annual report April 2010-March 2011. DECC, London.

Department of Energy and Climate Change, 2011b. National policy statement for nuclear power generation (EN-6). DECC, London.

Department of Energy and Climate Change, 2012a. Managing Radioactive Waste Safely: a framework for the desk-based identification and assessment of potential candidate sites for geological disposal. DECC, London.

Department of Energy and Climate Change, 2012b. Managing Radioactive Waste Safely: Government response to the consultation on desk-based identification and assessment of potential candidate sites for geological disposal. DECC, London

Department of Energy and Climate Change, 2012c. Environmental Protection Act 1990: Part iiA. Contaminated Land. Statutory Guidance. DECC, London.

Department of Energy and Climate Change, 2013. Call for Evidence. Managing Radioactive Waste Safely: Review of the Siting Process for a Geological Disposal Facility. Response form. DECC, London.

Department of Energy and Climate Change, Department of the Environment, Northern Ireland, The Scottish Government and Welsh Assembly Government, 2009. UK Strategy for Radioactive Discharges. DECC, London.

Department of Energy and Climate Change, Department of the Environment (Northern Ireland), the Scottish Government and Welsh Assembly Government, 2010. Response of the UK Government and the Devolved Administrations of Northern Ireland, Scotland and Wales to the Committee on radioactive Waste Management' (CoRWM) report on "National Research and Development for Interim Storage and Geological Disposal of Higher Activity Radioactivity Wastes, and Management of Nuclear Materials." DECC, DoENI, The Scottish Government and Welsh Assembly Government, London, Belfast, Edinburgh and Cardiff.

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

Department of the Environment, Northern Ireland, 2010. A Northern Ireland Marine Bill – policy proposals. Consultation document. DoENI, Belfast.

Department of the Environment, Northern Ireland, 2011. The State of the Seas Report. DoENI, Belfast.

http://www.doeni.gov.uk/niea/water-home/state_of_the_seas_ni_report.htms:

Department of the Environment, Transport and the Regions, 2000. Radioactive Substances (Basic Safety Standards) (England and Wales) Direction 2000. DETR, London.

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

Dounreay Particle Advisory Group, 2008. 4th Report, November 2008. SEPA, Stirling.

DSTL Radiological Protection Services, 2013. Marine environmental radioactivity surveys at nuclear submarine berths 2011. The Stationery Office, London.

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

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

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

Environment Agency, 2005. Water Framework Directive - Characterisation of impacts from radioactive substances. Technical Report: MAPG/TR/2004/004. Environment Agency, Bristol and London.

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

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

Environment Agency, 2008a. Radioactive substances regulation. Environmental Principles. Public consultation. Environment Agency, Bristol and London.

Environment Agency, 2008b. Assessment of Best Available Techniques (BAT). Consultation draft. Environment Agency, Bristol and London.

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

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

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

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

Environment Agency, 2010. Briefing Note – Enhanced Beach Monitoring for Radioactive Particles near Sellafield site, March 2010. Environment Agency, Bristol and London.

Environment Agency, 2011a. New nuclear power stations. Our decisions to issue interim generic statements of Design Acceptability for two new reactor designs. Environment Agency, Bristol and London.

Environment Agency, 2011b. Briefing Note – Enhanced Beach Monitoring for Radioactive Particles near Sellafield site, April 2011. Environment Agency, Bristol and London.

Environment Agency, 2012a. Environment Agency issues waste water permit for Hinkley Point C. Environment Agency, Bristol and London.

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

Environment Agency, 2012c. Decision Document, Permit Number CD0235, 14 August 2012. Environment Agency, Bristol and London.

Environment Agency, 2012d. Environment Agency permits Lancashire landfill for low hazard radioactive waste, 15 August 2012. Environment Agency, Bristol and London.

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

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

Environment Agency, Food Standards Agency, Northern Ireland Environment Agency and Scottish Environment Protection Agency, 2010a. Radioactivity in Food and the Environment, 2009. RIFE 15. Environment Agency, Food Standards Agency, NIEA and SEPA, Bristol, London, Belfast and Stirling.

Environment Agency, Food Standards Agency, Northern Ireland Environment Agency and Scottish Environment Protection Agency, 2010b. Summary of Radioactivity in Food and the Environment 2004-2008. Environment Agency, Food Standards Agency, NIEA and SEPA, Bristol, London, Belfast and Stirling.

Environment Agency, Food Standards Agency, Northern Ireland Environment Agency and Scottish Environment Protection Agency, 2011. Radioactivity in Food and the Environment, 2010. RIFE 16. Environment Agency, Food Standards Agency, NIEA and SEPA, Bristol, London, Belfast and Stirling.

Environment Agency, Food Standards Agency, Northern Ireland Environment Agency and Scottish Environment Protection Agency, 2012. Radioactivity in Food and the Environment, 2011. RIFE 17. Environment Agency, Food Standards Agency, NIEA and SEPA, Bristol, London, Belfast and Stirling.

Environment Agency, Food Standards Agency and Scottish Environment Protection Agency, 2010. Environmental Radiological Monitoring. Radiological Monitoring Technical Guidance Note 2. Environment Agency, Food Standards Agency and Scottish Environment Protection Agency, Bristol, London and Stirling.

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

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

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

European Commission, 2010. Draft Euratom Basic Safety Standards Directive. Version 24 February 2010. CEC, Luxembourg.

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

European Commission, 2012a. Proposal for a Council Directive laying down basic safety standards for protection against the dangers arising from exposure to ionising radiation. CEC, Brussels.

European Commission, 2012b. ACSUK_MSFD8bPressures_20121101, 1 Nov 2012. http://cdr.eionet.europa.eu/gb/eu/msfd8910/acsuk/envujjgjq CEC, Brussels.

European Commission, 2012c. Council implementing regulation (EU) No 996/2012 of 26 October 2012 imposing special conditions governing the import of feed and food originating in or consigned from Japan following the accident at the Fukushima nuclear power station and repealing Implementing Regulation (EU) No 284/2012. CEC, Brussels.

European Commission, 2012d. Proposal for a Council Directive laying down basic safety standards for protection against the dangers arising from exposure to ionising radiation. Version 30 May 2012. CEC, Brussels.

European Commission, 2013. Council implementing regulation (EU) No 495/2013 of 29 May 2013 amending Implementing Regulation (EU) No 996/2012 imposing special conditions governing the import of feed and food originating in or consigned from Japan following the accident at the Fukushima nuclear power station OJ L 299/31.

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

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

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

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

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

Food Standards Agency, 2011a. An assessment of radiocaesium activity concentrations in sheep in restricted areas of England and Wales. FSA/RS11/CHER/001. Food Standards Agency, London.

Food Standards Agency, 2011b. Lifting of post-Chernobyl sheep controls. News 17/11/2011. Food Standards Agency, London.

Food Standards Agency, 2012a. Radioactivity in Food Monitoring Review. Food Standards Agency, London.

Food Standards Agency, 2012b. The removal of post-Chernobyl sheep controls. FSA Board Paper 12/03/06. Food Standards Agency, London.

Food Standards Agency, 2013. Radioactivity in Food Monitoring Review. Summary report of responses to consultation from stakeholders. FOODSA0128. Food Standards Agency, London.

Food Standards Agency and Scottish Environment Protection Agency, 2002. Radioactivity in Food and the Environment, 2001. RIFE-7. Food Standards Agency and Scottish Environment Protection Agency, London and Stirling.

Garrod, C.J., Clyne, F.J., Tipple, J.R. and Edgar, A., 2008. Radiological Habits Survey: Harwell 2007. Project C2848. RL 07/08. Cefas, Lowestoft.

Garrod, C.J., Tipple, J.R., Clyne, F.J. and Jeffs, T.M., 2009. Radiological Habits Survey: Hartlepool 2008. Project C2848. RL 01/09. Cefas, Lowestoft.

Garrod, C.J., Clyne, F.J., Elliott, J. and Tipple, J.R., 2010. Radiological Habits Survey: Wylfa 2009. Project C2848. RL 03/10. Cefas, Lowestoft.

Garrod, C.J., Clyne, F.J., Rumney. P., Elliott, J., Smedley, C.A. and Ly, V.E. 2011. Radiological Habits Survey: Sizewell, 2010. Project C2848. RL 12/11. Cefas, Lowestoft.

Garrod, C.J., Clyne, F.J., Ly, V.E. and Rumney, P., 2012. Radiological Habits Survey: Heysham, 2011. Project C2848. RL 02/12. Cefas, Lowestoft.

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

Garrod, C.J., Clyne, F.J., Ly, V.E. and Papworth, G.P., (*in press*). Radiological Habits Survey: Dumfries and Galloway Coast, 2012. RL XX/XX. Cefas, Lowestoft.

Ham, G. J., Wilding, D. and Wilkins, B.T., 2007. Tritium concentrations in crops fertilised with contaminated sewage sludge. R01061. HPA-RPD-038. HPA, Chilton.

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

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

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

Harvey, M.P. and Jones, A.L., 2012. Radiological consequences resulting from accidents and incidents involving the transport of radioactive materials in the UK – 2011. HPA-CRCE-037, HPA, Chilton.

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

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

Her Majesty's Inspectorate of Pollution, 1995. Routine measurement of gamma ray air kerma rate in the environment. Technical Guidance Note (Monitoring) M5. HMSO, London.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

International Commission on Radiological Protection, 1991. 1990 Recommendations of the International Commission on Radiological Protection. Annal. ICRP 21(1 – 3). Pergamon Press, Oxford, 201pp. (ICRP Publ. (60)).

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

International Commission on Radiological Protection, 1996a. Age-dependent doses to members of the public from intake of radionuclides: Part 5 Compilation of ingestion and inhalation dose coefficients. Annal. ICRP 26(1). Elsevier Science, Oxford, 91pp. (ICRP Publ. (72)).

International Commission on Radiological Protection, 1996b. Conversion coefficients for use in radiological protection against external radiation. Annal ICRP 26(3/4). Elsevier Science, Oxford (ICRP Publ. (74)).

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

International Commission on Radiological Protection, 2006. Assessing dose of the representative person for the purpose of radiation protection of the public and the optimisation of radiological protection: broadening the process. Annal ICRP 36 (3). Elsevier Science, Oxford (ICRP Publ (101)).

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

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

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

Jenkinson, S.B., McCubbin, D., Kennedy, P.H.W., Dewar, A., Bonfield, R and Leonard, K.S., 2013. An estimate of the inventory of technetium-99 in the sub-tidal sediments in the Irish Sea. J. Environ. Rad., http://dx.doi.org/10.1016/j.jenvrad.2013.05.004

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

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

Jones, K.A., Smith, J.G., Anderson, T., Harvey, M.P., Brown, I., Field, S.J. and Jones, A.L., 2013. Implied doses to the population of the EU arising from reported discharges from EU nuclear power stations and reprocessing sites in the years 2004 to 2008, European Commission RP 179 http://ec.europa.eu/energy/nuclear/radiation_protection/doc/publication/176.pdf

Kelly, M. and Emptage, M.,1991. Radiological assessment of the estuary at Ravenglass: Distribution of radioactivity and its relationship to sedimentary processes. Department of Environment, London.

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

Kershaw, P.J., McCubbin, D. and Leonard, K.S., 1999. Continuing contamination of north Atlantic and Arctic waters by Sellafield radionuclides. Sci. Tot. Env., 237/238: 119 – 132.

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

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

Leonard, D.R.P., Camplin, W.C. and Tipple, J.R., 1990. The variability of radiocaesium concentrations in freshwater fish caught in the UK following the Chernobyl nuclear reactor accident: an assessment of potential doses to critical group consumers. pp. 247 – 256. In: 'Proc. Int. Symp. on Environmental Contamination Following a Major Nuclear Accident'. IAEA, Vienna, IAEA-SM-306/15.

Leonard, K.S., McCubbin, D., Brown, J., Bonfield, R. and Brooks, T., 1997a. A summary report of the distribution of Technetium-99 in UK Coastal Waters. Radioprotection, 32: 109 – 114.

Leonard, K.S., McCubbin, D., Brown, J., Bonfield, R. and Brooks, T., 1997b. Distribution of technetium-99 in UK coastal waters. Mar. Pollut. Bull., 34(8): 628 – 636.

Leonard, K.S., McCubbin, D., McMahon, C.A., Mitchell, P.I. and Bonfield, R., 1998. $^{137}Cs/^{90}Sr$ ratios in the Irish Sea and adjacent waters: a source term for the Arctic. Radiat. Prot. Dosim., 75(1 – 4): 207 – 212.

Leonard, K.S., McCubbin, D., Blowers, P. and Taylor, B.R., 1999. Dissolved plutonium and americium in surface waters of the Irish Sea, 1973 – 96. J. Environ. Rad., 44: 129 – 158.

Leonard, K.S., McCubbin, D. and Bailey, T.A., 2001. Organic forms of tritium in food chains. Project R01023/C0814. RL 6/01. Cefas, Lowestoft.

Leonard, K.S., McCubbin, D., McDonald, P., Service, M., Bonfield, R. and Conney, S., 2004. Accumulation of technetium-99 in the Irish Sea. Sci. Tot. Env., 322: 255 – 270.

Leonard, K. S. and Smedley, P. A., 2012. Radiological assessment of dredging application for Silloth Docks, Cumbria (2012). RL 10/12. Cefas, Lowestoft.

Ly, V.E., Garrod, C.J., Clyne, F.J. and Rumney, P., 2012. Radiological Habits Survey: Aldermaston and Burghfield, 2011. RL 03/12. Cefas, Lowestoft.

Ly, V.E., Clyne, F.J., Garrod, C.J. and Dewar, A., 2013. Radiological Habits Survey: Springfields, 2012. Project C2848. RL 03/13. Cefas, Lowestoft.

McCubbin, D., Leonard, K.S., Bailey, T.A., Williams, J. and Tossell, P., 2001. Incorporation of organic tritium (^{3}H) by marine organisms and sediment in the Severn Estuary/Bristol Channel (UK). Mar. Pollut. Bull., 42 (10): 852 – 863.

McCubbin, D., Leonard, K.S., Brown, J., Kershaw, P.J., Bonfield, R.A. and Peak, T., 2002. Further studies of the distribution of ^{99}Tc and ^{137}Cs in UK and European coastal waters. Cont. Shelf. Res. 22/10: 1417 – 1445.

McCubbin, D. and Vivian, C., 2006. Dose assessments in relation to disposal at sea under the London Convention 1972: judging *de minimis* radioactivity. FSA Project R01062. RL5/06. Cefas, Lowestoft.

McCubbin, D., Jenkinson, S.B., Leonard, K.S., Bonfield, R.A. and McMeekan, I.T., 2008. An assessment of the availability of Tc-99 to marine foodstuffs from contaminated sediments. Project R01062. RL09/08. Cefas, Lowestoft.

McKay, W.A., Barr H.M., Halliwell C.M., Spencer D., Adsley I. and Perks C.A., 1995. Site specific background dose rates in coastal areas. DoE/HMIP/RR/94/037. Her Majesty's Inspectorate of Pollution, London.

MacKerron, G., 2012. Evaluation of nuclear decommissioning and waste management. University of Sussex, Brighton.

McTaggart, K., 2003. Habits survey notebook, Unpublished. Cefas, Lowestoft.

McTaggart, K.A., Tipple, J.R., Clyne, F.J. and McMeekan, I.T., 2004a. Radiological habits survey: Cardiff, 2003. RL 03/04. Cefas, Lowestoft.

McTaggart, K.A., Tipple, J.R., Sherlock, M., Cogan, S.M., Joyce, A.E. and Clyne, F.J., 2004b. Radiological Habits Survey: Winfrith, 2003. Projects C1659, RB103 and C1666. RL02/04. Cefas, Lowestoft.

Ministry of Agriculture, Fisheries and Food, 1995. Terrestrial radioactivity monitoring programme (TRAMP) report for 1994. Radioactivity in food and agricultural products in England and Wales. MAFF, London, TRAMP/9, 223pp.

Ministry of Agriculture, Fisheries and Food, 1996. Pesticides Safety Directorate's Handbook. Appendix IC. MAFF, London.

Ministry of Agriculture, Fisheries and Food and Scottish Environment Protection Agency, 1998. Radioactivity in Food and the Environment, 1997. RIFE-3. MAFF and SEPA, London and Stirling.

Ministry of Agriculture, Fisheries and Food and Scottish Environment Protection Agency, 1999. Radioactivity in Food and the Environment, 1998. RIFE-4. MAFF and SEPA, London and Stirling.

Mobbs, S., Barraclough, I., Napier, I., Casey, A., Poynter, R. and Harvey, M., 1998. A review of the use and disposal of gaseous tritium light devices. Environment Agency, Lancaster.

National Radiological Protection Board, 1990. Gut transfer factors. Docs. NRPB 1(2). NRPB, Chilton, 26pp.

National Dose Assessment Working Group, 2004. Radiological Assessment Exposure Pathways Checklist (Common and Unusual). NDAWG/2/2004. Environment Agency, Food Standards Agency, NRPB, NII, Chilton.

National Radiological Protection Board, 2005. Guidance on the application of dose coefficients for the embryo and fetus from intakes of radionuclides by the mother. Docs NRPB 16(2). NRPB, Chilton, 41pp.

Northern Ireland Assembly, 2003. Radioactive Substances (Basic Safety Standards) Regulations (Northern Ireland).

Nuclear Decommissioning Authority, 2012. Strategy effective from April 2012. NDA, Moor Row, Cumbria.

Nuclear Decommissioning Authority, 2013. NDA Business Plan 2013/2016. NDA, Moor Row, Cumbria.

Office for Nuclear Regulation, 2011. Regulators issue interim DAC and interim SoDA as GDA reaches key milestone. 14 December 2011. ONR, Bootle.

Office for Nuclear Regulation, 2012. New nuclear reactors: Generic Design Assessment. Summary of the GDA Issue close-out assessment of the Electricite de France SA and AREVA NP SAS UK EPR nuclear reactor. ONR, Bootle.

Organisation for Economic Co-operation and Development, Nuclear Energy Agency, 1985. Review of the continued suitability of the dumping site for radioactive waste in the North-East Atlantic. OECD, Paris, 448pp.

OSPAR, 1998. SINTRA Statement. Summary Record OSPAR 98/14/1, Annex 45. OSPAR, London.

OSPAR, 2000a. Convention for the protection of the marine environment of the North-East Atlantic. OSPAR, London.

OSPAR, 2000b. Quality Status Report 2000. OSPAR, London.

OSPAR, 2003. 2003 Strategies of the OSPAR Commission for the Protection of the Marine Environment of the North-East Atlantic. 2003-21. OSPAR, London.

OSPAR, 2006. Agreement on a monitoring programme for concentrations of radioactive substances in the marine environment. Annex 14, ref 9.8c, Malahide (Ireland): 27 June-1 July 2005. OSPAR, London.

OSPAR, 2009a. Implementation of PARCOM Recommendation 91/4 on liquid discharges. Report from the United Kingdom. OPSAR, London.

OSPAR, 2009b. Towards the Radioactive Substances Strategy Objectives. Third Periodic Evaluation, OSPAR, London.

OSPAR, 2010a. The North-East Atlantic Environment Strategy. Strategy of the OSPAR Commission for the Protection of the Marine Environment of the North-East Atlantic 2010-2020. OSPAR Agreement 2010-3. OSPAR, London.

OSPAR, 2010b. Quality Status Report 2010. OSPAR, London.

OSPAR, 2011a. Liquid discharges from nuclear installations in 2009. OSPAR, London.

OSPAR, 2011b. Discharges of radioactive substances from the non-nuclear sectors in 2009. OSPAR, London.

OSPAR, 2013. Summary Record. Meeting of the Radioactive Substances Committee (RSC), The Hague: 5-7 February 2013. OSPAR, London.

Ould-Dada, Z., 2000. Sea-to-Land transfer of radionuclides. How much do we know. Proceedings of the second RADREM-TESC Workshop held in London on 21 January 1999. DETR/RADREM/00.001 DETR, London.

Papworth, G.P., Clyne, F.J., Garrod, C.J., Ly, V.E. and Dewar, A., 2013. Radiological Habits Survey: Sellafield Review, 2012. RL 04a/13. Cefas, Lowestoft.

Particles Retrieval Advisory Group (Dounreay), 2010. Annual report to SEPA and DSRL, March 2010. SEPA, Stirling.

Particles Retrieval Advisory Group (Dounreay), 2011. Annual report to SEPA and DSRL, March 2011. SEPA, Stirling.

Particles Retrieval Advisory Group (Dounreay), (*in press*). Annual report to SEPA and DSRL, SEPA, Stirling.

Patton, N., 2013. Dalgety Bay Appropriate Person Report, June 2013. SEPA, Stirling.

Povinec, P.P., Bailly Du Bois, P., Kershaw, P.J., Nies, H. and Scotto, P., 2003. Temporal and spatial trends in the distribution of ^{137}Cs in surface waters of Northern European Seas - a record of 40 years of investigations. Deep Sea Res. II, 50: 2785 – 2801.

Povinec, P.P., Aarkrog, A., Buesseler, K.O., Delfanti, R., Hirose, K., Hong, G.H., Ito, T., Livingston, H.D., Nies, H., Noshkin, V. E., Shima, S., Togawa,O., 2005. ^{90}Sr, ^{137}Cs and ^{239,240}Pu concentration surface water time series in the Pacific and Indian Oceans - WOMARS results. J. Environ. Rad, 81: 63 - 87.

Preston, A., Mitchell, N.T. and Jefferies, D.F., 1974. Experience gained in applying the ICRP Critical Group concept to the assessment of public radiation exposure in control of liquid waste disposal. Proc. Symp. IAEA Portoroz, IAEA-SM-184/10, 131 – 146.

Punt, A., Tyler, A., Saleh, S., Bradley, S and Copplestone, D., 2011. Measurement and assessment of external dose rates to people on houseboats and using riverbanks. Science Report: SC060080/SR. Environment Agency, Bristol and London.

Rollo, S.F.N., Camplin, W.C., Allington, D.J. and Young, A.K., 1992. Natural radionuclides in the UK marine environment. In: 'Proceedings of the Fifth International Symposium on Natural Radiation Environment, Salzburg, September 22 – 28, 1991'. Radiat. Prot. Dosim., 45(1/4): 203 – 210.

Rollo, S.F.N., Camplin, W.C., Duckett, L., Lovett, M.B. and Young, A.K., 1994. Airborne radioactivity in the Ribble Estuary. pp277 – 280. In: 'Proc. IRPA Regional Congress on Radiological Protection, 6 – 10 June 1994, Portsmouth, UK'. Nuclear Technology Publishing.

Rumney, P., Garrod, C.J. and Clyne, F.J., (*in press/a)*. Radiological Habits Survey: Faslane, 2011. RL XX/XX. Cefas, Lowestoft.

Rumney, P., Smedley, C.A., Garrod, C.J., Clyne, F.J. and Ly, V.E., (*in press/b)*. Radiological Habits Survey: Rosyth, 2010. RL XX/XX. Cefas, Lowestoft.

Rumney, P., Ly, V.E. and Clyne, F.J., (*in press/c)*. Radiological Habits Survey: Hunterston, 2012. RL XX/XX. Cefas, Lowestoft.

Scotland - Parliament, 2010. Marine (Scotland) Act, 2010. OQPS, Edinburgh.

Scottish Environment Protection Agency, 2007. Strategy for the Assessment of the potential impact of Sellafield Radioactive Particles on Southwest Scotland, December 2007. SEPA, Stirling.

Scottish Environment Protection Agency, 2012. SEPA Policy on the Regulation of Disposal of Radioactive Low Level Waste from Nuclear Sites. SEPA, Stirling.

Scottish Executive, 2000. Radioactive Substances (Basic Safety Standards) (Scotland) Direction 2000. Scottish Executive, Edinburgh.

Scottish Government, 2008. Environment Act 1995. The UK Strategy for Radioactive Discharges. Statutory Guidance. Scottish Government, Edinburgh.

Scottish Government, 2011. Scotland's Higher Activity Radioactive Waste Policy, 2011, Scottish Government, Edinburgh.

Simmonds, J.R., Lawson, G. and Mayall, A., 1995. Radiation Protection 72; Methodology for assessing the radiological consequences of routine releases of radionuclides to the environment. Report EUR 15760 EN. Office for Official Publications of the European Community, Luxembourg.

Smith, B.D. and Jeffs, T.M., 1999. Transfer of radioactivity from fishmeal in animal feeding stuffs to man. RL 8/99. Cefas, Lowestoft.

Smith, K.R. and Jones, A.L. 2003. Generalised habit data for radiological assessments. NRPB-W41. NRPB, Chilton.

Smith, J., Ottway, W., Brown, I. and Sherwood, J., 2009. PC Cream 08 User Guide. RPD-EA-9-2009. HPA, Chilton.

Smith, J.T., Comans, R.N.J., Beresford, N.A., Wright, S.M., Howard, B.J. and Camplin, W.C., 2000. Chernobyl's legacy in food and water. Nature, 405: 7141.

Smith, D.L., Smith, B.D., Joyce, A.E. and McMeekan, I.T., 2002. An assessment of aquatic radiation exposure pathways in Northern Ireland. SR(02)14. RL 20/02. Scotland and Northern Ireland Forum for Environmental Research, Edinburgh.

Smith, K.R., Mobbs, S.F. and Cooper, J.R., 2006. Dose criteria for the designation of radioactivity contaminated land. RCE-2. HPA, Chilton.

Statutory Instruments, 2007. SI 2007 No 3236. The Radioactive Contaminated Land (Amendment) Regulations (Northern Ireland) 2007.HMSO, London.

Statutory Instruments, 2010. SI 2010 No 2145. The Radioactive Contaminated Land (Amendment) Regulations (Northern Ireland) 2010. HMSO, London.

Swift, D.J., 2001. Cardiff radiological survey of selected foodstuffs. Project C1003. RL 11/01. Cefas, Lowestoft.

Swift, D.J. and Nicholson, M.D., 2001. Variability in the edible fraction content of ^{60}Co, ^{99}Tc, ^{110m}Ag, ^{137}Cs and ^{241}Am between individual crabs and lobsters from Sellafield (north eastern Irish Sea). J. Environ. Radioact., 54, 311 – 326.

Tipple, J.R., McTaggart, K., Clyne, F.J. and Sherlock, M., 2006. Radiological Habits Survey: Trawsfynydd, 2005. Projects C1659, RB103 and C1666. RL 02/06. Cefas, Lowestoft.

Tipple, J.R., Clyne, F.J., Garrod, C.J. and Sherlock, M., 2008. Radiological Habits Survey: Bradwell, 2007. Project C2848. RL 01/08. Cefas, Lowestoft.

Tipple, J.R., Jeffs, T.M., Clyne, F.J., Garrod, C.J. and Earl, T.J., 2009. Radiological Habits Survey: Capenhurst, 2008. Project C2848. RL 03/09. Cefas, Lowestoft.

United Kingdom - Parliament, 1965. Nuclear Installations Act, 1965. HMSO, London.

United Kingdom - Parliament, 1985. Food and Environment Protection Act, 1985. HMSO, London.

United Kingdom - Parliament, 1989. The Sludge (Use in Agriculture) Regulations 1989. HMSO, London.

United Kingdom - Parliament, 1993. Radioactive Substances Act, 1993. HMSO, London.

United Kingdom - Parliament, 1995a. Environment Act, 1995. HMSO, London.

United Kingdom - Parliament, 1995b. Review of Radioactive Waste Management Policy. HMSO, London, 55pp. (Cm 2919).

United Kingdom - Parliament, 1999. The Ionising Radiations Regulations 1999. Stat. Inst. 1999 No 3232. HMSO, London, 67pp.

United Kingdom - Parliament, 2004. Energy Act, 2004. HMSO, London.

United Kingdom – Parliament, 2009, Marine and Coastal Access Act 2009. HMSO, London

United Kingdom - Parliament, 2010a. Environmental Permitting (England and Wales) Regulations. Stat. Inst. 2010 No 675. HMSO, London.

United Kingdom - Parliament, 2010b. The Marine Strategy Regulations 2010. Stat. Inst. 2010 No 1627. HMSO, London.

Walker, S., 2013. Personal communication. Office for Nuclear Regulation, Health & Safety Executive, Bootle.

Watson, S.J., Jones, A.L., Oatway, W.B. and Hughes, J.S., 2005. Ionising radiation exposure of the UK population: 2005 Review. HPA-RPD-001. HPA, Chilton.

Wood, M.D., Marshall, W.A., Beresford, N.A., Jones, S.R., Howard, B.J, Copplestone, D. and Leah, R.T., 2008. Application of the ERICA Integrated Approach to the Drigg coastal sand dunes. J. Environ. Radioact. (Special Issue: The ERICA Project), 99 (9) 1484 – 1495.

Wood, M.D., Hall, P.J., Wittrick, S., Copplestone, D. and Leah, R.T., 2011. Survey of gamma dose rates in air around the Esk Estuary. Environment Agency, Bristol and London.

World Health Organisation, 2004. Guidelines for drinking water quality. 3rd Edition. WHO, Geneva.

Williams, J.L., Russ, R.M., McCubbin, D. and Knowles, J.F., 2001. An overview of tritium behaviour in the Severn estuary (UK). J. Rad. Prot., 21: 337 – 344.

Young, A.K., McCubbin, D. and Camplin, W.C., 2002. Natural radionuclides in seafood. Project R03010/C0808. RL 17/02. Cefas, Lowestoft.

Young, A.K., McCubbin, D., Thomas, K., Camplin, W.C., Leonard, K.S., and Wood, N., 2003. Po Concentrations in UK Seafood. 9th International Symposium on Environmental Radiochemical Analysis, 18-20 September 2002, Oxford. ERA III. Royal Society of Chemistry, London.

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

This Appendix contains information on the methods of sampling, measurement, presentation and assessment used in the Radioactivity in Food and the Environment report. It is provided in a separate file to the main report at http://www.cefas.defra.gov.uk/publications-and-data/scientific-series/radioactivity-in-food-and-the-environment-(rife).aspx

APPENDIX 2. Disposals of radioactive waste*

Table A2.1. Principal discharges of gaseous radioactive wastes from nuclear establishments in the United Kingdom, 2012

Establishment	Radioactivity	Discharge limit (annual equivalent)[a], Bq	Discharges during 2012	
			Bq	% of annual limit[b]
Nuclear fuel production and reprocessing				
Capenhurst (CNS Ltd)[1]	Alpha	BAT	3.61E+05	NA
Other authorised outlets	Beta	BAT	6.78E+05	NA
Capenhurst	Uranium	7.50E+06	4.23E+05	5.6
(Urenco UK Ltd)	Other alpha	2.40E+06	Nil	Nil
	Technetium-99	1.00E+08	Nil	Nil
	Others	2.25E+09	Nil	Nil
	Alpha (Incinerator)	2.00E+08	Nil	Nil
	Beta (Incinerator)	2.50E+08	Nil	Nil
Sellafield[c]	Alpha	8.80E+08	9.86E+07	11
	Beta	4.20E+10	1.00E+09	2.4
	Tritium	1.10E+15	1.02E+14	9.3
	Carbon-14	3.30E+12	3.78E+11	11
	Krypton-85	4.40E+17	3.85E+16	8.8
	Strontium-90	7.10E+08	3.25E+07	4.6
	Ruthenium-106[2]	2.30E+10	7.02E+08	3.1
	Antimony-125	3.00E+10	5.45E+08	1.8
	Iodine-129	7.00E+10	7.82E+09	11
	Iodine-131[2]	3.70E+10	2.40E+08	<1
	Caesium-137	5.80E+09	1.41E+08	2.4
	Radon-222[2]	5.00E+11	4.26E+10	8.5
	Plutonium alpha	1.90E+08	1.98E+07	10
	Plutonium-241	3.00E+09	2.39E+08	8.0
	Americium-241 and curium-242	1.20E+08	1.49E+07	12
Springfields	Uranium	5.30E+09	4.00E+08	7.5
Springfields	Tritium	1.00E+08	2.17E+06	2.2
(National Nuclear Laboratory)	Carbon-14	1.00E+07	4.44E+04	<1
	Other alpha radionuclides	1.00E+06	Nil	Nil
	Other beta radionuclides	1.00E+07	1.30E+06	13
Research establishments				
Dounreay	Alpha[e,f]	9.80E+08	1.23E+07	1.3
(Fuel Cycle Area)[d]	Beta[f,g,h]	4.50E+10	1.07E+08	<1
	Tritium	2.00E+12	1.08E+11	5.4
	Krypton-85[i,3]	4.36E+13	Nil	Nil
	Strontium-90	4.20E+09	1.53E+07	<1
	Ruthenium-106	3.90E+09	2.44E+06	<1
	Iodine-129	1.10E+09	4.87E+07	4.4
	Iodine-131	1.50E+08	7.31E+06	4.9
	Caesium-134	8.40E+08	3.18E+05	<1
	Caesium-137	7.00E+09	3.34E+05	<1
	Cerium-144	7.00E+09	1.93E+06	<1
	Plutonium-241	3.30E+09	8.14E+05	<1
	Curium-242	2.70E+08	6.61E+03	<1
	Curium-244[j]	5.40E+07	3.70E+02	<1
Dounreay	Alpha[f,k]	1.00E+07	9.56E+03	<1
(Fast Reactor)[d]	Beta[f,g,h]	1.50E+09	3.49E+04	<1
	Tritium	4.50E+12	2.25E+09	<1
	Krypton-85[i]	4.00E+08	1.79E+07	4.5
Dounreay	Alpha[f,k]	6.00E+06	2.94E+04	<1
(Prototype Fast Reactor)[d]	Beta[f,g,h]	5.10E+07	2.18E+05	<1
	Tritium	1.05E+13	9.49E+10	<1
	Krypton-85[i,3]	5.25E+14	Nil	Nil
Dounreay	Alpha[f,k]	6.00E+04	2.55E+02	<1
(PFR minor sources)[d]	Beta[f,g,h]	5.00E+05	9.66E+02	<1
	Tritium	2.00E+11	1.13E+10	5.7

Table A2.1. continued

Establishment	Radioactivity	Discharge limit (annual equivalent)[a], Bq	Discharges during 2012	
			Bq	% of annual limit[b]
Dounreay (East minor sources)[d]	Alpha[f,k]	1.37E+07	6.08E+04	<1
	Beta[f,h]	3.71E+08	3.34E+05	<1
	Krypton-85[i]	1.00E+12	Nil	Nil
Dounreay (West minor sources)[d]	Alpha[f,g,k]	3.00E+05	2.87E+03	<1
	Beta[g,h]	7.50E+07	1.26E+04	<1
	Tritium	1.00E+10	2.33E+08	2.3
Harwell Research Sites Restoration Ltd	Alpha	8.00E+05	3.70E+04	4.6
	Beta	2.00E+07	6.70E+05	3.4
	Tritium	1.50E+13	2.80E+11	1.9
	Krypton-85	2.00E+12	Nil	Nil
	Radon-220	1.00E+14	5.30E+12	5.3
	Radon-222	3.00E+12	2.10E+11	7.0
	Iodines	1.00E+10	Nil	Nil
	Other radionuclides	1.00E+11	Nil	Nil
Harwell (GE Healthcare B443.26)	Alpha	1.00E+05	Nil	Nil
	Beta/gamma	3.00E+07	Nil	Nil
	Radon-222	1.00E+12	Nil	Nil
	Tritium	2.00E+12	Nil	Nil
	Krypton-85	6.00E+10	Nil	Nil
Winfrith Inutec	Alpha	1.00E+05	Nil	Nil
	Tritium	1.95E+13	1.15E+13	59
	Carbon-14	3.00E+10	Nil	Nil
	Other	1.00E+05	Nil	Nil
Winfrith Research Sites Restoration Ltd	Alpha	2.00E+06	1.36E+03	<1
	Tritium	5.00E+13	1.93E+10	<1
	Carbon-14	6.00E+09	1.43E+08	2.4
	Other	5.00E+06	1.33E+04	<1
Minor sites				
Imperial College Reactor Centre Ascot	Tritium	3.00E+08	1.22E+07	4.1
	Argon-41	1.70E+12	5.33E+10	3.1
Nuclear power stations				
Berkeley[l]	Beta	2.00E+07	9.60E+04	<1
	Tritium	2.00E+10	1.01E+10	51
	Carbon-14	5.00E+09	5.24E+08	10
Bradwell	Beta	6.00E+08	5.73E+05	<1
	Tritium[4]	1.50E+12	2.51E+10	<1
	Carbon-14[4]	6.00E+11	4.20E+08	<1
Chapelcross	Tritium	5.00E+15	6.05E+13	1.2
	Sulphur-35	5.00E+10	Nil	Nil
	Argon-41	4.50E+15	Nil	Nil
Dungeness A Station[5]	Beta[f]	5.00E+08	3.44E+06	<1
	Tritium	2.60E+12	3.08E+10	1.2
	Carbon-14	5.00E+12	6.34E+08	<1
Dungeness B Station	Tritium	1.20E+13	1.31E+12	11
	Carbon-14	3.70E+12	5.28E+11	14
	Sulphur-35	3.00E+11	1.02E+10	3.4
	Argon-41	7.50E+13	1.10E+13	15
	Cobalt-60[f]	1.00E+08	4.94E+06	4.9
	Iodine-131	1.50E+09	2.77E+07	1.8
Hartlepool	Tritium	1.00E+13	5.15E+11	5.2
	Carbon-14	4.50E+12	2.17E+12	48
	Sulphur-35	2.30E+11	1.54E+10	6.7
	Argon-41	1.50E+14	1.40E+13	9.3
	Cobalt-60[f]	1.00E+08	1.81E+07	18
	Iodine-131	1.50E+09	1.71E+08	11

Table A2.1. continued

Establishment	Radioactivity	Discharge limit (annual equivalent)[a], Bq	Discharges during 2012	
			Bq	% of annual limit[b]
Heysham Station 1	Tritium	1.00E+13	1.47E+12	15
	Carbon-14	4.50E+12	1.74E+12	39
	Sulphur-35	2.00E+11	2.55E+10	13
	Argon-41	1.50E+14	4.60E+12	3.1
	Cobalt-60[f]	1.00E+08	6.45E+06	6.4
	Iodine-131	1.50E+09	7.07E+07	4.7
Heysham Station 2	Tritium	1.00E+13	8.81E+11	8.8
	Carbon-14	3.70E+12	1.38E+12	37
	Sulphur-35	2.30E+11	8.64E+09	3.8
	Argon-41	7.50E+13	8.45E+12	11
	Cobalt-60[f]	1.00E+08	1.03E+07	10
	Iodine-131	1.50E+09	8.64E+07	5.8
Hinkley Point A Station	Beta	5.00E+07	2.00E+05	<1
	Tritium	7.50E+11	4.30E+10	5.7
	Carbon-14	5.00E+10	6.00E+08	1.2
Hinkley Point B Station	Tritium	1.20E+13	9.98E+11	8.3
	Carbon-14	3.70E+12	1.16E+12	31
	Sulphur-35	3.50E+11	5.80E+10	17
	Argon-41	1.00E+14	1.06E+13	11
	Cobalt-60[f]	1.00E+08	9.10E+06	9.1
	Iodine-131	1.50E+09	8.75E+06	<1
Hunterston A Station	Beta[f]	6.00E+07	1.60E+06	2.7
	Tritium	2.00E+10	8.60E+08	4.3
	Carbon-14	2.00E+09	8.00E+07	4.0
Hunterston B Station[d]	Particulate beta	5.00E+08	6.12E+07	12
	Tritium	1.50E+13	2.56E+12	17
	Carbon-14	4.50E+12	1.39E+12	31
	Sulphur-35	5.00E+11	9.33E+10	19
	Argon-41	1.50E+14	9.20E+12	6.1
	Iodine-131	2.00E+09	3.01E+06	<1
Oldbury	Beta	1.00E+08	1.37E+07	14
	Tritium	9.00E+12	9.82E+11	11
	Carbon-14	4.00E+12	2.63E+11	6.6
	Sulphur-35	4.50E+11	1.20E+10	2.7
	Argon-41	5.00E+14	1.07E+12	<1
Sizewell A Station	Beta	8.50E+08	Nil	Nil
	Tritium	3.50E+12	6.51E+10	1.9
	Carbon-14	1.00E+11	6.62E+09	6.6
Sizewell B Station	Noble gases	3.00E+13	2.93E+12	9.8
	Particulate Beta	1.00E+08	2.40E+06	2.4
	Tritium	3.00E+12	8.03E+11	27
	Carbon-14	5.00E+11	3.25E+11	65
	Iodine-131	5.00E+08	2.10E+07	4.2
Torness	Particulate beta	4.00E+08	3.86E+06	1.0
	Tritium	1.10E+13	1.55E+12	14
	Carbon-14	4.50E+12	1.04E+12	23
	Sulphur-35	3.00E+11	5.04E+10	17
	Argon-41	7.50E+13	4.07E+12	5.4
	Iodine-131	2.00E+09	3.18E+06	<1
Trawsfynydd	Particulate Beta	5.00E+07	1.90E+06	3.8
	Tritium[6]	3.75E+11	4.30E+10	11
	Carbon-14	1.00E+10	5.60E+08	5.6
Wylfa	Particulate Beta	7.00E+08	3.05E+07	4.4
	Tritium	1.80E+13	2.14E+12	12
	Carbon-14	2.30E+12	9.65E+11	42
	Sulphur-35	4.50E+11	1.16E+11	26
	Argon-41	1.00E+14	9.02E+12	9.0

Table A2.1. continued

Establishment	Radioactivity	Discharge limit (annual equivalent)[a], Bq	Discharges during 2012	
			Bq	% of annual limit[b]
Defence establishments				
Aldermaston[m,7]	Alpha	1.65E+05	2.72E+04	17
	Particulate Beta	6.00E+05	1.00E+04	1.7
	Tritium	3.90E+13	7.10E+11	1.8
	Carbon-14	6.00E+06	Nil	Nil
	Activation products	NA	2.00E+04	NA
	Volatile beta	4.40E+06	2.90E+05	6.6
Barrow[n]	Tritium	3.20E+06	Nil	Nil
	Argon-41	4.80E+10	Nil	Nil
Burghfield[m]	Tritium	1.00E+10	Nil	Nil
	Alpha	5.00E+03	8.20E+02	16
Coulport	Tritium	5.00E+10	6.95E+09	14
Derby[o,p]	Uranium	4.00E+06	8.02E+05	20
	Alpha[f]	2.40E+04	4.30E+01	<1
	Beta[f]	1.80E+06	4.11E+04	2.3
Devonport[q]	Beta/gamma[f]	3.00E+05	3.66E+04	12
	Tritium	4.00E+09	7.40E+08	19
	Carbon-14	4.30E+10	1.79E+10	42
	Argon-41	1.50E+10	5.50E+08	3.7
Dounreay (Vulcan)	Beta[f]	5.10E+06	1.20E+06	24
	Noble gases	5.00E+09	2.16E+09	43
Rosyth[r]	Beta (particulate)	1.00E+05	Nil	Nil
	Tritium	2.00E+08	Nil	Nil
	Carbon-14	5.00E+08	Nil	Nil
Radiochemical production				
Amersham (GE Healthcare)	Alpha	2.25E+06	2.99E+05	13
	Radionuclides T1/2<2hr	7.50E+11	3.96E+10	5.3
	Tritium	2.00E+12	1.08E+06	<1
	Sulphur-35	3.50E+10	Nil	Nil
	Iodine-125	2.00E+10	5.11E+08	2.6
	Radon-222	1.00E+13	1.67E+12	17
	Other noble gases	5.00E+13	Nil	Nil
	Other including selenium-75 and iodine-131	1.60E+10	1.18E+07	<1
Cardiff (GE Healthcare)	Soluble tritium	1.56E+14	7.00E+11	<1
	Insoluble tritium	6.00E+14	6.60E+11	<1
	Carbon-14	2.38E+12	1.84E+11	7.7
	Phosphorus-32/33	5.00E+06	Nil	Nil
	Iodine-125	1.80E+08	Nil	Nil
	Other radionuclides	1.00E+09	Nil	Nil
Industrial and landfill sites				
LLWR	Alpha	BAT	2.87E+04	NA
	Beta	BAT	1.41E+05	NA
Lillyhall (Studsvik)	Alpha (particulate)	5.00E+05	4.65E+03	<1
	Beta (particulate)	5.00E+05	1.68E+04	3.4

Table A2.1. continued

* *As reported to SEPA and the Environment Agency*
[a] *In some cases permits specify limits in greater detail than can be summarised in a single table; in particular, periods shorter than one year are specified at some sites*
[b] *Data quoted to 2 significant figures except where values are <1%*
[c] *Limits for tritium, carbon-14, krypton-85 and iodine-129 vary with the mass of uranium processed by THORP*
[d] *Some discharges are upper estimates because they include 'less than' data derived from analyses of effluents at limits of detection*
[e] *Excluding curium-242 and 244*
[f] *Particulate activity*
[g] *Excluding tritium*
[h] *Excluding krypton-85*
[i] *Krypton-85 discharges are calculated monthly*
[j] *Data excludes any curium-243 present*
[k] *Excluding radon and daughter products*
[l] *Combined data for Berkeley Power Station and Berkeley Centre*
[m] *Discharges were made by AWE plc*
[n] *Discharges from Barrow are included with those from MoD sites because they are related to submarine activities. Discharges were made by BAE Systems Marine Ltd*
[o] *Discharges were made by Rolls Royce Marine Power Operations Ltd*
[p] *Annual limits on beta and alpha derived from monthly and weekly notification levels*
[q] *Discharges were made by Devonport Royal Dockyard Ltd*
[r] *Discharges were made by Rosyth Royal Dockyard Ltd*
[1] *Permit formerly held by Sellafield Limited prior to 30 November 2012*
[2] *Discharge permit revised with effect from 1 June 2012*
[3] *Discharge permit revised with effect from 22 August 2012*
[4] *Discharge permit revised with effect from 1 October 2012*
[5] *Discharge permit revised with effect from 1 September 2011, sulphur-35 and argon-41 are no longer within the permit*
[6] *Discharge permit revised with effect from 1 November 2011*
[7] *Discharge permit revised with effect 1 November 2012, krypton-85 is now exempt from regulation (up to 1.00E+11 Bq per year), the description argon-41 was changed to Activation products and the limit is no longer applicable*
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, 2012

Establishment	Radioactivity	Discharge limit (annual equivalent)[a], Bq	Discharges during 2012	
			Bq	% of annual limit[b]
Nuclear fuel production and reprocessing				
Capenhurst (Urenco UK Ltd)[1] (Rivacre Brook)	Uranium	7.50E+08	3.80E+06	<1
	Uranium daughters	1.36E+09	4.19E+06	<1
	Non-uranic alpha	2.20E+08	1.10E+07	5.0
	Technetium-99	1.00E+09	1.27E+06	<1
Sellafield (sea pipelines)[c]	Alpha	1.00E+12	1.42E+11	14
	Beta	2.20E+14	9.49E+12	4.3
	Tritium	2.00E+16	1.05E+15	5.3
	Carbon-14	2.10E+13	4.09E+12	19
	Cobalt-60	3.60E+12	5.35E+10	1.5
	Strontium-90[2]	4.50E+13	1.19E+12	2.6
	Zirconium-95 + Niobium-95[2]	2.80E+12	1.03E+11	3.7
	Technetium-99	1.00E+13	9.24E+11	9.2
	Ruthenium-106[2]	5.10E+13	6.45E+11	1.3
	Iodine-129	2.00E+12	2.14E+11	11
	Caesium-134	1.60E+12	5.55E+10	3.5
	Caesium-137	3.40E+13	3.58E+12	11
	Cerium-144	4.00E+12	2.46E+11	6.2
	Neptunium-237[2]	7.30E+11	3.53E+10	4.8
	Plutonium alpha	7.00E+11	1.40E+11	20
	Plutonium-241	2.50E+13	3.01E+12	12
	Americium-241	3.00E+11	1.78E+10	5.9
	Curium-243+244[2]	5.00E+10	1.84E+09	3.7
	Uranium[d]	2.00E+03	3.39E+02	17
Sellafield (factory sewer)	Alpha	3.00E+08	1.28E+08	43
	Beta	6.10E+09	4.10E+09	67
	Tritium	6.80E+10	1.08E+10	16
Springfields	Alpha	1.00E+11	2.37E+10	24
	Beta	2.00E+13	4.54E+12	23
	Technetium-99	6.00E+11	1.60E+11	27
	Thorium-230	2.00E+10	2.09E+09	10
	Thorium-232	1.50E+10	2.05E+08	1.4
	Neptunium-237	4.00E+10	4.95E+08	1.2
	Other transuranic radionuclides	2.00E+10	1.59E+09	8.0
	Uranium	4.00E+10	1.78E+10	45
Research establishments				
Dounreay PFR liquid metal disposal plant[e]	Alpha[f]	2.00E+10	8.43E+04	<1
	Beta[g]	1.10E+11	4.07E+06	<1
	Tritium	1.40E+12	6.78E+07	<1
	Sodium-22	1.80E+12	5.24E+06	<1
	Caesium-137	6.60E+10	9.89E+07	<1
Dounreay Other facilities[e]	Alpha[f]	9.00E+10	2.74E+08	<1
	Beta[g]	6.20E+11	3.44E+08	<1
	Tritium	5.50E+12	7.57E+10	1.4
	Strontium-90	7.70E+11	4.41E+09	<1
	Caesium-137	1.00E+12	3.31E+10	3.3
Harwell (River Thames)[3]				
	Alpha	1.00E+07	2.24E+06	22
	Beta	6.00E+08	1.13E+08	19
	Tritium	1.00E+11	4.78E+08	<1
	Cobalt-60	5.00E+06	9.56E+05	19
	Caesium-137	2.00E+08	3.50E+07	18
Harwell (Lydebank Brook)[3]	Alpha	3.00E+07	7.56E+06	25
	Beta	3.00E+08	4.04E+07	13
	Tritium	2.00E+10	2.93E+09	15
Winfrith (inner pipeline)[h]	Alpha	2.00E+10	8.77E+07	<1
	Tritium	2.20E+14	2.69E+13	12
	Caesium-137	2.00E+12	3.51E+08	<1
	Other radionuclides	1.00E+12	1.67E+10	1.7

Table A2.2. continued

Establishment	Radioactivity	Discharge limit (annual equivalent)[a], Bq	Discharges during 2012	
			Bq	% of annual limit[b]
Winfrith (outer pipeline)	Alpha	2.00E+09	4.96E+06	<1
	Tritium	1.50E+11	1.73E+09	1.2
	Other radionuclides	1.00E+09	2.33E+07	2.3
Winfrith (River Frome)	Tritium	7.50E+11	Nil	Nil
Minor sites				
Imperial College Reactor Centre	Tritium	4.00E+07	2.50E+05	<1
Ascot	Other radioactivity	1.00E+06	Nil	Nil
Nuclear power stations				
Berkeley	Tritium	1.00E+12	1.01E+09	<1
	Caesium-137	2.00E+11	4.24E+08	<1
	Other radionuclides	2.00E+11	3.00E+08	<1
Bradwell	Tritium	7.00E+12	1.45E+10	<1
	Caesium-137	7.00E+11	2.40E+09	<1
	Other radionuclides	7.00E+11	2.70E+09	<1
Chapelcross	Alpha	1.00E+11	7.71E+06	<1
	Beta[i]	2.50E+13	5.99E+09	<1
	Tritium	5.50E+12	3.17E+09	<1
Dungeness A Station	Tritium	8.00E+12	8.01E+10	1.0
	Caesium-137	1.10E+12	5.07E+09	<1
	Other radionuclides	8.00E+11	4.90E+09	<1
Dungeness B Station	Tritium	6.50E+14	1.62E+14	25
	Sulphur-35	2.00E+12	9.18E+10	4.6
	Cobalt-60	1.00E+10	3.42E+08	3.4
	Caesium-137	1.00E+11	7.75E+08	<1
	Other radionuclides	8.00E+10	1.56E+09	2.0
Hartlepool	Tritium	6.50E+14	3.78E+14	58
	Sulphur-35	3.00E+12	1.55E+12	52
	Cobalt-60	1.00E+10	3.92E+08	3.9
	Caesium-137	1.00E+11	2.24E+09	2.2
	Other radionuclides	8.00E+10	3.27E+09	4.1
Heysham Station 1	Tritium	6.50E+14	3.30E+14	51
	Sulphur-35	2.00E+12	4.45E+11	22
	Cobalt-60	1.00E+10	2.28E+08	2.3
	Caesium-137	1.00E+11	3.66E+09	3.7
	Other radionuclides	8.00E+10	5.86E+09	7.3
Heysham Station 2	Tritium	6.50E+14	3.50E+14	54
	Sulphur-35	2.00E+12	5.03E+10	2.5
	Cobalt-60	1.00E+10	8.25E+07	<1
	Caesium-137	1.00E+11	1.53E+09	1.5
	Other radionuclides	8.00E+10	1.22E+10	15
Hinkley Point A Station	Tritium	1.00E+12	1.18E+11	12
	Caesium-137	1.00E+12	3.53E+10	3.5
	Other radionuclides	7.00E+11	1.73E+11	25
Hinkley Point B Station	Tritium	6.50E+14	1.53E+14	24
	Sulphur-35	2.00E+12	3.04E+11	15
	Cobalt-60	1.00E+10	1.02E+08	1.0
	Caesium-137	1.00E+11	2.18E+09	2.2
	Other radionuclides	8.00E+10	2.52E+09	3.2
Hunterston A Station	Alpha	4.00E+10	2.54E+08	<1
	Beta	6.00E+11	4.84E+10	8.1
	Tritium	7.00E+11	6.98E+09	1.0
	Plutonium-241	1.00E+12	1.98E+08	<1

Table A2.2. continued

Establishment	Radioactivity	Discharge limit (annual equivalent)[a], Bq	Discharges during 2012	
			Bq	% of annual limit[b]
Hunterston B Station	Alpha	1.00E+09	2.79E+07	2.8
	All other non-alpha	1.50E+11	1.00E+10	6.7
	Tritium	7.00E+14	1.85E+14	26
	Sulphur-35	6.00E+12	8.50E+11	14
	Cobalt-60	1.00E+10	3.90E+08	3.9
Oldbury	Tritium	1.00E+12	1.32E+11	13
	Caesium-137	7.00E+11	1.27E+11	18
	Other radionuclides	7.00E+11	7.65E+10	11
Sizewell A Station	Tritium	5.00E+12	1.19E+11	2.4
	Caesium-137	1.00E+12	1.20E+11	12
	Other radionuclides	7.00E+11	5.13E+10	7.3
Sizewell B Station	Tritium	8.00E+13	4.15E+13	52
	Caesium-137	2.00E+10	5.00E+09	25
	Other radionuclides	1.30E+11	1.30E+10	10
Torness	Alpha	5.00E+08	4.34E+06	<1
	All other non-alpha	1.50E+11	3.74E+09	2.5
	Tritium	7.00E+14	3.36E+14	48
	Sulphur-35	3.00E+12	5.93E+11	20
	Cobalt-60	1.00E+10	2.58E+08	2.6
Trawsfynydd[4]	Tritium	3.00E+11	1.93E+09	<1
	Caesium-137	1.50E+10	1.92E+09	13
	Other radionuclides[j]	3.00E+10	2.29E+09	7.6
Wylfa	Tritium	1.50E+13	2.87E+12	19
	Other radionuclides	1.10E+11	5.08E+09	4.6
Defence establishments				
Aldermaston (Silchester)	Alpha	1.00E+07	2.69E+06	27
	Other beta emitting radionuclides	2.00E+07	3.51E+06	18
	Tritium	2.50E+10	1.40E+08	<1
Aldermaston (to Stream)[k]	Tritium	NA	5.60E+08	NA
Barrow[l,5]	Tritium	1.20E+10	9.44E+06	<1
	Carbon-14	2.70E+07	1.23E+05	<1
	Other gamma emitting radionuclides	3.50E+06	1.56E+04	<1
Derby[m]	Alpha[n]	2.00E+09	7.40E+07	3.7
	Alpha[o]	3.00E+05	2.20E+04	7.3
	Beta[o]	3.00E+08	5.80E+05	<1
Devonport (sewer)[p]	Tritium	2.00E+09	6.61E+07	3.3
	Cobalt-60	3.50E+08	5.12E+06	1.5
	Other radionuclides	6.50E+08	1.36E+08	21
Devonport (estuary)[p]	Tritium	7.00E+11	2.05E+11	29
	Carbon-14	1.70E+09	3.07E+08	18
	Cobalt-60	8.00E+08	6.74E+07	8.4
	Other radionuclides	3.00E+08	4.43E+07	15
Faslane	Alpha	2.00E+08	4.00E+04	<1
	Beta[q,r]	5.00E+08	4.40E+05	<1
	Tritium	1.00E+12	8.00E+09	<1
	Cobalt-60	5.00E+08	2.20E+05	<1
Rosyth[s]	Tritium	3.00E+09	5.82E+08	19
	Cobalt-60	3.00E+08	2.46E+06	<1
	Other radionuclides	3.00E+08	2.09E+06	<1

Table A2.2. continued

Establishment	Radioactivity	Discharge limit (annual equivalent)[a], Bq	Discharges during 2012	
			Bq	% of annual limit[b]
Radiochemical production				
Amersham (GE Healthcare)[q]	Alpha	3.00E+08	9.30E+06	3.1
	Tritium	1.41E+11	3.30E+06	<1
	Iodine-125	4.00E+09	5.96E+06	<1
	Caesium-137	5.00E+09	3.80E+06	<1
	Other radionuclides	6.50E+10	9.41E+08	1.4
Cardiff (GE Healthcare)	Tritium	1.30E+14	1.14E+10	<1
	Carbon-14	9.10E+11	1.01E+09	<1
	Phosphorus-32/33	8.50E+07	Nil	Nil
	Iodine-125	3.00E+08	Nil	Nil
	Others	1.20E+08	Nil	Nil
Industrial and landfill sites				
LLWR	Alpha	BAT	5.40E+07	NA
	Beta	BAT	1.05E+09	NA
	Tritium	BAT	6.39E+10	NA
Lillyhall (Studsvik)	Alpha	5.00E+05	5.32E+02	<1
	Beta	5.00E+05	1.32E+03	<1

[a] *In some cases permits specify limits in greater detail than can be summarised in a single table; in particular, periods shorter than one year are specified at some sites*
[b] *Data quoted to 2 significant figures except when values are less than 1%*
[c] *Limits for tritium and iodine-129 vary with the mass of uranium processed by the THORP plant*
[d] *The limit and discharge data are expressed in kg*
[e] *Some discharges are upper estimates because they include 'less than' data derived from analyses of effluents at limits of detection. Data quoted to 2 decimal places*
[f] *All alpha emitting radionuclides taken together*
[g] *All beta and gamma emitting radionuclides (excluding tritium, strontium-90 and caesium-137) taken together*
[h] *Discharges reported include those from INUTEC*
[i] *All beta and gamma emitting radionuclides (excluding tritium, sodium-22 and caesium-137) taken together*
[j] *Including strontium*
[k] *The discharge permit has been replaced by a quarterly notification level of 30 Bq l^{-1}*
[l] *Discharges from Barrow are included with those from MOD sites because they are related to submarine activities. Discharges were made by BAE Systems Marine Ltd*
[m] *Discharges were made by Rolls Royce Marine Power Operations Ltd*
[n] *Discharge limit is for Nuclear Fuel Production Plant*
[o] *Discharge limit is for Neptune Reactor and Radioactive Components Facility*
[p] *Discharges were made by Devonport Royal Dockyard Ltd*
[q] *Excluding cobalt-60*
[r] *Excluding tritium*
[s] *Discharges were made by Rosyth Royal Dockyard Ltd*
[1] *Permit formerly held by Sellafield Limited prior to 30 November 2012*
[2] *Discharge permit revised with effect from 1 June 2012*
[3] *Discharge permit revised with effect from 7 November 2011*
[4] *Discharge permit revised with effect from 1 November 2011*
[5] *BAE were granted a minor variation to their discharge permit, effective 26 July 2011, for the sampling and analysis of carbon-14, with an annual discharge limit of 2.70E+07 Bq, to the sewer*

NA Not applicable under permit
BAT Best available technology

Table A2.3. Disposals of solid radioactive waste at nuclear establishments in the United Kingdom, 2012

Establishment	Radioactivity	Disposal limit	Disposals during 2012	
		Bq	Bq	% of limit[a]
LLWR[b]	Tritium	1.00E+13	1.98E+09	<1
	Carbon-14	5.00E+10	1.36E+08	<1
	Cobalt-60	2.00E+12	1.20E+09	<1
	Iodine-129	5.00E+10	3.20E+06	<1
	Radium-226 plus thorium-232	3.00E+10	3.43E+08	1.1
	Uranium	3.00E+11	2.37E+08	<1
	Other alpha[c]	3.00E+11	7.80E+09	2.6
	Others[c,d]	1.50E+13	5.72E+10	<1
Dounreay[e]	Alpha		Nil	NA
	Beta/gamma		Nil	NA

[a] *Data quoted to 2 significant figures except where values are less than 1%*
[b] *Under current planning permission at the LLWR near to Drigg, certain wastes are temporarily stored, as opposed to being disposed, pending disposal/storage elsewhere or permission for disposal in-situ*
[c] *With half-lives greater than 3 months excluding uranium, radium-226 and thorium-232*
[d] *Iron-55 and beta-emitting radionuclides with half-lives greater than three months unless individually specified in this table*
[e] *The current permit includes limits on concentrations of activity. At no time did the concentrations exceed the limits*
NA Not applicable

Table A2.4. Summary of unintended leakages, spillages, emissions or unusual findings of radioactive substances from nuclear licensed sites in the UK in 2012

Site	Month	Summary of incident	Consequences and action taken
Dounreay	March	Unauthorised disposals of radioactively contaminated effluent into the site's inactive drainage system were identified, which is discharged to sea via an inactive outfall. The disposals related to effluent discharges from the environmental laboratories and involved very low levels of radioactivity.	There was no discernible environmental impact as a result of the discharges. However, the discharges constituted a contravention of the limitations and conditions of the RSA 93 authorisation held by the operator. SEPA issued a Warning Letter to DSRL.
Dounreay	July	A consignment of solid waste was removed from site without it going through DSRL's due process for waste leaving site. The incident did not result in an unauthorised disposal of radioactive waste, as the waste was subsequently proven to be clean.	As there was a failure in the arrangements in place to control the disposal of waste from the site, the event constituted a contravention of the limitations and conditions of the RSA 93 authorisation held by the operator. SEPA issued a Warning Letter to DSRL.
Hinkley Point A	August	An acid leak occurred in the Chemical Treatment Plant (CTP). The secondary containment system was damaged by the acid and a loss to ground occurred. Some radioactivity contained within the pipework from past operations, approximately 100 kBq of pond fingerprint mixed fission products, was estimated to have been discharged. This is a small quantity – a tiny fraction of the site annual liquid discharge limit of 1 TBq for caesium-137. However, the permit for the site does not allow discharges to ground to be made and this leak is indicative of poor system specification, maintenance and control arrangements around the CTP.	A Warning Letter was issued to Hinkley Point A.
Sellafield	February	After restarting a cell extract fan to enforce the contingency plan for the Purification Plant (Shutdown) Separation Area Ventilation tie in, the flexible ducting failed. A very small quantity of radiological material may have been discharged from an unpermitted discharge point.	This incident led to a minor release of radioactivity to the environment. Overall, the Environment Agency concluded that there was negligible additional environmental or public human health impact associated with this incident. Advice and guidance has been given to the operator.
Sellafield	November	Small apertures around the duct flange on the Separation Area Ventilation tie in, resulted in a minor loss of radiological material.	The initial assessment indicated that negligible, additional environmental or public human health impact had resulted. Event remains under investigation.
Springfields	October	Pressure surge caused a paper filter to shred.The fragments, along with some uranium tetra fluoride powder, were ejected from the stack.	There were insignificant radiological consequences, as the release did not go as far as the site boundary. A Warning Letter was issued.

APPENDIX 3. Abbreviations and glossary

ABL	AWE plc, Babcock and Lockheed Martin UK
AGIR	Advisory Group on Ionising Radiation
AGR	Advanced Gas-cooled Reactor
AHVLA	Animal Health and Veterinary Laboratories Agency
AWE	Atomic Weapons Establishment
BAT	Best Available Techniques or Best Available Technology
BNFL	British Nuclear Fuels plc
BNGSL	British Nuclear Group Sellafield Limited
BPEO	Best Practicable Environmental Option
BPM	Best Practicable Means
BSS	Basic Safety Standards
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
CNS	Capenhurst Nuclear Services Limited
COBR	Cabinet Office Briefing Room
COS	Carbonyl Sulphide
CoRWM	Committee on Radioactive Waste Management
DBPAG	Dalgety Bay Particles Advisory Group
DECC	Department of Energy and Climate Change
Defra	Department for Environment, Food and Rural Affairs
DETR	Department of the Environment, Transport and the Regions
DH	Department of Health
DPAG	Dounreay Particles Advisory Group
DSRL	Dounreay Site Restoration Limited
DSTL	Defence Science and Technology Laboratory
Euratom	European Atomic Energy Community
EA	Environment Agency
EARP	Enhanced Actinide Removal Plant
EC	European Commission
EDF	Electricité de France
EPR 10	Environment Permitting (England and Wales) Regulations 2010
ERICA	Environmental Risk from Ionising Contaminants: Assessment and Management
ESC	Environmental Safety Case
ESG	Environmental Scientifics Group
EU	European Union
FEPA	Food and Environment Protection Act
FSA	Food Standards Agency
GDA	Generic Design Assessment
GDL	Generalised Derived Limit
GE	General Electric
GOCO	Government Owned Contractor Operator
HMIP	Her Majesty's Inspectorate of Pollution
HMNB	Her Majesty's Naval Base
HMSO	Her Majesty's Stationery Office
HPA	Health Protection Agency
HSE	Health & Safety Executive
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
IRPA	International Radiation Protection Association
ISO	International Standards Organisation
JET	Joint European Torus
LGC	Laboratory of the Government Chemist
LLLETP	Low Level Liquid Effluent Treatment Plant
LLW	Low Level Waste
LLWR	Low Level Waste Repository
LoD	Limit of Detection
MAC	Medium Active Concentrate
MAFF	Ministry of Agriculture, Fisheries & Food
MCAA	Marine and Coastal Act 2009
MMO	Marine Management Organisation
MoD	Ministry of Defence
MODP	Magnox Optimised Decommissioning Programme
MRF	Metals Recycling Facility
MRL	Minimum Reporting Level
MRWS	Managing Radioactive Waste Safely
NaK	Sodium / Potassium
ND	Not Detected
NDA	Nuclear Decommissioning Authority
NIEA	Northern Ireland Environment Agency
NII	Nuclear Installations Inspectorate
NMP	Nuclear Management Partners Limited
NORM	Naturally Occurring Radioactive Material
NRPB	National Radiological Protection Board
NRW	Natural Resources Wales
NPS	National Policy Statement
NRTE	Naval Reactor Test Establishment
OBT	Organically Bound Tritium
OECD	Organisation for Economic Co-operation and Development
ONR	Office for Nuclear Regulation
OSPAR	Oslo and Paris Convention
PBO	Parent Body Organisation
PRAG (D)	Particles Retrieval Advisory Group (Dounreay)
PHE	Public Health England
PWR	Pressurised Water Reactor
RAPs	Reference Animals and Plants
RDPP	Reactor Decommissioning Planning Project
REP	RSR Environmental Principle
RIFE	Radioactivity in Food and the Environment
RRDL	Rosyth Royal Dockyard Limited
RRMPOL	Rolls-Royce Marine Power Operations Limited
RNAS	Royal Naval Air Station
RSA 93	Radioactive Substances Act 1993
RSR	Radioactive Substances Regulation
RSRL	Research Sites Restoration Limited

RSS	Radioactive Substances Strategy
SAGE	Scientific Advisory Group in Emergencies
SEPA	Scottish Environment Protection Agency
SFL	Springfields Fuels Limited
SIXEP	Site Exchange Effluent Plant
SLC	Site Licence Company
SRP	Society for Radiological Protection
STW	Sewage Treatment Works
SWIMMER	Sustainable Water Integrated Management and Ecosystem Research
THORP	Thermal Oxide Reprocessing Plant
TNORM	Technologically enhanced Naturally-Occurring Radioactive Material
TRAMP	Terrestrial Radioactive Monitoring Programme
UKAEA	United Kingdom Atomic Energy Authority
UKNWM	UK Nuclear Waste Management Limited
UOC	Uranium Ore Concentrate
UUK	Urenco UK Limited
VLLW	Very Low Level Waste
WFD	Water Framework Directive
WHO	World Health Organisation
WWTW	Waste Water Treatment Works
YP	Ystradyfodwg and Pontypridd

Absorbed dose	The ionising radiation energy absorbed in a material per unit mass. The unit for absorbed dose is the gray (Gy) which is equivalent to J kg^{-1}.
Authorised Premises	This is a premises that has been authorised by the environment agencies to discharge to the environment.
Becquerel	One radioactive transformation per second.
Bioaccumulation	Excretion may occur, however the rate of excretion is less than the rate of intake + accumulation.
Biota	Flora and fauna.
Committed effective dose	The sum of the committed equivalent doses for all organs and tissues in the body resulting from an intake (of a radionuclide), having been weighted by their tissue weighting factors. The unit of committed effective dose is the sievert (Sv). The 'committed' refers to the fact that the dose is received over a number of years but it is accounted for in the year of the intake of the activity.
Direct shine	Ionising radiation which arises directly from processes or operations on premises using radioactive substances and not as a result of discharges of those substances to the environment.
Dose	Shortened form of 'effective dose' or 'absorbed dose'.
Dose limits	Maximum permissible dose resulting from ionising radiation from practices covered by the Euratom Basic Safety Standards Directive, excluding medical exposures. It applies to the sum of the relevant doses from external exposures in the specified period and the 50 year committed doses (up to age 70 for children) from intakes in the same period. Currently, the limit has been defined as 1 mSv per year for the UK.
Dose rates	The radiation dose delivered per unit of time.
Effective dose	The sum of the equivalent doses from internal and external radiation in all tissue and organs of the body, having been weighted by their tissue weighting factors. The unit of effective dose is the sievert (Sv).
Environmental materials	Environmental materials include freshwater, grass, seawater, seaweed, sediment, soil and various species of plants.
Equivalent dose	The absorbed dose in a tissue or organ weighted for the type and quality of the radiation by a radiation-weighting factor. The unit of equivalent dose is the sievert (Sv).
External dose	Doses to humans from sources that do not involve ingestion or inhalation of the radionuclides.

Fragments	'Fragments' are considered to be fragments of irradiated fuel, which are up to a few millimetres in diameter.
Generalised Derived Limit	A convenient reference level against which the results of environmental monitoring can be compared. GDLs are calculated using deliberately cautious assumptions and are based on the assumption that the level of environmental contamination is uniform over the year. GDLs relate the concentrations of a single radionuclide in a single environmental material to the dose limit for members of the public.
Indicator materials	Environmental materials may be sampled for the purpose of indicating trends in environmental performance or likely impacts on the food chain. These include seaweed, soil and grass.
In-growth	Additional activity produced as a result of radioactive decay of parent radionuclides.
Kerma air rate	Air kerma is the quotient of the sum of the kinetic energies of all the charged particles liberated by indirectly ionising particles in a specified mass of air.
Millisievert	The millisievert is a 1/1000 of a sievert. A sievert is one of the International System of Units used for the measurement of dose equivalent.
Radiation exposure	Being exposed to radiation from which a dose can be received.
Radiation weighting	Factor used to weight the tissue or organ absorbed dose to take account Factor of the type and quality of the radiation. Example radiation weighting factors: alpha particles = 20; beta particles = 1; photons = 1.
Radioactivity	The emission of alpha particles, beta particles, neutrons and gamma or x-radiation from the transformation of an atomic nucleus.
Radionuclide	An unstable form of an element that undergoes radioactive decay.
Representative person	A hypothetical individual receiving a dose that is representative of the most exposed individuals in the population.
TNORM	Naturally-occurring radioactive materials that may have been technologically enhanced in some way. The enhancement has occurred when a naturally-occurring radioactive material has its composition, concentration, availability, or proximity to people altered by human activity. The term is usually applied when the naturally-occurring radionuclide is present in sufficient quantities or concentrations to require control for purposes of radiological protection of the public or the environment.
Tissue weighting factors	Factor used to weight the equivalent dose in a tissue or organ to takes account of the different radiosensitivity of each tissue and organ. Example tissue weighting factors: lung = 0.12; bone marrow = 0.12; skin = 0.01.
Total dose	An assessment of dose that takes into account all exposure pathways such as radionuclides in food and the environment and direct radiation.

APPENDIX 4. Research in support of the monitoring programmes

The Food Standards Agency 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 habit and agricultural practice data, in order to improve the realism of dose assessment calculations
- To develop more sensitive and/or efficient analytical techniques for measurement of radionuclides in natural matrices
- To evaluate the competence of laboratories' radiochemical analytical techniques for specific radionuclides in food and environmental materials
- To develop improved methods for handling and processing monitoring data

Other studies include projects relating to effects on wildlife, emergency response and planning and development of new environmental models and data.

The contents of the research programmes are regularly reviewed and open meetings are held to discuss ongoing, completed and potential future projects. Occasionally specific topics are the subject of dedicated workshops (for example, Ould-Dada, 2000). A summary of all the research and development undertaken by the Environment Agency between 1996 and 2001 was published in 2002 (Environment Agency, 2002b). A review of research funded by the Food Standards Agency was published in 2004 (Food Standards Agency, 2004).

Information on recently completed extramural research is presented in Table A4.1. Those sponsored by the Environment Agency and the Food Standards Agency are also listed on their websites (www.environment-agency.gov.uk, www.food.gov.uk, respectively). Copies of the final reports for each of the projects funded by the Food Standards Agency are available from Aviation House, 125 Kingsway, London WC2B 6NH. Further information on studies funded by the Scottish Environment Protection Agency and the Scotland and Northern Ireland Forum for Environmental Research is available from Greenside House, 25 Greenside Place, Edinburgh, EH1 3AA. Environment Agency reports are available from www.environment-agency.gov.uk. A charge may be made to cover costs. Table A4.1 also provides information on research that is currently underway. The results of this research will be made available in due course.

Table A4.1. Extramural Projects

Topic	Reference	Further details	Target completion date
Soil and herbage survey	UKRSR01 and SCO00027	E, S	In press
Measurement of radioactivity in canteen meals for Euratom (2005-2013)	R03025	F	Mar-14

E *Environment Agency*
F *Food Standards Agency*
S *Scotland and Northern Ireland Forum for Environmental Research or SEPA*

APPENDIX 5. Disposal of dredge material from Silloth Docks, Cumbria

In England, the Marine Management Organisation (MMO) administers a range of statutory controls that apply to marine works on behalf of the Secretary of State for Environment, Food and Rural Affairs (Defra), this includes issuing licences under the Marine and Coastal Access Act (MCAA), 2009 (United Kingdom - Parliament, 2009) for the disposal of dredged material at sea. Licences for disposals made in Scottish waters and around the coast of Northern Ireland are the responsibility of the Scottish Government (Marine Scotland) and the Department of Environment (NIEA), respectively. As of 1 April 2010, licences for Welsh waters are the responsibility of the Welsh Government.

The protection of the marine environment is considered before a licence is issued. Since dredge material will contain radioactivity from natural and man-made sources at varying concentrations, assessments are undertaken when appropriate for assurance that there is no significant food chain or other risk from the disposal. Guidance on exemption criteria for radioactivity in relation to sea disposal is available from the International Atomic Energy Agency (IAEA) (International Atomic Energy Agency, 1999). IAEA has published a system of assessment that can be applied to dredge spoil disposal (International Atomic Energy Agency, 2003). This has been adapted to reflect operational practices in England and Wales (McCubbin and Vivian, 2006). In 2012, Associated British Ports Holdings Limited lodged a licensing application to carry out a dredging programme (3 years), involving the disposal at sea of ~ 7,142 m^3 per annum of sediment from Silloth Docks in Cumbria. A specific assessments was conducted for the disposal of the dredge material for this location (Leonard and Smedley, 2012).

The dock sediments contained artificial radionuclides typical of muddy sediments along the Cumbrian coastline, due to the legacy of large discharges from the Sellafield Limited reprocessing plant (formerly British Nuclear Fuels) at Sellafield in the 1970s. Samples of the material were taken and analysed, and the results are given in Table A5.1. The contributions from individual radionuclides to the doses for individual crew members and individual members of the public are given in Figures A5.1-2. Under the London Convention, only materials with *de minimis* levels of radioactivity may be considered for dumping. Using the conservative generic radiological assessment procedure developed by the IAEA (International Atomic Energy Agency, 2003) to convert radionuclide concentrations in dumped material into radiation doses due to dumping, the total dose (from artificial and naturally-occurring radionuclides) to individual members of the crew and public were within the IAEA *de minimis* criteria of 0.010 mSv per year.

Table A5.1. Concentrations of radionuclides in sediment dredged from Silloth Docks, 2012

Sample number	Mean radioactivity concentration (dry), Bq kg^{-1}					
	^{60}Co	^{137}Cs	^{226}Ra (via ^{214}Pb)[1]	^{232}Th (via ^{228}Ac)[1]	^{238}U (via ^{234}Th)[1]	^{241}Am
1	<0.75	140	21	22	26	170
2	<0.62	560	21	22	33	290
3	<0.55	690	26	22	29	300
7	<0.89	230	20	33	33	290
8	2.2	350	21	27	39	420
9	2.7	510	27	34	53	550
13	<0.49	83	31	23	27	89
14	<0.58	56	17	16	24	92
15	<0.53	67	18	17	25	88
Mean*	1	299	22	24	32	255

[1] *Parent nuclides not directly detected by the method used. Instead, concentrations were estimated from levels of their daughter products*

* *Mean determinations use < results as positively measured values to produce a conservative estimate, and are calculated from raw data (raw data are rounded in the table above)*

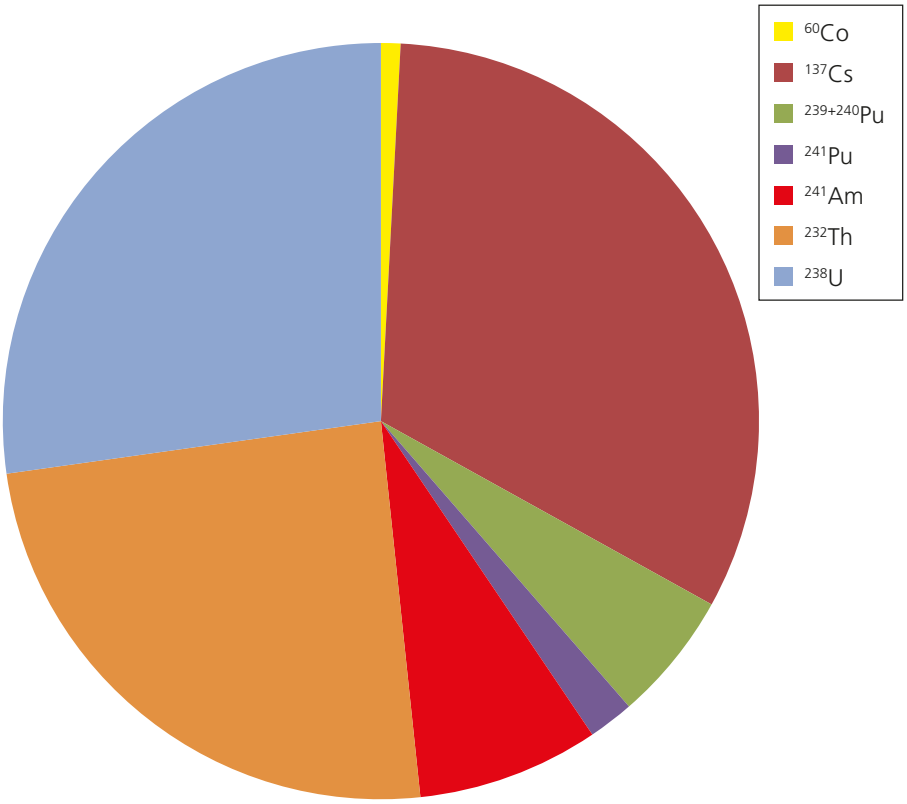


Figure A5.1. Radionuclide contribution to dose to individual crew members due to dredging at Silloth Docks, 2012

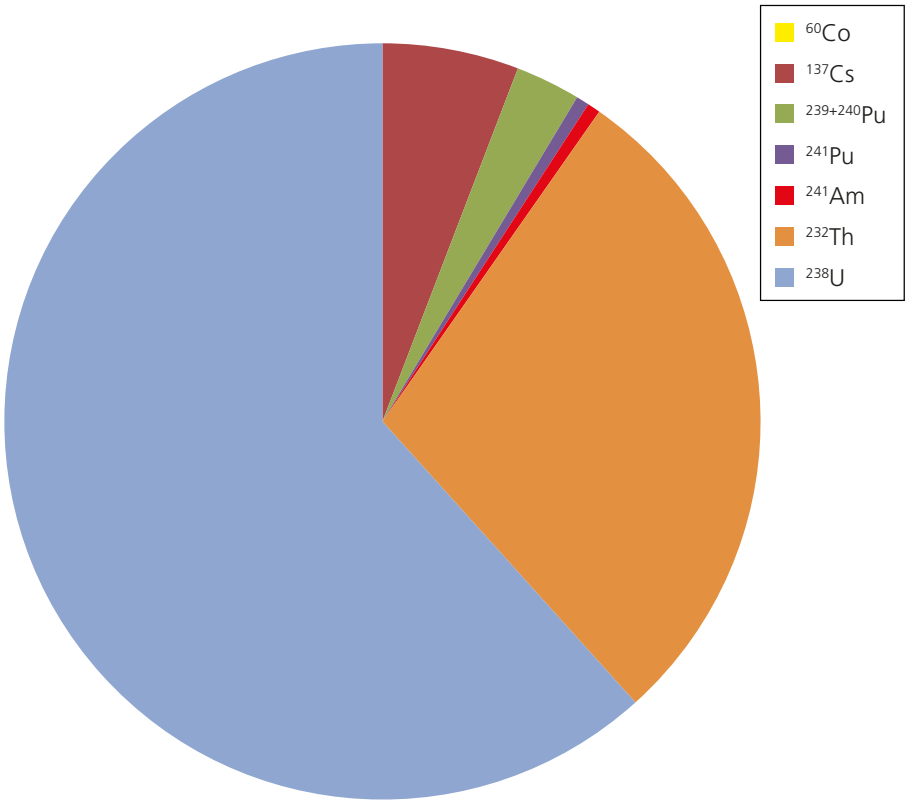


Figure A5.2. Radionuclide contribution to dose to individual members of the public due to dredging at Silloth Docks, 2012

Environment Agency
Monitoring Assessment and New Reactor Permitting
Nuclear Regulation (North)
Lutra House, Off Seedlee Road, Walton Summit
Bamber Bridge
Preston PR5 8BX

Food Standards Agency
Chemical Safety Division
Aviation House
125 Kingsway
London WC2B 6NH

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
Erskine Court
Castle Business Park
Stirling FK9 4TR

ISSN 1365-6414

ENVIRONMENT AGENCY
FOOD STANDARDS AGENCY
NORTHERN IRELAND ENVIRONMENT AGENCY
SCOTTISH ENVIRONMENT PROTECTION AGENCY

Radioactivity in Food and the Environment, 2012 Appendix 1 CD Supplement

RIFE – 18

October 2013

Contents Page

1. Introduction 5

2. Methods of sampling, measurement and presentation 6
2.1 Sampling programmes 6
2.1.1 Nuclear sites 7
2.1.2 Industrial and landfill sites 7
2.1.3 Fallout in the UK from overseas accidents and regional monitoring 7
2.2 Methods of measurement 8
2.2.1 Sample analysis 9
2.2.2 Measurement of dose rates and contamination 9
2.3 Presentation of results 10
2.4 Detection limits 10
2.5 Additional information 11

3. Assessment methods and data 12
3.1 Radiation protection standards 12
3.2 Assessment methods 13
3.3 Concentrations of radionuclides in foodstuffs, drinking water sources, sediments and air 14
3.4 Consumption, drinking and inhalation rates 14
3.4.1 Source specific assessments 14
3.4.2 *Total dose* assessments 15
3.5 Dose coefficients 15
3.6 External exposure 15
3.7 Subtraction of 'background levels' 15
3.8 Uncertainties in dose assessment 16

4. References 17

Annex 1. Modelling of concentrations of radionuclides in foodstuffs, air and sewage systems 18

Annex 2. Consumption, inhalation, handling and occupancy rates 21

Annex 3. Dosimetric data 25

Annex 4. Estimates of concentrations of natural radionuclides 28

List of Tables

Abbreviated Title	Number	Page
Annex 1		
Models - food chain data	X1.1	19
Models - predicted concentrations	X1.2	19
Air - assessment data 1	X1.3	20
Air - assessment data 2	X1.4	20
Sewer assessment data	X1.5	20
Annex 2		
Terrestrial habit data	X2.1	21
Aquatic habit data	X2.2	22
Annex 3		
Dosimetric data	X3.1	26
Annex 4		
Naturals in seafood	X4.1	28
Carbon-14 in terrestrial foods	X4.2	28

List of Figures

Total dose method	X1.1	13

1. Introduction

This appendix contains a summary of the sampling, measurement, presentation and assessment methods and data used in producing the RIFE report. This information is included as a separate document accompanying the main report. Accompanying this file is a further set of files giving full details of each assessment of *total dose* summed over all sources at each site.

Annexes are provided to this appendix giving further information on:

- Modelling to extend or improve the results of monitoring
- Consumption, occupancy and other habit data
- Dosimetric data
- Estimates of concentrations of natural radionuclides

References in this appendix are given in the report.

Guidance on planning and implementing routine environmental radiological monitoring programmes has been published (Environment Agency, Food Standards Agency and Scottish Environment Protection Agency, 2010). The Food Standards Agency completed a public consultation exercise to review the way it monitors radioactivity in food in June 2013 (Food Standards Agency, 2012a and 2013). It is intended that the results will be taken forward in revised programmes taking effect in 2014.

2. Methods of sampling, measurement and presentation

This section explains the scope of the monitoring programmes presented in this report and summarises the methods and data used to measure and assess radioactivity in food and the environment. The bulk of the programmes and assessment methods and data have continued from 2011 unchanged. The main changes are:

Sampling and measurement

- Special sampling at nuclear sites - this was continued where there were unusual short-term increases in discharges and inadvertent releases
- Sampling directed at the effects of fallout in the UK from the Fukushima Dai-ichi accident was largely completed in 2011

Assessment and presentation

- Site maps - maps of sites and sampling locations have been revised and updated
- New habits data - consumption and occupancy rates for critical groups have been updated with the benefit of recent habit survey results at Barrow, Drigg, Sellafield and Springfields in England and Dumfries and Galloway and Hunterston in Scotland
- Research related to the monitoring programmes has been reviewed and relevant results have been presented in Appendix 4

2.1 Sampling programmes

The primary purpose of the programmes is to check on levels of radioactivity in food and the environment. The results are used to demonstrate that the safety of people is not compromised and that doses, as a result of discharges of radioactivity, are below the dose limit. The scope extends throughout the UK and the Insular States (the Channel Islands and the Isle of Man) and is undertaken independently of the industries which discharge wastes to the environment. Samples of food, water and other materials are collected from the environment and analysed in specialist laboratories. *In situ* measurements of radiation dose rates and contamination are also made and the results of the programme are assessed in terms of limits and trends in this report. Subsidiary objectives for the programmes are:

- To provide information to assess the impact on non-human species
- To enable indirect confirmation of compliance with authorisations for disposal of radioactive wastes
- To determine whether undisclosed releases of radioactivity have occurred from sites
- To establish a baseline from which to judge the importance of accidental releases of radioactivity should they occur
- To demonstrate compliance with OSPAR obligations

In 2011, additional monitoring of the effects of long range transport of radioactivity to the UK from the Fukushima Dai-ichi accident in Japan was assessed. This work was largely completed in 2011.

Routine sampling is focused on nuclear sites licensed by the HSE under the Nuclear Installations Act, 1965 (United Kingdom - Parliament, 1965) since these generally discharge more radioactivity and have a greater impact on the environment. The programmes also serve to provide information to assist the environment agencies to fulfil statutory duties under the Radioactive Substances Act, 1993 (United Kingdom - Parliament, 1993) and the Environmental Permitting (England and Wales) Regulations, 2010 (United Kingdom – Parliament, 2010a). Additional sampling is conducted in areas remote from nuclear sites to establish the general safety of the food chain, drinking water and the environment. Results from this sampling generate data that are used as background levels to compare with results from around nuclear sites and to show the variation in levels across the UK. Levels in the environment can also be affected by disposals of radioactive waste from nuclear sites abroad and show the legacy of atmospheric fallout from both past nuclear weapons testing and the nuclear reactor accident in 1986 at Chernobyl in Ukraine.

Various methods for undertaking sampling and analysis are available. The programmes are primarily directed at relatively widespread contamination where the likelihood of encounter or consumption is certain. Where a source of potential exposure to particles of radioactivity is concerned, the likelihood of encounter is an important factor. This is considered separately in the main report in site specific programmes targeted at contamination from radioactive particles.

The programmes can be divided into three main sectors largely on the basis of the origin of radioactivity in the environment:

1. Nuclear sites discharging gaseous and liquid radioactive wastes
2. Industrial and landfill sites
3. Overseas accidents and regional monitoring

2.1.1 Nuclear sites

Nuclear sites are the prime focus of the programme as they are responsible for the largest individual discharges of radioactive waste. Sampling and direct monitoring is conducted close to each of the sites shown in Figure 1.3 of the main text with the exception of Ascot and Lillyhall which have a very low impact. In the case of Sellafield, some radionuclides that were discharged in liquid effluent can be detected in the marine environment in many parts of north-European waters and so the programme for this site extends beyond national boundaries.

The frequency and type of measurement and the materials sampled vary from site to site and are chosen to be representative of existing exposure pathways. Knowledge of such pathways is gained from surveys of local peoples' diets and way of life. As a result the programme varies from site to site and from year to year. Detailed information on the scope of the programme at individual sites is given in the tables of results. The routine programme is supplemented by additional monitoring when necessary, for example, in response to incidents or reports of unusual or high discharges of radioactivity with the potential to get into the food chain or the environment. The results of both routine and additional monitoring are included in this report.

The main aim of the programme is to monitor the environment and diet of people who live or work near nuclear sites in order to estimate exposures for those small groups of people who are most at risk from disposals of radioactive waste. It is assumed that if the most exposed people have a dose below the national and international legal limit then all others should be at an even lower level of risk. For liquid wastes, the pathways that are the most relevant to discharges are the ingestion of seafood and freshwater fish, drinking water and external exposure from contaminated materials. For gaseous wastes, the effects are due to the ingestion of terrestrial foods, inhalation of airborne activity and external exposure from material in the air and deposited on land. Inhalation of airborne activity and external exposure from airborne material and surface deposition are difficult to assess by direct measurement but can be assessed using environmental models. The main thrust of the monitoring is therefore directed at a wide variety of foodstuffs and measurements of external dose rates on the shores of seas, rivers and lakes. The programme also includes some key environmental indicators, in order that levels can be put in an historic context.

The European Commission undertakes a verification programme of discharge and environmental monitoring programmes in support of the objectives of Articles 35 and 36 of the Euratom Treaty. The objectives are for Member States to have monitoring programmes to ensure compliance with the Basic Safety Standards (Commission of the European Communities, 1996). The Commission undertakes periodic inspections of operator and Government facilities in the UK and has undertaken a project to investigate the need for harmonisation of procedures across the Community (Hunt *et al.*, 2007).

2.1.2 Industrial and landfill sites

Whilst the main focus of the programme is the nuclear industry, a watching brief is kept on other activities, which may have a radiological impact on people and the food chain. This part of the programme considers the impact of disposals of naturally-occurring and man-made radionuclides from non-nuclear industries and of disposal into landfill sites other than at Dounreay (which is considered separately in Section 3.2 of the main report).

The impact of the non-nuclear industry was studied at one main site, Whitehaven, in 2012. In addition, a small-scale programme was undertaken near Hartlepool over and above that directed at the effects of the power station itself. In each case the sampling and analysis was directed at materials potentially containing enhanced levels of naturally-occurring radionuclides from non-nuclear industrial activity (i.e. Technologically enhanced Naturally-Occurring Radioactive Materials (TNORM)). There are also occasional specific programmes that consider, for example, the effects of land contaminated with historic sources of radioactivity and discharges from non-nuclear sites such as hospitals.

The distribution of landfill sites considered in 2012 is shown in Figure 7.1 of the main text. They were studied to assess the extent, if any, of the contamination leaching from the site and re-entering the terrestrial environment in leachates collected in surface waters close to the sites. The most significant site is the engineered facility at LLWR near Drigg, in Cumbria.

2.1.3 Fallout in the UK from overseas accidents and regional monitoring

Monitoring of the long range effects of the Fukushima Dai-ichi accident was initiated across the UK in March 2011. Samples from all sectors of the environment were taken and analysed by gamma spectrometry. Key determinands were iodine-131 and caesium-137 which were prevalent in the release from the accident. Further details of the programme and the results are given in the report for 2011. Very little radioactivity was detected and the extended programme ceased in 2012.

Monitoring of the effects of the 1986 Chernobyl accident was undertaken in relation to the upland contamination of lakes but sheep monitoring ceased in 2012 due to the removal of restrictions on the movement, sale and slaughter of sheep in parts of Cumbria and North Wales. Monitoring of other foodstuffs is now at a much-reduced rate as levels have declined significantly since the accident, but there remains a small-scale survey of radiocaesium in freshwater fish taken from a small number of upland lakes.

The programme of regional monitoring considers the levels of radionuclides in the environment in areas away from specific

sources as an indication of general contamination of the food supply and the environment. The component parts of this programme are:

- Monitoring of the Channel Islands, the Isle of Man and Northern Ireland
- Dietary surveys
- Sampling of milk, crops, and meat
- Drinking water sources, groundwater, rain and airborne particulates
- Seawater surveys

Channel Islands, Isle of Man and Northern Ireland

The programmes for the Insular States and Northern Ireland are designed to complement that for the rest of the UK and to take account of the possibility of long-range transport of radionuclides.

Channel Islands monitoring is conducted on behalf of the Channel Island States. It consists of sampling and analysis of seafood, crops and indicator materials as a measure of the potential effects of UK and French disposals into the English Channel and historic disposal of solid waste in the Hurd Deep.

Monitoring on the Isle of Man for terrestrial foodstuffs is conducted on behalf of the Department of Environment, Food and Agriculture. Sampling is undertaken of a range of foodstuffs that are analysed for Chernobyl, Sellafield and Heysham related radionuclides. Monitoring of seafood is primarily directed at the effects of disposals from Sellafield.

The Northern Ireland programme is directed at the far-field effects of disposals of liquid radioactive wastes into the Irish Sea. Dose rates are monitored on beaches and seafood and indicator materials are collected from a range of coastal locations including marine loughs.

General diet

The purpose of the general diet surveys is to provide information on radionuclides in the food supply to the whole population, rather than to those in the vicinity of particular sources of contamination such as the nuclear industry. This programme, based on sampling and analysis of canteen meals, provides background information that is useful in interpreting site-related measurements and also helps ensure that all significant sources of contamination form part of the site-related programme. Data are also supplied as part of the UK submission to the EC under Article 36 of the Euratom Treaty* to allow comparison with those from other EU Member States (Commission of the European Communities, 2000a; Joint Research Centre, 2009).

* *The treaty establishing the European Atomic Energy Community (Euratom) was signed in Rome on 25th March 1957.*

Specific foods, freshwater, rain and airborne particulates

Further background information on the relative concentrations of radionuclides is gained from the sampling and analysis of foods, particularly milk and crops. Freshwater, rain and airborne particulates are also analysed to add to the understanding of radionuclide intakes by the population via ingestion and inhalation and as general indicators of the state of the environment.

Milk sampling took place at dairies throughout the UK in 2012. Samples were taken monthly and data are also supplied as part of the UK submission to the EC under Article 36 of the Euratom Treaty to allow comparison with those from other EU Member States (e.g. Joint Research Centre, 2009).

Other food sampling complements the regional dairy programme described above. Crop samples were taken from locations throughout the UK. The results are used to give an indication of background levels of radioactive contamination from naturally-occurring and man-made sources (nuclear weapon tests and Chernobyl fallout) for comparison with samples collected from around nuclear sites. In 2012, surveillance of food at ports of entry using radiation screening equipment continued. Where screening and subsequent sample analysis shows levels which fail to comply with EU food standards, consignments are removed from the UK market.

Freshwater used for the supply of drinking water was sampled throughout England, Northern Ireland, Scotland and Wales. Regular measurements of radioactivity in air and rain water were also made. The UK provides information from these programmes of work to the EC under Article 36 of the Euratom Treaty.

Seawater surveys

Seawater surveys are conducted in the seas around the UK on behalf of Defra to provide information on radionuclide levels and fluxes in the coastal seas of northern Europe. Such information is used to support international studies of the health of the seas under the aegis of the OSPAR Conventions (OSPAR, 2000b), to which the UK is a signatory and in support of research on the fate of radionuclides discharged to sea. These surveys are mounted using government research vessels and are supplemented by a programme of spot sampling of seawater at coastal locations.

2.2 Methods of measurement

There are two basic types of measurement made: (i) dose rates are measured directly in the environment; and (ii) samples collected from the environment are analysed for their radionuclide content in a laboratory.

2.2.1 Sample analysis

The analyses conducted on samples vary according to the nature of the radionuclide under investigation. The types of analysis can be broadly categorised into two groups: (i) gamma-ray spectrometry: and (ii) radiochemical methods. The former is a cost-effective method of detecting a wide range of radionuclides commonly found in radioactive wastes and is used for most samples. The latter comprise a range of analyses involving chemical separation techniques to quantify the alpha and beta emitting radionuclides under study. They are sensitive but more labour intensive. They are, therefore, only used when there is clear expectation that information is needed on specific radionuclides that are not detectable using gamma-ray spectrometry (see 2.4 for discussion on limits of detection).

Several laboratories analysed samples in the programmes described in this report. Their main responsibilities were as follows:

- Cefas Centre for Environment, Fisheries and Aquaculture Science, analysis of food related aquatic samples in England, Wales, Northern Ireland, Isle of Man and the Channel Islands
- ESG Environmental Scientifics Group, gamma-ray spectrometry and radiochemistry of environment related samples in England and Wales
- PHE Health Protection Agency, gamma-ray spectrometry and radiochemistry of samples from Scotland, air and rain samples in England, Wales, Northern Ireland and the Shetland Islands, Total Diet and canteen meals from England and Wales and freshwater for Northern Ireland
- LGC Laboratory of the Government Chemist, analysis of drinking water in England and Wales
- AHVLA Animal Health and Veterinary Laboratories Agency, gamma-ray spectrometry and radiochemistry of food related terrestrial samples in England, Wales, the Channel Islands and the Isle of Man

Each laboratory operates quality control procedures to the standards required by the environment agencies and the Food Standards Agency. In most cases, contractors are third-party assessed for their operating procedures, i.e. they are accredited by an agency such as the UK Accreditation Service that certifies they meet the requirements of the international standard ISO 17025 (International Organisation for Standardisation, 2005). Regular calibration of detectors is undertaken and intercomparison exercises are held with participating laboratories. The quality assurance procedures and data are made available to the UK environment agencies and the Food Standards Agency for auditing. The methods of measurement include alpha and gamma-ray spectrometry, beta and Cerenkov scintillation counting and alpha and beta counting using proportional detectors.

Corrections are made for the radioactive decay of short-lived radionuclides between the time of sample collection and measurement in the laboratory. This is particularly important for sulphur-35 and iodine-131. Where bulking of samples is undertaken, the date of collection of the bulked sample is assumed to be in the middle of the bulking period. Otherwise the actual collection date for the sample is used. In a few cases where short-lived radionuclides are part of a radioactive decay chain, the additional activity ('in-growth' and equilibrium status) produced as a result of radioactive decay of parent and daughter radionuclides after sample collection is also considered. Corrections to the activity present at the time of measurement are made to take this into account for the radionuclides protactinium-233 and thorium-234.

The analysis of foodstuffs is conducted on that part of the sampled material that is normally eaten, for example, the shells of shellfish and the pods of some of the legumes are discarded before analysis. Foodstuff samples are prepared in such a way so as to minimise losses of activity during the analytical stage. Most shellfish samples are boiled soon after collection to minimise losses from the digestive gland. Although some activity may be lost, these generally reflect the effects of the normal cooking process for shellfish. Most other foodstuffs are analysed raw, as it is conceivable that all of the activity in the raw foodstuff could be consumed.

2.2.2 Measurement of dose rates and contamination

Measurements of gamma dose in air over intertidal and other areas are normally made at 1 m above the ground using Mini Instruments* environmental radiation meters type 680 and 690 with compensated Geiger-Muller tubes type MC-71. For certain key activities, for example for people living on houseboats or for wildfowlers lying on the ground, measurements at other distances from the ground may be made. External beta doses are measured on contact with the source, for example fishing nets, using Berthold* LB 1210B or Mini 900/EP 15* contamination monitors. These portable instruments are calibrated against recognised reference standards and the inherent instrument background is subtracted. There are two quantities that can be presented as measures of external gamma dose rate, total gamma dose rate or terrestrial gamma dose rate. Total gamma dose rate includes all sources external to the measuring instrument. Terrestrial gamma dose rate excludes cosmic sources of radiation but includes all others. In this report we have presented the total gamma dose rate. The PHE reports terrestrial gamma dose rates to SEPA. Terrestrial gamma dose rate is converted to total gamma dose rate by

* *The reference to proprietary products in this report should not be construed as an official endorsement of those products, nor is any criticism implied of similar products which have not been mentioned.*

the addition of 0.037 μGy h^{-1} which is an approximation of the contribution made by cosmic radiation (Her Majesty's Inspectorate of Pollution, 1995).

Beta/gamma monitoring of contamination on beaches or riverbanks is undertaken using similar instrumentation to that for measurements of dose rates. In England and Wales, a Mini Instruments series 900 mini monitor with a beach monitoring probe is used. The aim is to cover a large area including strand-lines where radioactive debris may become deposited. Any item found with activity levels in excess of the action levels is removed for analysis. An action level of 100 counts per second (equivalent to 0.01 mSv h^{-1}) is used in England and Wales. At Dounreay, in Scotland, and at Sellafield, in Cumbria, special monitoring procedures are in place due to the potential presence of radioactive particles on beaches. Further information regarding Dounreay and Sellafield is provided in the main report.

2.3 Presentation of results

The tables of monitoring results contain summarised values of observations obtained during the year under review. The data are generally rounded to two significant figures. Values near to the limits of detection will not have the precision implied by using two significant figures. Observations at a given location for radioactivity levels and dose rates may vary throughout the year. This variability may be due to changes in rates of discharge, different environmental conditions and uncertainties arising from the methods of sampling and analysis.

The method of presentation of the summarised results allows the data to be interpreted in terms of public radiation exposures for comparison with agreed safety standards.

For milk samples, the most appropriate quantity for use in assessments is the arithmetic mean in the year sampled for the farm where the highest single concentration is observed. This is labelled 'max' in the tables of results to distinguish it from the values that are averaged over a range of farms. For other terrestrial foods, an alternative approach is adopted since it is recognised that the possible storage of foods harvested during a particular time of the year has to be taken into account. Greater public exposures would be observed when foods are harvested at times when levels of contamination are high. For such foods, we have presented the maximum concentration observed of each radionuclide at any time in the relevant year well as the mean value. The maximum is labelled 'max' in the tables and forms the basis for the assessment of dose.

Results are presented for each location or source of supply where a sample is taken or a measurement is made. Sample collectors are instructed to obtain samples from the same location during the year. Spatial averaging is therefore not generally undertaken though it is inherent in the nature of some samples collected. A fish may move some tens of kilometres in an environment of changing concentrations in seawater, sediments and lower tropic levels. The resulting level of contamination therefore represents an average over a large area. Similarly cows providing milk at a farm may feed on grass and other fodder collected over a distance of a few kilometres of the farm. In the case of dose rate measurements, the position where the measurement is conducted is within a few metres of other measurements made within a year. Each observation consists of the mean of a number of instrument readings at a given location.

The numbers of farms that were sampled to provide information on activities in milk at nuclear sites are indicated in the tables of results. Milk samples collected weekly or monthly are generally bulked to provide four quarterly samples for analysis each year. For some radionuclides weekly, monthly or annual bulks are taken for analysis. Otherwise, the number of sampling observations in the tables of concentrations refers to the number of samples that were prepared for analysis during the year. In the case of small animals such as molluscs, one sample may include several hundred individual animals.

The number of sampling observations does not necessarily indicate the number of individual analyses conducted for a specific radionuclide. In particular, determinations by radiochemical methods are sometimes conducted less frequently than those by gamma-ray spectrometry. However, the results are often based on bulking of samples such that the resulting determination remains representative.

2.4 Detection limits

There are two main types of results presented in the tables (i) positive values and (ii) values preceded by a 'less than' symbol ("<"). Where the results are an average of more than one datum, and each datum is positive, the result is positive. Alternatively, where there is a mixture of data, or all data are at the LoD or Minimum Reporting Level (MRL), the result is preceded by a 'less than' symbol. Gamma-ray spectrometry can provide a large number of 'less than' results. In order to minimise the presentation of redundant information for gamma-ray spectrometry, 'less than' values are only reported for one, or more, of the following reasons: (i) the radionuclide is one which is in the relevant authorisation, (ii) it has been analysed by radiochemistry, (iii) it has been reported as being a positive value in that table in the previous 5 years, (iv) a positive result is detected in any other sample presented in the table in the relevant year. Naturally occurring radionuclides measured by gamma-ray spectrometry are not usually reported unless they are intended to establish whether there is any enhancement above the expected background levels.

Limits of detection are governed by various factors relating to the measurement method used and these are described in earlier reports (Ministry of Agriculture, Fisheries and Food, 1995). There are also a few results quoted as 'not detected' (ND) by the methods used. This refers to the analysts' judgement that there is insufficient evidence to determine whether the radionuclide is present or absent.

2.5 Additional information

The main aim of this report is to present all the results of routine monitoring from the programmes described previously. However, it is necessary to carry out some averaging for clarity and to exclude some basic data that may be of use only to those with particular research interests. Full details of the additional data are available from the environment agencies and the Food Standards Agency. Provisional results of concentrations of radionuclides in food samples collected in the vicinity of nuclear sites in England and Wales are published quarterly on the Food Standards Agency's website (www.food.gov.uk).

The main categories of additional data are:

- Data for individual samples prior to averaging
- Uncertainties in measurements
- Data for very short-lived radionuclides supported by longer-lived parents
- Data which are not relevant to a site's discharges for naturally-occurring radionuclides and for artificial radionuclides below detection limits
- Measurements conducted as part of the research programme described in Appendix 4 of the main report.

Very short-lived radionuclides such as yttrium-90, rhodium-103m, rhodium-106m, barium-137m and protactinium-234m (which are formed by decay of, strontium-90, ruthenium-103, ruthenium-106, caesium-137 and thorium-234, respectively) are taken into account when calculations of exposure are made. They are not listed in the tables of results. As a first approximation, their concentrations can be taken to be the same as those of their respective parents.

3. Assessment methods and data

3.1 Radiation protection standards

The monitoring results in this report are interpreted in terms of radiation exposures of the public, commonly termed 'doses'. This section describes the dose standards that apply in ensuring protection of the public.

Current UK practice relevant to the general public is based on the recommendations of the ICRP as set out in ICRP Publication 60 (International Commission on Radiological Protection, 1991). The dose standards are embodied in national policy on radioactive waste (United Kingdom - Parliament, 1995b) and in guidance from the IAEA in their Basic Safety Standards for Radiation Protection (International Atomic Energy Agency, 1996). Legislative dose standards are contained in the Basic Safety Standards Directive 96/29/ Euratom (Commission of the European Communities, 1996) and subsequently incorporated into UK law in the Ionising Radiations Regulations 1999 (United Kingdom - Parliament, 1999). In order to implement the Basic Safety Standards Directive, Ministers have provided the Environment Agency and SEPA with Directions concerning radiation doses to the public and their methods of estimation and regulation for all pathways (Department of the Environment, Transport and the Regions, 2000 and Scottish Executive, 2000). In Northern Ireland, regulations were made to implement the requirements of the BSS Directive in the Radioactive Substances (Basic Safety Standards) Regulations (Northern Ireland) 2003 (Northern Ireland Assembly, 2003). The methods and data used in this report are consistent with the Directions.

The ICRP issued revised recommendations for a system of radiological protection in 2007 (International Commission on Radiological Protection, 2007). PHE (formally HPA) have provided advice on the application of the ICRP 2007 recommendations to the UK (Health Protection Agency, 2009). Overall, they consider that the new recommendations do not imply any major changes to the system of protection applied in the UK. In particular, limits for effective and skin doses remain unchanged. Dose coefficients are also unchanged until such a time as new values are available and receive legislative endorsement.

International Commission on Radiological Protection (2007) 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'. The new term is equivalent to 'critical group' which has been used in previous RIFE reports. Where appropriate we have adopted the term 'representative person' in this report. The implications of the new ICRP recommendations in relation to the EU and UK radiation protection law and standards are being considered. For example the EU is updating the Basic Safety Standards Directive (Commission of the European Communities, 1996) and a draft Directive has been published (European Commission, 2010 and 2012a). Changes in EU and UK radioprotection law and standards will be taken into account for future issues of this report.

The relevant dose limits for members of the public are 1 mSv (millisievert) per year for whole-body (more formally 'committed effective') dose and 50 mSv per year specifically for skin. The latter limit exists to ensure that specific effects on skin due to external exposure are prevented. It is applicable, for example, in the case of handling of fishing gear. The dose limits are for use in assessing the impact of direct radiations and controlled releases (authorised discharges) from radioactive sources. These limits are appropriate for 'certain' exposure situations where the encounter with radioactivity is expected to occur. In situations where this is not certain, 'potential' exposure routes and standards are determined. These are discussed further by Dale *et al.* (2008) in relation to particles of radioactivity. Where contamination due to particles is known in the UK, a site-specific assessment is considered in the relevant section of the main report.

The mean dose received by the 'representative person' is compared with the dose limit. The term 'representative person' refers to those who are most exposed to radiation. In this report they are generally people who eat large quantities of locally harvested food (high-rate consumers) or who spend long periods of time in areas where radiation sources may exist. The limits apply to all age groups. Children may receive higher doses than adults because of their physiology, anatomy and dietary habits. The embryo/foetus can also receive higher doses than its mother. Consequently doses have been assessed for different age groups, i.e. adults, 10-year-old children, 1-year-old infants and prenatal children, and from this information it is possible to determine which of these age groups receives the highest doses.

For drinking water, the World Health Organisation (WHO) has provided screening levels to compare with the results of measurements of gross alpha and gross beta activity (World Health Organisation, 2004). The screening levels are 0.5 and 1.0 Bq l^{-1}, respectively, and are based on consideration of the dose that would result from radium-226 (alpha) and strontium-90 (beta) intakes. These were chosen as representative of the most radiotoxic radionuclides likely to be present in significant quantities. The values represent concentrations below which water can be considered potable without any further radiological examination. The Commission of the European Communities (CEC) has prepared a directive on the quality of water intended for human consumption, which includes parameters for tritium

(with a reference value of 100 Bq l^{-1}) and total indicative dose with a reference value of 0.1 mSv per year (Commission of the European Communities, 1998).

Accidental releases may be judged against EU and ICRP standards in emergency situations (Commission of the European Communities, 1989 and International Commission on Radiological Protection, 2007). In addition, it is Government policy that EU food intervention levels will be taken into account when setting discharge limits. Guidelines for radionuclides in foods following accidental radiological contamination for use in international trade has been published by the Codex Alimentarius Commission (Codex Alimentarius Commission, 2006).

The main focus of this report, and radiological regulation and monitoring more generally, is towards protection of man. However, ICRP in its 2007 recommendations has concluded that there is a need for a systematic approach for the radiological assessment of non-human species to support the management of radiation effects in the environment (International Commission on Radiological Protection, 2007). In its most recent publication concerning protection of the environment (International Commission on Radiological Protection, 2008), ICRP considers the use of a set of Reference Animals and Plants (RAPs) for dose assessments. Whilst this approach is being developed, no dose limits are proposed to apply. The Habitats Directive (Commission of the European Communities, 1992) requires a 3-stage approach to the assessment of the impact of radioactive discharges on sensitive habitats. Details are provided in Section 1 of the main text of this report.

The Commission of the European Communities has made a proposal for updating the Directive for basic safety standards for protection against the dangers arising from exposure to ionising radiation (European Commission, 2012d). This includes the requirement for member states to include provision for protection on non-human species in legal frameworks and for consideration of relevant monitoring. The Directive is expected to take effect in 2014 and subsequently transposed into UK law in due course.

3.2 Assessment methods

Calculations of exposures to members of the public in this report are primarily based on the environmental monitoring data for the year shown under study. The methods used have been assessed for conformity with the principles endorsed by the UK National Dose Assessment Working Group (Allott, 2005), and were found to be compatible (Camplin and Jenkinson, 2007). There are two types of dose assessment made. The first type gives an estimate of the *total dose* to people around the nuclear sites. It considers the effects of all sources, i.e. discharges of gaseous and liquid wastes and direct radiation from sources on the site premises (Camplin *et al.*, 2005). A flow diagram of the method is given as Figure X1.1.

The second type of assessment is focused on specific sources and their associated pathways. It serves as a check on the adequacy of the *total dose* assessment and is also compatible with the approach used prior to the introduction of total dose in 2004.

Total dose assessments include direct radiation. The estimates of direct radiation dose are provided by the HSE based on information supplied by industry (Walker, 2012). Both types of assessment provide information on two other main pathways:

- Ingestion of foodstuffs and
- External exposure from contaminated materials in the aquatic environment

Monitoring data are also used to assess doses from pathways, which are generally of lesser importance:

- Drinking water
- Inadvertent ingestion of water and sediments and
- Inhalation of resuspended soil and sediment

In addition, models are used to supplement the monitoring data in four situations:

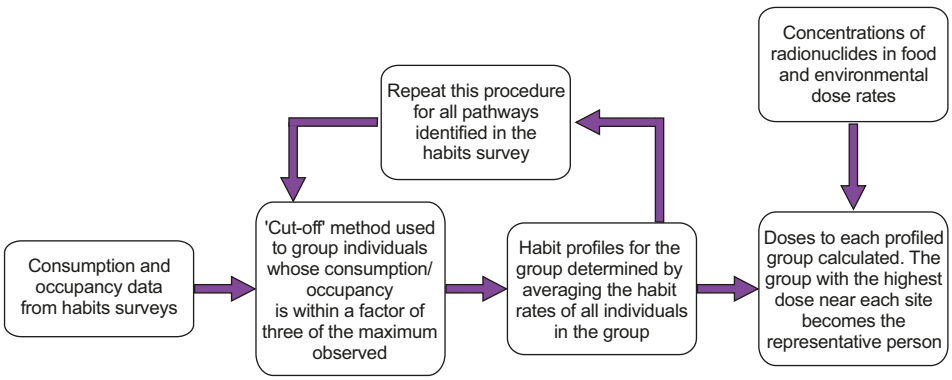


Figure X1.1. Steps in the *total dose* methodology

- Atmospheric dispersion models are used for non-food pathways where monitoring is not an effective method of establishing concentrations or dose rates in the environment.
- Food chain models provide additional data to fill gaps and to adjust for high-limits of detection and
- Modelling of exposures of sewage workers is undertaken for discharges from Aldermaston, Amersham and Cardiff
- Modelling of exposures from the use of sewage sludge pellets at Cardiff

Full details are given in Annex 1.

For pathways involving intakes of radionuclides, the data required for assessment are:

- Concentrations in foodstuffs, drinking water sources, sediments or air
- The amounts eaten, drunk or inhaled
- The dose coefficients that relate an intake of activity to a dose

For external radiation pathways, the data required are:

- The dose rate from the source, for example a beach or fishermen's nets, and
- The time spent near the source

In both cases, the assessment estimates exposures from these pathways for people who are likely to be most exposed.

3.3 Concentrations of radionuclides in foodstuffs, drinking water sources, sediments and air

In nearly all cases, the concentrations of radionuclides are determined by monitoring and are given in the main text of this report. The concentrations chosen for the assessment are intended to be representative of the intakes of the most exposed consumers in the population. All of the positively determined concentrations tabulated are included irrespective of the origin of the radionuclide. In some cases, this means that the calculated exposures could include contributions due to disposals from other sites as well as from weapon test fallout and activity deposited following the Chernobyl accident. Where possible, corrections for background concentrations of naturally-occurring radionuclides are made in the calculations of dose (see Section 3.7).

For aquatic foodstuffs, drinking water sources, sediments and air, the assessment is based on the mean concentration near the site in question. For milk, the mean concentration at a nearby farm with the highest individual result is used in the dose assessment. This procedure accounts for the possibility that any farm close to a site can act as the sole source of supply of milk to high-rate consumers.

For other foodstuffs, the maximum concentrations are selected for the assessment. This allows for the possibility of storage of food harvested at a particular time when the peak levels in a year may have been present in the environment.

The tables of concentrations include 'less than' values as well as positive determinations. This is particularly evident for gamma-ray spectrometry of terrestrial foodstuffs. Where a result is presented as a 'less than' value, the dose assessment methodology treats it as if it were a positive determination as follows: (i) when that radionuclide is specified in the relevant authorisation (gaseous or liquid), (ii) when that radionuclide was determined using radiochemical methods or (iii) when a positive result is reported for that radionuclide in another sample from the same sector of the environment at the site (aquatic or terrestrial). Although this approach may produce an overestimation of dose, particularly at sites where levels are low, it ensures that estimated exposures are unlikely to be understated.

3.4 Consumption, drinking and inhalation rates

3.4.1 Source specific assessments

In the assessment of the effects of disposals of liquid effluents, the amounts of fish and shellfish consumed are determined by site-specific dietary habit surveys. Data are collected primarily by direct interviews with potential high-rate consumers who are often found in fishing communities. Children are rarely found to eat large quantities of seafood and their resulting doses are invariably less than those of adults. The calculations presented in this report are therefore representative of adult seafood consumers or their unborn children if the foetal age group is more restrictive.

In assessments of terrestrial foodstuffs, the amounts of food consumed are derived from national surveys of diet and are defined for three ages: adults, 10-year-old children and 1-year-old infants (based on Byrom *et al.*, 1995). Adult consumption rates are used in the assessment of foetal doses. For each food type, consumption rates at the 97.5th percentile of consumers have been taken to represent the people who consume a particular foodstuff at a high level (the 'representative person' consumption rate).

Drinking and inhalation rates are general values for the population, adjusted according to the times spent in the locations being studied.

The consumption, drinking and inhalation rates are given in Annex 2. Estimates of dose are based on the most up to date information available at the time of writing the report. Where appropriate, the data from site-specific surveys are averaged over a period of 5 years following the recommendation of the report of the Consultative Exercise on Dose Assessments (CEDA) (Food Standards Agency, 2001a).

The assessment of terrestrial foodstuffs is based on two assumptions: (i) that the foodstuffs eaten by the most exposed individuals are those that are sampled for the purposes of monitoring; and (ii) that the consumption of such foodstuffs is sustained wholly by local sources. The two food groups resulting in the highest dose are taken to be consumed at 'high level' consumption rates, while the remainder are consumed at mean rates. The choice of two food groups at the higher consumption rates is based on statistical analysis of national diet surveys. This shows that only a very small percentage of the population were critical rate consumers in more than two food groups (Ministry of Agriculture, Fisheries and Food, 1996). Locally grown cereals are not considered in the assessment of exposures as it is considered highly unlikely that a significant proportion of cereals will be made into locally consumed (as opposed to nationally consumed) foodstuffs, notably bread.

3.4.2 *Total dose* assessments

The *total dose* assessments are based on consumption and occupancy data collected from site specific surveys which are targeted at those most likely to be exposed around the site. The habit profiles that give rise to the highest doses in the assessment of RIFE data are given in files on the CD accompanying this report. Care should be taken in using these data in other circumstances because the profile leading to the highest doses may change if the measured or forecast concentrations and dose rates change.

3.5 Dose coefficients

Dose calculations for intakes of radionuclides by ingestion and inhalation are based on dose coefficients taken from ICRP Publication 72 (International Commission on Radiological Protection, 1996a), ICRP Publication 88 (International Commission on Radiological Protection, 2001) and National Radiological Protection Board (2005).

These coefficients (often referred to as 'dose per unit intake') relate the committed dose received to the amount of radioactivity ingested or inhaled. The dose coefficients used in this report are provided in Annex 3 for ease of reference.

Calculations are performed for four ages: adults, 10-year-old children, 1-year-old infants and prenatal children as appropriate to the pathways being considered. The prenatal age group was introduced following the publication of recommendations by the National Radiological Protection Board in 2005 (National Radiological Protection Board, 2005). We have assumed that the 'representative person' is pregnant in order for the dose assessment of the embryo and foetus to be valid. This assumption is considered reasonable in the context of making comparisons with dose limits because it is difficult to demonstrate otherwise. When applied in practice, the doses estimated for the prenatal group are rarely larger than the values for other age groups.

The dose assessments include the use of appropriate gut uptake factors (proportion of radioactivity being absorbed from the digestive tract). Where there is a choice of gut uptake factors for a radionuclide, we have generally chosen the one that gives the highest predicted exposure. In particular where results for total tritium are available, we have assumed that the tritium content is wholly in an organic form. However, we have also taken into account specific research work of relevance to the foods considered in this report. This affects the assessments for tritium, polonium, plutonium and americium radionuclides as discussed in Annex 3.

3.6 External exposure

In the assessment of external exposure, there are two factors to consider: (i) the dose rate from the source and (ii) the time spent near the source. In the case of external exposure to penetrating gamma radiation, uniform whole body exposure has been assumed. The radiation as measured is in terms of the primary quantity known as 'air kerma rate', a measure of the energy released when the radiation passes through air. This has been converted into exposure using the factor 1 milligray = 0.85 millisievert (International Commission on Radiological Protection, 1996b). This factor applies to a rotational geometry with photon energies ranging from 50 keV to 2 MeV. This is appropriate for the instrument used whose sensitivity is much reduced below 50 keV, and to the geometry of deposits of artificial radionuclides. Applying an isotropic geometry gives a value of 0.70 Sv Gy^{-1} which would be more appropriate for natural background radiation. The choice of 0.85 will therefore tend to overestimate dose rates for the situations considered in this report which include both artificial and natural radiation.

For external exposure of skin, the measured quantity is contamination in Bq cm^{-2}. In this case, dose rate factors in Sv y^{-1} per Bq cm^{-2} are used, which are calculated for a depth in tissue of 7 mg cm^{-2} (Kocher and Eckerman, 1987). The times spent near sources of external exposure are determined by site-specific habits surveys in a similar manner to consumption rates of seafood. The occupancy and times spent handling fishing gear are given in Annex 2.

3.7 Subtraction of 'background levels'

When assessing internal exposures due to ingestion of carbon-14, and radionuclides in the uranium and thorium decay series, in seafood, concentrations due to natural background levels are subtracted. Background carbon-14 concentrations in terrestrial foods are also subtracted. The estimates of background concentrations are given in Annex 4. When assessing the man-made effect on external exposures to gamma radiation, dose rates due to background levels are subtracted. On the basis of measurements made previously as part of the programmes reported here, the gamma dose rate backgrounds in the aquatic environment are taken to be 0.05 μGy h^{-1} for sandy substrates, 0.07 μGy h^{-1} for mud and salt marsh and 0.06 μGy h^{-1} for other substrates. These

data are compatible with those presented by McKay *et al.* (1995). However, where it is difficult to distinguish the result of a dose rate measurement from natural background, the method of calculating exposures based on the concentrations of man-made radionuclides in sediments is used (Hunt, 1984). Estimates of external exposures to beta radiation include a component due to naturally-occurring (and un-enhanced) sources because of the difficulty in distinguishing between naturally-occurring and man-made contributions. Such estimates are therefore conservative when compared with the relevant dose limit that excludes natural sources of radiation.

3.8 Uncertainties in dose assessment

Various methods are used to reduce the uncertainties in the process of dose estimation for critical groups from monitoring programmes. These address the following main areas of concern:

- Programme design
- Sampling and *in situ* measurement
- Laboratory analysis
- Description of pathways to man
- Radiation dosimetry
- Calculational and presentational error

Quantitative estimation of uncertainties in doses is beyond the scope of this report.

4. References

References for Appendix 1 are given in Section 10 of the main report.

Annex 1. Modelling of concentrations of radionuclides in foodstuffs, air and sewage systems

A1.1 Foodstuffs

At Sellafield, the LLWR near Drigg, Ravenglass and the Isle of Man, a simple food chain model has been used to provide concentrations of activity in milk and livestock for selected radionuclides to supplement data obtained by direct measurements. This is done where relatively high limits of detection exist or where no measurements were made.

Activities in milk, meat and offal were calculated for technetium-99, ruthenium-106, cerium-144, promethium-147 and plutonium-241 using the equations:

$$C_m = F_m Ca\, Q_f \quad \text{and}$$
$$C_f = F_f\, Ca\, Q_f \quad \text{where}$$

C_m *is the concentration in milk (Bq l^{-1}),*
C_f *is the concentration in meat or offal (Bq kg^{-1} (fresh)),*
F_m *is the fraction of the animal's daily intake by ingestion transferred to milk (d l^{-1})*
F_f is the fraction of the animal's daily intake by ingestion transferred to meat or offal (d kg^{-1} (fresh)),
Ca is the concentration in fodder (Bq kg^{-1} (dry)),
Q_f is the amount of fodder eaten per day (kg (dry) d^{-1})

No direct account is taken of radionuclide decay or the intake by the animal of soil associated activity. The concentration in fodder is assumed to be the same as the maximum observed concentration in grass or, in the absence of such data, in leafy green vegetables. The food chain data for the calculations are given in Table X1.1 (Simmonds *et al.*, 1995; Brenk *et al.*, unpublished) and the estimated concentrations in milk, meat and offal are presented in Table X1.2.

The Cardiff East Waste Water Treatment Works provides dried sludge pellets, containing elevated concentrations of tritium, to farms for use as a soil conditioner. The transfer of tritium from treated soil into crops is a potential pathway of exposure. An FSA-funded research project (Ham *et al.*, 2007) estimated the aggregated transfer quotient, relating the concentration in the edible part of the crop to the amount of activity applied to the soil, to be approximately 2 x 10^{-4}. This assumed a conservative application rate of 2 kg m^{-2}. These values can be used to perform an assessment of exposure from consuming foodstuffs grown in soil conditioned with sludge pellets near Cardiff.

A1.2 Air

For some sites, discharges to air can lead to significant doses. Doses may arise from radionuclides transferred from the plume to food crops and animal products, inhalation of radionuclides in the plume itself and external doses from radionuclides in the plume.

Average annual concentrations of radionuclides in the air at nearest habitations were calculated using a Gaussian plume model, PC CREAM (Smith *et al.*, 2009), and the reported discharges of radionuclides to air. Site-specific meteorological data were used in the assessments. The key modelling assumptions (i.e. discharge height, habitations) are shown in Table X1.3.

External radiation doses from radionuclides in the plume and from deposited activity were calculated taking into account occupancy indoors and outdoors and location factors to allow for building shielding. During the time people are assumed to be indoors, the standard assumption that the dose from gamma-emitting radionuclides in the plume will be reduced by 80 per cent (i.e. shielding factor of 0.2) has been made. Internal radiation doses from inhalation of discharged radionuclides were assessed using breathing rates. Doses were initially assessed for three age groups: infants (1y), children (10 y) and adults. All ages are assumed to have year-round occupancy at the nearest habitation. The inhalation and occupancy rates assumed in this assessment are shown in Table X1.4. The dose to the foetal age group was taken to be the same as that for an adult.

A1.3 Sewage systems

The facilities at Aldermaston, Amersham and Cardiff discharge liquid radioactive waste to local sewers. Wastes are processed at local Sewage Treatment Works (STW). The prolonged proximity to raw sewage and sludge experienced by sewage treatment workers could lead to an increase in the dose received, via a combination of external irradiation from the raw sewage and sludge and the inadvertent ingestion and inhalation of resuspended radionuclides.

An assessment of the dose received by workers at the Maple Lodge STW, near Amersham, the Silchester STW near Aldermaston and at the Cardiff East Waste Water Treatment Works (WWTW) has been conducted using the methodology and data given in Environment Agency (2006a,b). The flow rate through the sewage works are used to calculate a mean concentration in raw sewage and sludge of each nuclide discharged. These mean concentrations are combined with habits data concerning the workers' occupancy near raw sewage and sludge, external and internal dosimetric data, and physical data such as inhalation rates to provide estimates of dose. Workers are assumed to spend 75 per cent of a working year in proximity to the raw sewage, and the other 25 per cent in proximity to the sewage sludge. Where liquid discharges

are not nuclide-specific, a composition has been assumed based on advice from the operators and concentrations calculated accordingly.

The model parameters and habits data used to assess the dose to sewage treatment workers are given in Table X1.5, and the amounts of radioactivity discharged from each site can be found in Appendix 2 of the main report.

Table X1.1. Data for food chain model

Parameter	Nuclide	Food				
		Milk	Beef	Beef offal	Sheep	Sheep offal
Q_f		13	13	13	1.5	1.5
F_m or F_f	^{99}Tc	10^{-2}	10^{-2}	$4\ 10^{-2}$	10^{-1}	$4\ 10^{-1}$
	^{106}Ru	10^{-6}	10^{-3}	10^{-3}	10^{-2}	10^{-2}
	^{144}Ce	$2\ 10^{-5}$	10^{-3}	$2\ 10^{-1}$	10^{-2}	2
	^{147}Pm	$2\ 10^{-5}$	$5\ 10^{-3}$	$4\ 10^{-2}$	$5\ 10^{-2}$	$3\ 10^{-1}$
	^{241}Pu	10^{-6}	10^{-4}	$2\ 10^{-2}$	$4\ 10^{-4}$	$3\ 10^{-2}$

Table X1.2. Predicted concentrations of radionuclides from food chain model used in assessments of exposures

Foodstuff	Location	Radioactivity concentration (fresh weight), Bq kg^{-1}			
		^{99}Tc	^{106}Ru	^{144}Ce	^{241}Pu
Milk	Sellafield	[a]	$7.2\ 10^{-5}$	[b]	$5.6\ 10^{-6}$
	Ravenglass	[a]	$1.8\ 10^{-4}$	$2.4\ 10^{-3}$	$3.1\ 10^{-5}$
	LLWR near Drigg	[a]	$2.0\ 10^{-4}$	$2.6\ 10^{-3}$	$1.4\ 10^{-5}$
	Isle of Man	[a]	$1.9\ 10^{-4}$	[b]	$1.2\ 10^{-5}$
Beef	Sellafield	[a]	$7.2\ 10^{-2}$	[b]	$5.6\ 10^{-4}$
	Ravenglass	[a]	$1.8\ 10^{-1}$	$1.2\ 10^{-1}$	$3.1\ 10^{-3}$
	LLWR near Drigg	$3.3\ 10^{-1}$	$2.0\ 10^{-1}$	$1.3\ 10^{-1}$	$1.4\ 10^{-3}$
	Isle of Man	$3.8\ 10^{-2}$	$1.9\ 10^{-1}$	[b]	$1.2\ 10^{-3}$
Sheep	Sellafield	[a]	$8.3\ 10^{-2}$	[b]	$2.6\ 10^{-4}$
	Ravenglass	[a]	$2.1\ 10^{-1}$	$1.4\ 10^{-1}$	[a]
	LLWR near Drigg	[a]	$2.3\ 10^{-1}$	$1.5\ 10^{-1}$	$6.3\ 10^{-4}$
	Isle of Man	$4.4\ 10^{-2}$	$2.2\ 10^{-1}$	[b]	$5.8\ 10^{-4}$
Beef offal	Sellafield	[a]	$7.2\ 10^{-2}$	[b]	[a]
	Ravenglass	[a]	$1.8\ 10^{-1}$	[a]	[a]
	LLWR near Drigg	$1.3\ 10^{0}$	$2.0\ 10^{-1}$	$2.6\ 10^{1}$	$2.7\ 10^{-1}$
	Isle of Man	$1.5\ 10^{-1}$	$1.9\ 10^{-1}$	[b]	$2.5\ 10^{-1}$
Sheep offal	Sellafield	[a]	$8.3\ 10^{-2}$	[b]	$2.0\ 10^{-2}$
	Ravenglass	[a]	$2.1\ 10^{-1}$	[a]	$1.1\ 10^{-1}$
	LLWR near Drigg	[a]	$2.3\ 10^{-1}$	[a]	$4.7\ 10^{-2}$
	Isle of Man	$1.8\ 10^{-1}$	$2.2\ 10^{-1}$	[b]	$4.3\ 10^{-2}$

[a] *Positive result used, or LoD result used because modelling result greater than LoD*
[b] *No grass or leafy green vegetable data available*

Table X1.3. Air concentrations modelling assumptions

Nuclear site	Stack height, m	Estimated site diameter, km	Estimated distance from stack to nearest habitation, km	Frequency of Pasquill stability category D
Aldermaston	15	2	0.3	60
Amersham	20	1	0.3	55
Berkeley	20	1.6	0.4	55
Bradwell	14	0.4	0.3	65
Burghfield	15	0.6	0.3	60
Capenhurst	15	1.1	0.3	65
Cardiff	20	0.4	0.4	60
Chapelcross	30	1.2	0.7	60
Derby	50	0.5	0.5	55
Devonport	15	1	0.3	65
Dounreay	15	1	1	75
Dungeness	17	1	0.3	70
Hartlepool	23	0.6	2	70
Harwell	20	1	0.2	55
Heysham	21	1	0.5	70
Hinkley	21	0.8	1	55
Hunterston	15	0.4	0.4	60
Oldbury	20	0.8	0.7	55
Sellafield	93	2	0.5	65
Sizewell	18	0.4	1	70
Springfields	27	1	0.3	70
Torness	72	0.5	0.6	70
Trawsfynydd	18	0.6	0.6	70
Winfrith	15	1.6	0.4	60
Wylfa	17	1	0.4	70

Table X1.4. Inhalation and occupancy data for dose assessment of discharges to air

Age group, y	Inhalation rates, $m^3\ h^{-1}$	Fraction of time indoors
1	0.22	0.9
10	0.64	0.8
Adult	0.92	0.7

Table X1.5. Sewage workers dose assessment modelling assumptions and occupancy data

Flow rate, $m^3\ d^{-1}$	Aldermaston (Silchester STW)	$6.7\ 10^{3}$[a]
	Amersham (Maple Lodge STW)	$1.5\ 10^{5}$[b]
	Cardiff (Cardiff East WWTW)	$2.6\ 10^{4}$[c]
Occupancy - sewage, $h\ y^{-1}$		1380
Occupancy - sludge, $h\ y^{-1}$		460[d]
Inadvertent ingestion rate, $kg\ h^{-1}$		$5\ 10^{-6}$[e]
Inhalation rate, $m^3\ h^{-1}$		1.2[e]
Airborne concentration of sewage or sludge, $kg\ m^{-3}$		$1\ 10^{-7}$[e]
Density of raw sewage and treated sludge, $kg\ l^{-1}$		1[e]

[a] *Based on average flow rate of 0.078 $m^3\ s^{-1}$ (Dick, 2012)*
[b] *Based on average flow rate of 1.8 $m^3\ s^{-1}$ (Jobling et al., 2006)*
[c] *Based on an average flow rate of 0.3 $m^3\ s^{-1}$, this has been derived as 5% of the maximum flow rate at the works (McTaggart, 2003)*
[d] *A working year is assumed to be 40 hours per week and 48 weeks per year*
[e] *Parameter values used in Environment Agency methodology (see text for reference)*

Annex 2. Consumption, inhalation, handling and occupancy rates

This annex gives the consumption, handling and occupancy rate data used in the source specific assessment of exposures from terrestrial consumption and aquatic pathways. Consumption rates for terrestrial foods are based on Byrom *et al.* (1995) and are given in Table X2.1. These are derived from national statistics and are taken to apply at each site. Site-specific data for aquatic pathways based on local surveys are given in Table X2.2. The site-specific data has been supplemented with generic information from Environment Agency (2002a) and Smith and Jones (2003) where appropriate. Occupancy over intertidal areas and rates of handling from local surveys has been reassessed to take account of a change in the factor used to determine the range of rates typical of those most exposed. Previously, when using the 'cut-off' method to define those most exposed (Hunt *et al.*, 1982; Preston, *et al.*, 1974), a factor of 1.5 was used to describe the ratio of the maximum to the minimum rate within the group. From 2002, sites in England and Wales with new local surveys were adjusted to adopt a factor of 3.0 to make the selection process consistent with that used for consumption pathways. From 2003, all sites in Scotland were adjusted. Data used for routine assessments of external and inhalation pathways from gaseous discharges are given in Annex 1.

Consumption rates refer to the mass of a foodstuff as prepared for consumption (with, for example, stalks or shells removed) and are consistent with the mass quantity used for presentation of concentration data in this report. The term 'fresh weight' is used in the data tables of concentrations. For shellfish, the consumption rates and concentrations are for cooked weights. For other foodstuffs, uncooked weights are used.

Table X2.1. Consumption rates for terrestrial foods

Food Group	Consumption rates (kg y^{-1})					
	Average			Above average consumption rate*		
	Adult	10 year old	Infant	Adult	10 year old	Infant
Beef	15	15	3	45	30	10
Cereals	50	45	15	100	75	30
Eggs	8.5	6.5	5	25	20	15
Fruit	20	15	9	75	50	35
Game	6	4	0.8	15	7.5	2.1
Green vegetables	15	6	3.5	45	20	10
Honey	2.5	2	2	9.5	7.5	7.5
Legumes	20	8	3	50	25	10
Milk	95	110	130	240	240	320
Mushrooms	3	1.5	0.6	10	4.5	1.5
Nuts	3	1.5	1	10	7	2
Offal	5.5	3	1	20	10	5.5
Pig	15	8.5	1.5	40	25	5.5
Potatoes	50	45	10	120	85	35
Poultry	10	5.5	2	30	15	5.5
Root crops	10	6	5	40	20	15
Sheep	8	4	0.8	25	10	3
Wild fruit	7	3	1	25	10	2

* *These rates are the 97.5th percentile of the distribution across all consumers*

Table X2.2. Consumption, inhalation, handling and occupancy rates for aquatic pathways

Site (Year of Last Survey)	Group[a]	Rates
Aldermaston (2011)		1 kg y^{-1} pike
		660 h y^{-1} over riverbank
Amersham (2009)		1 kg y^{-1} pike
		1100 h y^{-1} over riverbank
Barrow (2012)	A	27 kg y^{-1} fish
		12 kg y^{-1} crabs and lobsters
		5.9 kg y^{-1} molluscs
		760 h y^{-1} over mud and sand
	B (houseboats)	2800 h y^{-1} over mud and sand
Berkeley and Oldbury (2007)		14 kg y^{-1} eels and other fish
		2.7 kg y^{-1} shrimps
		900 h y^{-1} over mud, stones and saltmarsh
Bradwell (2007)		25 kg y^{-1} fish
		1.1 kg y^{-1} crabs and lobsters
		2.9 kg y^{-1} Pacific and European oysters
		3100 h y^{-1} over mud
Capenhurst (2008)	10 year old children	500 h y^{-1} over sediment
		5 10^{-3} kg y^{-1} sediment by inadvertent ingestion
		20 l y^{-1} water by inadvertent ingestion
Cardiff	A (2003)	24 kg y^{-1} fish
		3.8 kg y^{-1} prawns and lobster
		500 h y^{-1} over mud
	B (NA)	500 h y^{-1} over bank of River Taff
		2.5 10^{-3} kg y^{-1} sediment by inadvertent ingestion
		34 l y^{-1} water by inadvertent ingestion
	C (2003)	5.6 kg y^{-1} wildfowl
Channel Islands (1997)		62 kg y^{-1} fish
		30 kg y^{-1} crabs, spider crabs and lobsters
		30 kg y^{-1} scallops and whelks
		1400 h y^{-1} over mud and sand
Chapelcross (2010)	A	8.7 kg y^{-1} salmonids
		31 kg y^{-1} wildfowl
		720 h y^{-1} over mud and salt marsh
	B	15 kg y^{-1} shrimps
	C	390 h y^{-1} handling nets
		610 h y^{-1} handling sediment
Clyde (small users) (NA)		20 kg y^{-1} molluscs
Culham (NA)		600 l y^{-1} water
Derby (2009)		600 l y^{-1} water
		1 kg y^{-1} pike
		610 h y^{-1} over riverbank
Devonport (2011)	A	30 kg y^{-1} fish
		2.4 kg y^{-1} crabs
		0.1 kg y^{-1} queen scallops
		400 h y^{-1} over mud, sand and stones
	B	2100 h y^{-1} over mud
Dounreay (2008)	A	1700 h y^{-1} handling fishing gear
	B	18 kg y^{-1} fish
		21 kg y^{-1} crab and lobster
		2.1 kg y^{-1} winkles and mussels
		470 h y^{-1} over sand
	C	8 h y^{-1} in a Geo
LLWR near Drigg	NA	35 l y^{-1} water
	2012	Marine pathways as Sellafield
Drinking water (NA)	Adults	600 l y^{-1}
	10 y	350 l y^{-1}
	1 y	260 l y^{-1}

Table X2.2. continued

Site (Year of Last Survey)	Group[a]	Rates
Dungeness (2010)	A	87 kg y^{-1} fish
		11 kg y^{-1} crabs and shrimps
		11 kg y^{-1} king scallops
		900 h y^{-1} over mud and sand
	B (Rye Harbour houseboats)	2000 h y^{-1} over mud
Faslane (2011)		19 kg y^{-1} fish
		1.2 kg y^{-1} winkles
		160 h y^{-1} sand and stones
Hartlepool (2008)	A	28 kg y^{-1} fish
		19 kg y^{-1} crab and lobster
		5.8 kg y^{-1} winkles and whelks
		600 h y^{-1} over sand
	B	1200 h y^{-1} over sand and sea coal
Harwell (2007)		1.1 kg y^{-1} fish
		1.1 kg y^{-1} crayfish
		420 h y^{-1} over riverbank
Heysham (2011)	A	27 kg y^{-1} fish
		11 kg y^{-1} shrimps
		6.7 kg y^{-1} cockles and mussels
		750 h y^{-1} over sand
	B	510 h y^{-1} over salt marsh
Hinkley Point (2010)		14 kg y^{-1} fish
		13 kg y^{-1} shrimps
		0.8 kg y^{-1} whelks
		1000 h y^{-1} over mud
Holy Loch (1989)		730 h y^{-1} over mud
Hunterston (2012)		11 kg y^{-1} fish
		12 kg y^{-1} *Nephrops* and other crustaceans
		11 kg y^{-1} king scallops and oysters
		440 h y^{-1} over sand
Landfill (NA)		2.5 l y^{-1} water
Rosyth (2010)		17 kg y^{-1} fish
		4.6 kg y^{-1} crabs and lobsters
		5.8 kg y^{-1} winkles
		510 h y^{-1} over mud and sand
Sellafield	A (Sellafield fishing community) (2012)	37 kg y^{-1} cod (25%) and other fish (75%)
		29 kg y^{-1} crab (30%), lobster (20%) and *Nephrops* (50%)
		9.1 kg y^{-1} winkles (60%) and other molluscs (40%)
		850 h y^{-1} over mud and sand
	B (Fishermen's nets and pots) (2012)	1200 h y^{-1} handling nets and pots
	C (Bait digging and mollusc collecting) (2012)	710 h y^{-1} handling sediment
	D (Whitehaven commercial) (1998)	40 kg y^{-1} plaice and cod
		9.7 kg y^{-1} *Nephrops*
		15 kg y^{-1} whelks
	E (Morecambe Bay)	see Heysham
	F (Fleetwood) (1995)	93 kg y^{-1} plaice and cod
		29 kg y^{-1} shrimps
		23 kg y^{-1} whelks
	G (Dumfries and Galloway) (2012)	18 kg y^{-1} fish
		15 kg y^{-1} crabs and other crustaceans
		19 kg y^{-1} winkles and other molluscs
		31 kg y^{-1} wildfowl
		600 h y^{-1} over mud and salt marsh
	H (Laverbread) (1972)	47 kg y^{-1} laverbread
	I (Typical fish consumer) (NA)	15 kg y^{-1} cod and plaice
	J (Isle of Man) (NA)	100 kg y^{-1} fish
		20 kg y^{-1} crustaceans
		20 kg y^{-1} molluscs
	K (Northern Ireland) (2000)	99 kg y^{-1} haddock and other fish
		34 kg y^{-1} *Nephrops* and crabs
		7.7 kg y^{-1} mussels and other molluscs
		1100 h y^{-1} over mud and sand

Table X2.2. continued

Site (Year of Last Survey)	Group[a]	Rates
	L (North Wales) (NA)	100 kg y^{-1} fish
		20 kg y^{-1} crustaceans
		20 kg y^{-1} molluscs
		300 h y^{-1} over mud and sand
	M (Sellafield fishing community 2008-2012) (NA)	9.9 kg y^{-1} cod
		30 kg y^{-1} other fish
		9.4 kg y^{-1} crabs
		6.4 kg y^{-1} lobsters
		6.4 kg y^{-1} *Nephrops*
		9.9 kg y^{-1} winkles
		11 kg y^{-1} other molluscs
		890 h y^{-1} over mud and sand
	N (Typical recreational use over beaches, muddy areas or salt marsh) (NA)	300 h y^{-1} over intertidal substrates
	O (Typical beach user e.g. tourist) (NA)	1 kg y^{-1} fish
		0.2 kg y^{-1} crustaceans
		0.2 kg y^{-1} molluscs
		30 h y^{-1} over sand
	P (Ravenglass marsh users) (2012)	310 h y^{-1} over salt marsh
		5.0 10^{-6} kg y^{-1} mud by inadvertent ingestion
		9.2 10^{-8} kg y^{-1} mud by resuspension and inhalation
Sizewell (2010)	A	28 kg y^{-1} fish
		14 kg y^{-1} crab and lobster
		4.2 kg y^{-1} whelks
		280 h y^{-1} over mud
	B (houseboats)	3000 hy^{-1} over mud
Springfields	A (2012)	10 kg y^{-1} fish
		7.2 kg y^{-1} shrimps
		0.8 kg y^{-1} cockles
		530 h y^{-1} over mud and sand
	B (2012)	340 h y^{-1} handling nets
	C (Ribble Estuary houseboats) (2008-2012)	3600 h y^{-1} over mud
	D (10 year old children) (NA)	30 h y^{-1} over mud
		1.0 10^{-5} kg y^{-1} mud by inadvertent ingestion
		6.3 10^{-8} kg y^{-1} mud by resuspension and inhalation
	E (Farmers) (2012)	900 h y^{-1} over salt marsh
	F (Wildfowlers) (2012)	14 kg y^{-1} wildfowl
		140 h y^{-1} over mud
Torness (2011)	A	33 kg y^{-1} fish
		10 kg y^{-1} crab and lobster
		12 kg y^{-1} winkles
		690 h y^{-1} over sand and stones
	B	1500 h y^{-1} handling fishing gear
Trawsfynydd (2005)		1.3 kg y^{-1} brown trout
		60 kg y^{-1} rainbow trout
		450 h y^{-1} over lake shore
Upland lake (NA)		37 kg y^{-1} fish
Whitehaven (phosphate processing) (2012)		Marine pathways as Sellafield
Winfrith (2003)		40 kg y^{-1} fish
		15 kg y^{-1} crabs and lobsters
		14 kg y^{-1} scallops and whelks
		300 h y^{-1} over sand and stones
Wylfa (2009)		29 kg y^{-1} fish
		16 kg y^{-1} crabs, lobsters and prawns
		6.9 kg y^{-1} mussels
		390 h y^{-1} over mud and sand

[a] *Where more than one group exists at a site the groups are denoted A, B etc. Year of habits survey is given where appropriate*
NA Not appropriate

Annex 3. Dosimetric data

The dose coefficients used in assessments in this report are provided in Table X3.1 for ease of reference. For adults and postnatal children they are based on generic data contained in International Commission on Radiological Protection Publication 72 (International Commission on Radiological Protection, 1996a). Doses for prenatal children have been obtained primarily from ICRP 88 (International Commission on Radiological Protection, 2001) and National Radiological Protection Board (2005). For a few radionuclides where prenatal dose coefficients are unavailable the relevant adult dose coefficient has been used.

In the case of tritium, polonium, plutonium and americium radionuclides, dose coefficients have been adjusted according to specific research work of relevance to assessments in this report.

A3.1 Polonium

The current ICRP advice is that a gut uptake factor of 0.5 is appropriate for dietary intakes of polonium by adults (International Commission on Radiological Protection, 1994). A study involving the consumption of crab meat containing natural levels of polonium-210 has suggested that the factor could be as high as 0.8 (Hunt and Allington, 1993). More recently, similar experiments with mussels, cockles and crabs suggested a factor in the range 0.15 to 0.65, close to the ICRP value of 0.5 (Hunt and Rumney, 2004 , 2005 and 2007). Previous assessments have considered the effects of a factor of 0.8 when considering monitoring results in RIFE. In view of the most recent review (Hunt and Rumney, 2007), a value of 0.5 has been adopted for all food, consistent with the ICRP advice.

A3.2 Plutonium and americium

Studies using adult human volunteers have suggested a gut uptake factor of 0.0002 is appropriate for the consumption of plutonium and americium in winkles from near Sellafield (Hunt *et al.*, 1986, 1990). For these and other actinides in food in general, PHE (formally NRPB) considers a factor of 0.0005 to be a reasonable best estimate (National Radiological Protection Board, 1990) to be used when data for the specific circumstances under consideration are not available. In this report, when estimating doses to consumers of winkles from Cumbria, a gut uptake factor of 0.0002 is used for plutonium and americium and this is consistent with PHE advice. For other foods and for winkles outside Cumbria, the factor of 0.0005 is used for these radioelements. This choice is supported by studies of cockle consumption (Hunt, 1998).

A3.3 Technetium-99

Volunteer studies have been extended to consider the transfer of technetium-99 in lobsters across the human gut (Hunt *et al.*, 2001). Although values of the gut uptake factor found in this study were lower than the ICRP value of 0.5, dose coefficients are relatively insensitive to changes in the gut uptake factor. This is because the effective dose is dominated by 'first pass' dose to the gut (Harrison and Phipps, 2001). In this report, we have therefore retained use of the standard ICRP factor and dose coefficient for technetium-99.

A3.4 Tritium

In 2002, PHE reviewed the use of dose coefficients for tritium associated with organic material (Harrison *et al.*, 2002). Subsequently, PHE published a study of the uptake and retention of organically bound tritium in rats fed with fish from Cardiff Bay (Hodgson *et al.*, 2005). These experiments suggested that the dose coefficient for OBT in fish from the Severn Estuary near Cardiff should be 6.0×10^{-11} Sv Bq^{-1}, higher than the standard ICRP value for OBT ingestion. The higher value is used for adults in the assessment of seafood collected near the Cardiff site in this report, and the standard ICRP value for other assessments. This approach is consistent with recent advice from PNE, (Cooper, 2008) which takes account of the conclusions reached by the HPA Independent Advisory Group on Ionising Radiation (now PHE) concerning relative biological effectiveness and radiation weighting (Health Protection Agency, 2007). More recent experimental evidence provided by Hunt *et al.* (2009) involving adult volunteers who ate samples of sole from Cardiff Bay confirms that this approach is indeed cautious.

Table X3.1. Dosimetric data

Radionuclide	Half Life (years)	Mean β energy (MeV per disintegration)	Mean γ energy (MeV per disintegration)	Dose per unit intake by ingestion using ICRP-60 methodology (Sv Bq^{-1})			
				Adults	10 yr.	1 yr.	Fetus
H-3	1.24E+01	5.68E-03	0.00E+00	1.8E-11	2.3E-11	4.8E-11	3.1E-11
H-3 (f)				4.2E-11	5.7E-11	1.2E-10	6.3E-11
H-3 (h)				6.0E-11	8.0E-11	2.0E-10	9.0E-11
C-14	5.73E+03	4.95E-02	0.00E+00	5.8E-10	8.0E-10	1.6E-09	8.0E-10
P-32	3.91E-02	6.95E-01	0.00E+00	2.4E-09	5.3E-09	1.9E-08	2.5E-08
S-35 (g)	2.39E-01	4.88E-02	0.00E+00	7.7E-10	1.6E-09	5.4E-09	1.6E-09
Ca-45	4.46E-01	7.72E-02	0.00E+00	7.1E-10	1.8E-09	4.9E-09	8.7E-09
Cr-51	7.59E-02	0.00E+00	3.20E-01	3.8E-11	7.8E-11	2.3E-10	3.8E-11
Mn-54	8.56E-01	4.22E-03	8.36E-01	7.1E-10	1.3E-09	3.1E-09	7.1E-10
Fe-55	2.70E+00	4.20E-03	1.69E-03	3.3E-10	1.1E-09	2.4E-09	8.1E-11
Co-57	7.42E-01	1.86E-02	1.25E-01	2.1E-10	5.8E-10	1.6E-09	1.1E-10
Co-58	1.94E-01	3.41E-02	9.98E-01	7.4E-10	1.7E-09	4.4E-09	5.8E-10
Co-60	5.27E+00	9.66E-02	2.50E+00	3.4E-09	1.1E-08	2.7E-08	1.9E-09
Zn-65	6.67E-01	6.87E-03	5.85E-01	3.9E-09	6.4E-09	1.6E-08	4.1E-09
Se-75	3.28E-01	1.45E-02	3.95E-01	2.6E-09	6.0E-09	1.3E-08	2.7E-09
Sr-90†	2.91E+01	1.13E+00	3.16E-03	3.1E-08	6.6E-08	9.3E-08	4.6E-08
Zr-95†	1.75E-01	1.61E-01	1.51E+00	1.5E-09	3.0E-09	8.8E-09	7.6E-10
Nb-95	9.62E-02	4.44E-02	7.66E-01	5.8E-10	1.1E-09	3.2E-09	3.7E-10
Tc-99	2.13E+05	1.01E-01	0.00E+00	6.4E-10	1.3E-09	4.8E-09	4.6E-10
Ru-103†	1.07E-01	7.48E-02	4.69E-01	7.3E-10	1.5E-09	4.6E-09	2.7E-10
Ru-106†	1.01E+00	1.42E+00	2.05E-01	7.0E-09	1.5E-08	4.9E-08	3.8E-10
Ag-110m†	6.84E-01	8.70E-02	2.74E+00	2.8E-09	5.2E-09	1.4E-08	2.1E-09
Sb-124	1.65E-01	1.94E-01	1.69E+00	2.5E-09	5.2E-09	1.6E-08	1.0E-09
Sb-125	2.77E+00	1.01E-01	4.31E-01	1.1E-09	2.1E-09	6.1E-09	4.7E-10
Te-125m	1.60E-01	1.09E-01	3.55E-02	8.7E-10	1.9E-09	6.3E-09	8.7E-10
I-125	1.65E-01	1.94E-02	4.21E-02	1.5E-08	3.1E-08	5.7E-08	9.1E-09
I-129	1.57E+07	6.38E-02	2.46E-02	1.1E-07	1.9E-07	2.2E-07	4.4E-08
I-131†	2.20E-02	1.94E-01	3.81E-01	2.2E-08	5.2E-08	1.8E-07	2.3E-08
Cs-134	2.06E+00	1.63E-01	1.55E+00	1.9E-08	1.4E-08	1.6E-08	8.7E-09
Cs-137†	3.00E+01	2.49E-01	5.65E-01	1.3E-08	1.0E-08	1.2E-08	5.7E-09
Ba-140†	3.49E-02	8.49E-01	2.50E+00	4.6E-09	1.0E-08	3.1E-08	3.5E-09
Ce-144†	7.78E-01	1.28E+00	5.28E-02	5.2E-09	1.1E-08	3.9E-08	3.1E-11
Pm-147	2.62E+00	6.20E-02	4.37E-06	2.6E-10	5.7E-10	1.9E-09	2.6E-10
Eu-154	8.80E+00	2.92E-01	1.24E+00	2.0E-09	4.1E-09	1.2E-08	2.0E-09
Eu-155	4.96E+00	6.34E-02	6.06E-02	3.2E-10	6.8E-10	2.2E-09	3.2E-10
Pb-210†	2.23E+01	4.28E-01	4.81E-03	6.9E-07	1.9E-06	3.6E-06	1.4E-07
Bi-210	1.37E-02	3.89E-01	0.00E+00	1.3E-09	2.9E-09	9.7E-09	6.6E-12
Po-210(c)	3.79E-01	0.00E+00	0.00E+00	1.2E-06	2.6E-06	8.8E-06	1.3E-07
Po-210(d)				1.9E-06	4.2E-06	1.4E-05	2.1E-07
Ra-226†	1.60E+03	9.56E-01	1.77E+00	2.8E-07	8.0E-07	9.6E-07	3.2E-07
Th-228†	1.91E+00	9.13E-01	1.57E+00	1.4E-07	4.3E-07	1.1E-06	2.4E-07
Th-230	7.70E+04	1.46E-02	1.55E-03	2.1E-07	2.4E-07	4.1E-07	8.6E-09
Th-232	1.41E+10	1.25E-02	1.33E-03	2.3E-07	2.9E-07	4.5E-07	9.4E-09
Th-234†	6.60E-02	8.82E-01	2.10E-02	3.4E-09	7.4E-09	2.5E-08	1.5E-11
U-234	2.44E+05	1.32E-02	1.73E-03	4.9E-08	7.4E-08	1.3E-07	1.5E-08
U-235†	7.04E+08	2.15E-01	1.82E-01	4.7E-08	7.1E-08	1.3E-07	1.4E-08
U-238†	4.47E+09	8.92E-01	2.24E-02	4.8E-08	7.5E-08	1.5E-07	1.3E-08
Np-237†	2.14E+06	2.67E-01	2.38E-01	1.1E-07	1.1E-07	2.1E-07	3.6E-09
Pu-238(a)	8.77E+01	1.06E-02	1.81E-03	2.3E-07	2.4E-07	4.0E-07	9.0E-09
Pu-238(b)				9.2E-08	9.6E-08	1.6E-07	3.6E-09
Pu-239(a)	2.41E+04	6.74E-03	8.07E-04	2.5E-07	2.7E-07	4.2E-07	9.5E-09
Pu-239(b)				1.0E-07	1.1E-07	1.7E-07	3.8E-09
Pu-α(e)	2.41E+04	6.74E-03	8.07E-04	2.5E-07	2.7E-07	4.2E-07	9.5E-09
Pu-240(a)	6.54E+03	1.06E-02	1.73E-03	2.5E-07	2.7E-07	4.2E-07	9.5E-09
Pu-240(b)				1.0E-07	1.1E-07	1.7E-07	3.8E-09
Pu-241(a)	1.44E+01	5.25E-03	2.55E-06	4.8E-09	5.1E-09	5.7E-09	1.1E-10
Pu-241(b)				1.9E-09	2.0E-09	2.3E-09	4.4E-11
Am-241(a)	4.32E+02	5.21E-02	3.25E-02	2.0E-07	2.2E-07	3.7E-07	2.7E-09
Am-241(b)				8.0E-08	8.8E-08	1.5E-07	1.1E-09
Cm-242	4.46E-01	9.59E-03	1.83E-03	1.2E-08	2.4E-08	7.6E-08	4.7E-10
Cm-243	2.85E+01	1.38E-01	1.35E-01	1.5E-07	1.6E-07	3.3E-07	1.5E-07
Cm-244	1.81E+01	8.59E-03	1.70E-03	1.2E-07	1.4E-07	2.9E-07	2.2E-09

Table X3.1. continued

Radionuclide	Dose per unit intake by inhalation using ICRP-60 methodology (Sv Bq^{-1})			
	Adults	10 yr.	1 yr.	Fetus
H-3	4.5E-11	8.2E-11	2.7E-10	2.6E-12
H-3(f)	4.1E-11	5.5E-11	1.1E-10	6.3E-11
C-14	2.0E-09	2.8E-09	6.6E-09	6.6E-11
P-32	3.4E-09	5.3E-09	1.5E-08	6.5E-09
S-35(g)	1.4E-09	2.0E-09	4.5E-09	1.5E-11
Ca-45	2.7E-09	3.9E-09	8.8E-09	1.7E-09
Cr-51	3.7E-11	6.6E-11	2.1E-10	3.7E-11
Mn-54	1.5E-09	2.4E-09	6.2E-09	1.5E-09
Fe-55	3.8E-10	6.2E-10	1.4E-09	6.6E-11
Co-57	5.5E-10	8.5E-10	2.2E-09	6.1E-11
Co-58	1.6E-09	2.4E-09	6.5E-09	2.5E-10
Co-60	1.0E-08	1.5E-08	3.4E-08	1.2E-09
Zn-65	1.6E-09	2.4E-09	6.5E-09	7.4E-10
Se-75	1.0E-09	2.5E-09	6.0E-09	1.1E-09
Sr-90†	3.8E-08	5.4E-08	1.2E-07	1.0E-08
Zr-95†	6.3E-09	9.0E-09	2.1E-08	4.6E-10
Nb-95	1.5E-09	2.2E-09	5.2E-09	1.6E-10
Tc-99	4.0E-09	5.7E-09	1.3E-08	8.3E-11
Ru-103†	2.4E-09	3.5E-09	8.4E-09	1.1E-10
Ru-106†	2.8E-08	4.1E-08	1.1E-07	4.1E-10
Ag-110m†	7.6E-09	1.2E-08	2.8E-08	1.5E-09
Sb-124	6.4E-09	9.6E-09	2.4E-08	4.4E-10
Sb-125	4.8E-09	6.8E-09	1.6E-08	2.6E-10
Te-125m	3.4E-09	4.8E-09	1.1E-08	3.4E-09
I-125	5.1E-09	1.1E-08	2.3E-08	3.1E-09
I-129	3.6E-08	6.7E-08	8.6E-08	1.5E-08
I-131†	7.4E-09	1.9E-08	7.2E-08	8.1E-09
Cs-134	6.6E-09	5.3E-09	7.3E-09	3.0E-09
Cs-137†	4.6E-09	3.7E-09	5.4E-09	2.0E-09
Ba-140†	6.2E-09	9.6E-09	2.6E-08	1.4E-09
Ce-144†	3.6E-08	5.5E-08	1.6E-07	4.2E-10
Pm-147	5.0E-09	7.0E-09	1.8E-08	5.0E-09
Eu-154	5.3E-08	6.5E-08	1.5E-07	5.3E-08
Eu-155	6.9E-09	9.2E-09	2.3E-08	6.9E-09
Pb-210†	1.2E-06	1.6E-06	4.0E-06	6.1E-08
Bi-210	9.3E-08	1.3E-07	3.0E-07	9.1E-12
Po-210	3.3E-06	4.6E-06	1.1E-05	1.9E-08
Ra-226†	3.5E-06	4.9E-06	1.1E-05	9.9E-08
Th-228†	4.3E-05	5.9E-05	1.4E-04	2.5E-07
Th-230	1.4E-05	1.6E-05	3.5E-05	2.6E-08
Th-232	2.5E-05	2.6E-05	5.0E-05	2.8E-08
Th-234†	7.7E-09	1.1E-08	3.1E-08	6.7E-12
U-234	3.5E-06	4.8E-06	1.1E-05	4.9E-08
U-235†	3.1E-06	4.3E-06	1.0E-05	4.5E-08
U-238†	2.9E-06	4.0E-06	9.4E-06	4.4E-08
Np-237†	2.3E-05	2.2E-05	4.0E-05	4.3E-07
Pu-238	4.6E-05	4.4E-05	7.4E-05	1.1E-06
Pu-239	5.0E-05	4.8E-05	7.7E-05	1.2E-06
Pu-α(e)	5.0E-05	4.8E-05	7.7E-05	1.2E-06
Pu-240	5.0E-05	4.8E-05	7.7E-05	1.2E-06
Pu-241	9.0E-07	8.3E-07	9.7E-07	1.4E-08
Am-241	4.2E-05	4.0E-05	6.9E-05	3.2E-07
Cm-242	5.2E-06	7.3E-06	1.8E-05	5.1E-08
Cm-243	3.1E-05	3.1E-05	6.1E-05	3.1E-05
Cm-244	2.7E-05	2.7E-05	5.7E-05	2.6E-07

† *Energy and dose per unit intake data include the effects of radiations of short-lived daughter products*
(a) *Gut transfer factor 5.00E-4 for consumption of all foodstuffs except Cumbrian winkles*
(b) *Gut transfer factor 2.00E-4 for consumption of Cumbrian winkles*
(c) *Gut transfer factor 0.5*
(d) *Gut transfer factor 0.8*
(e) *Pu-239 data used*
(f) *Organically bound tritium*
(g) *Organically bound sulphur*
(h) *Organically bound tritium for seafood near the Cardiff site*

Annex 4. Estimates of concentrations of natural radionuclides

A4.1 Aquatic foodstuffs

Table X4.1 gives estimated values of concentrations of radionuclides due to natural sources in aquatic foodstuffs. The values are based on sampling and analysis conducted by Cefas (Young *et al.*, 2002; 2003). Data for lead-210 and polonium-210 are from a detailed study and are quoted as medians with minimum and maximum values given in brackets. Dose assessments for aquatic foodstuffs are based on activity concentrations of these radionuclides net of natural background.

A4.2 Terrestrial foodstuffs

The values of carbon-14 in terrestrial foodstuffs due to natural sources that are used in dose assessments are given in Table X4.2 (Ministry of Agriculture, Fisheries and Food, 1995).

Table X4.1. Concentrations of radionuclides in seafood due to natural sources

Radionuclide	Concentration of radioactivity (Bq kg^{-1} (fresh))[a]									
	Fish	Crustaceans	Crabs	Lobsters	Molluscs	Winkles	Mussels	Cockles	Whelks	Limpets
Carbon-14	23	27			23					
Lead-210	0.042 (0.0030-0.55)	0.02 (0.013-2.4)	0.24 (0.043-0.76)	0.080 (0.02-0.79)	1.2 (0.18-6.8)	1.5 (0.69-2.6)	1.6 (0.68-6.8)	0.94 (0.59-1.3)	0.39 (0.18-0.61)	1.5 (0.68-4.9)
Polonium-210	0.82 (0.18-4.4)	9.1 (1.1-35)	19 (4.1-35)	5.3 (1.9-10)	17 (1.2-69)	13 (6.1-25)	42 (19-69)	18 (11-36)	6.5 (1.2-11)	8.4 (5.9-15)
Radium-226	0.04	0.03	0.03	0.06	0.08	0.08				
Thorium-228	0.0054	0.0096	0.04	0.0096	0.37	0.46		0.37		
Thorium-230	0.00081	0.0026	0.008	0.0026	0.19	0.26		0.19		
Thorium-232	0.00097	0.0014	0.01	0.0014	0.28	0.33		0.28		
Uranium-234	0.0045	0.040	0.055	0.040	0.99	0.99				
Uranium-238	0.0039	0.035	0.046	0.035	0.89	0.89				

[a] *Values are quoted as medians with minimum and maximum values given in brackets*

Table X4.2. Carbon-14 in terrestrial foodstuffs due to natural sources

Food Category	% Carbon content (fresh)	Concentration of carbon-14 (Bq kg^{-1} (fresh))
Milk	7	18
Beef meat	17	44
Sheep meat	21	54
Pig meat	21	54
Poultry	28	72
Game	15	38
Offal	12	31
Eggs	15	38
Green vegetables	3	8
Root vegetables	3	8
Legumes / other domestic vegetables	8	20
Dry beans	20	51
Potato	9	23
Cereals	41	105
Cultivated fruit	4	10
Wild fruit	4	10
Mushrooms	2	5
Honey	31	79
Nuts	58	148